Azadi Ka Amrit Mahotsav

Research Contributions
1962-2021

भाकृअनुप
ICAR

भा.कृ.अनु.प.–केन्द्रीय भेड़ एवं ऊन अनुसंधान संस्थान
अविकानगर - 304 501 (राजस्थान)

ICAR-Central Sheep and Wool Research Institute
Avikanagar - 304 501 (Rajasthan)

ICAR-CSWRI : Research Contribution 1962-2021

Directors

S.No.	Name	From	To
1	Dr M.V. Krishna Rao	04.01.1962	28.09.1964
2	Dr O.N. Singh	29.09.1964	05.12.1968
3	Dr M.L. Kohli	06.12.1968	19.02.1969
4	Dr A. Roy	20.02.1969	23.01.1970
5	Dr B.D. Patil	24.01.1970	15.12.1970
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7	Dr C.L. Arora	21.06.1978	25.03.1979
8	Dr R.M. Acharya	26.03.1979	11.06.1981
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10	Dr R. Nagarcenkar	12.05.1982	04.06.1984
11	Dr Manohar Singh	05.06.1984	22.07.1984
12	Dr C.L. Arora	23.07.1984	04.06.1985
13	Dr B.C. Patnayak	05.06.1985	24.11.1986
14	Dr A.L. Chaudhary	25.11.1986	26.01.1990
15	Dr B.C. Patnayak	27.01.1990	30.11.1995
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17	Dr R.N. Singh	23.03.1996	31.08.2000
18	Dr R.C. Jakhmola	01.09.2000	08.10.2000
19	Dr B.U. Khan	09.10.2000	30.06.2002
20	Dr V.K. Singh	01.07.2002	31.01.2007
21	Dr A.L. Arora	01.02.2007	19.02.2007
22	Dr S.A. Karim	20.02.2007	19.02.2012
23	Dr S.M.K. Naqvi	20.02.2012	07.08.2017
24	Dr Arun Kumar Tomar	08.08.2017	22.04.2019
25	Dr Artabandhu Sahoo	22.04.2019	13.09.2019
26	Dr Raghvendra Singh	13.09.2019	07.10.2020
27	Dr Arun Kumar Tomar	07.10.2020	Cont.....

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अविकानगर – 304 501 (राजस्थान)

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Preface

It is a matter of pride that the ICAR-Central Sheep and Wool Research Institute, Avikanagar is celebrating its Diamond Jubilee Year. This premier Institute under the aegis of the Indian Council of Agricultural Research (ICAR) is primarily engaged in research, training and extension activities in sheep and rabbit production. The main campus of the Institute is at Avikanagar and it has three Regional Research Centers viz. The North Temperate Regional Station, Garsa, Kullu (HP), Southern Regional Research Centre, Mannavanur (Tamil Nadu) and Arid Research Campus, Bikaner (Rajasthan) for developing and propagating region-specific technologies. The Institute has been undertaking work aimed at increasing the sheep and rabbit productivity by way of new technologies, scientific interventions and refining the package of practices, having direct implications for the farmers. The Institute had a broad vision of sustainable sheep production by redressal of the issues and to inspire an exchange of ideas among experts, policy makers, stakeholders, industrial leaders and general public. Further, the mandate and objectives of the Institute is to enhance productivity of sheep and rabbit for livelihood security, economic upliftment & sustenance of farmers; availability of optimum, wholesome and hygienic meat to the consumers and wool for woolen industry in the country.

The Institute has, so far, persuaded relevant and crucial research areas of sheep and rabbit and have made an excellent progress during its journey of 60years (1962-2021). The achievements of the Institute have been recognised both nationally and internationally and have won many accolades. The work on genetic improvement of sheep by way of improvement of native germplasm, development of new strains and development of prolific sheep (Avishaan) are notable. Institute have made significant progress in improvement of feed resources and their utilization, development of feeding practices, development of feed supplements (Memnaprash), surplus fodder products and approaches for enhancing mutton production. Seasonal reproductive sheep behaviour and issue of use of elite germplasm in the field has been addressed by way of developing oestrus synchronization kit, artificial insemination protocol, use of fresh semen dilutors for broader coverage and improving the reproductive efficiency. Most discouraging factor (diseases) in sheep farming has been tackled effectively by development of flock health calendar, resistant animals, diagnostics and disease surveillance. Wool and fibers have been developed into valuable products like carpets, apparels, decorative products, environmentally friendly plant nursery bags and composites. Also, diagnostic for wool adulteration and manure (Avikhad) from waste wool has been developed. The milk and meat from animals have been converted into products with wider acceptability and business incubators for post-harvest products are already on roll. Institute has a very strong extension coverage and has been successful in transfer of most of its technologies to the field.

Institute has been very pertinent and regular in updating its achievement on the occasion of its silver and golden jubilee years and this document is a continuation of that tradition. Also, it is an acknowledgement and recognition of the efforts of all those workers, who have worked tirelessly and selflessly during past 60 years to groom and develop this Institute to present standing. I am of the firm view that this publication will be of immense use and help for researchers, policymakers and stakeholders and will act as pedestal for redressal of future challenges in sheep and rabbit production. I thank all the scientists of the Institute for their contributions to this publication. I express my gratitude to Dr. Trilochan Mohapatra, Secretary, DARE and the Director General, ICAR, Ministry of Agriculture and Farmer Welfare, New Delhi for his invaluable guidance from time to time. I am grateful to Dr. B. N. Tripathi, DDG (Animal Science) and Dr. V. K. Saxena, ADG (AP&B), ICAR, New Delhi for their keen interest, constant motivation and generous support in the activities of the Institute. I appreciate the efforts of Dr. S. R. Sharma, Chairman, Editorial Board, Members of the Editorial Board and Dr. C. P. Swarnkar, Incharge, PME in bringing out this document on the occasion of Diamond Jubilee Year of the Institute.

(Arun Kumar)
Director

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ICAR - CSWRI : An Introduction

The ICAR - Central Sheep and Wool Research Institute is a premier Institute of Indian Council of Agricultural Research, New Delhi. It was established in 1962 at Malpura in Rajasthan to conduct basic and applied research on all aspects of sheep and rabbit production and product utilization. Presently campus is popular by the name of Avikanagar. The campus is located at 26° 12' 52.2" N (26.2145° N) latitude and 75° 45' 24.84" E (75.7569° E) longitude at 320 meters above mean sea level. The campus is spread over an area of 1510.0 hectare in hot semi-arid region of the country.

It has three Regional Research Centres in different climatic zones of the country to develop region specific technologies. North Temperate Regional Station (NTRS) was established in 1963 in temperate region at Garsa, Kullu in Himachal Pradesh. The Southern Regional Research Centre (SRRC) was established in 1965 in sub temperate region at Mannavanur in Tamil Nadu. Arid Region Campus (ARC) was established in 1974 at Bikaner in arid Rajasthan. The Institute and its regional centres have been working for enhancing the productivity of sheep and rabbit by applying scientific methods and developing new technologies.

Name and address of Institute	ICAR – Central Sheep and Wool Research Institute, Avikanagar- 304 501 Rajasthan
Head Quarter	Avikanagar, Rajasthan
Regional Stations	Arid Region Campus Beechwal, Bikaner- 334 006 Rajasthan
	North Temperate Regional Station, Garsa, Kullu- 175 141 Himachal Pradesh
	Southern Regional Research Centre, Mannavanur, Kodaikanal – 624 103 Tamil Nadu

VISION

Sustainable sheep production to address the issues and to inspire an exchange of ideas among experts, policy makers, stakeholders, industrial leaders and general public.

MANDATE

- Basic and applied research for improving sheep production, products processing and rabbit husbandry
- Dissemination of technologies for sheep productivity enhancement and management

OBJECTIVES

- To undertake basic and applied research on all aspects of sheep and rabbit production
- To develop, update and standardize meat, and fibre technologies
- To impart trainings on sheep and rabbit production and utilization
- To transfer improved technologies on sheep and rabbit production to farmers, rural artisans and development workers
- To provide referral and consultancy services on production and products technology of sheep

The institute has developed new sheep strains like Avikalin for carpet wool production, Bharat Merino for fine wool production and Avishaan for increased prolificacy in terms of more lambs per ewe. The scientific rearing, breeding, feeding, reproductive, health and management practices were developed for improving the performance of indigenous sheep breeds. Some of the important technologies developed are intensive lamb production for mutton, complete feed block for scarcity feeding, different types of pasture production system, Avikesil - indigenous intravaginal sponges for estrus synchronization, artificial insemination, embryo transfer technology, area specific mineral mixture, milk replacer (Memnaprash) for lambs, disease data information system for organized sheep and goat farms, planned flock health calendar for sheep flocks, region specific modified worm management programme, targeted selective treatment for judicious use of anthelmintics, value added products of wool such as blended woollen blankets, shawl, carpet, quilt, braided ropes, mats, composites, handicraft items and value added products of meat, milk and fur. In addition, technology for utilization of wool waste in agriculture was also developed and prepared Avikhad for use as organic manure. In general, every year more than 3500 elite sheep, goat and rabbits are being sold / distributed to farmers by institute, its regional centres and cooperating units under Network Programme on Sheep Improvement and Mega Sheep Seed Project.

Main Campus ICAR-CSWRI Avikanagar


Avikalin


Avishaan


Patanwadi

Regional Stations

ARC Bikaner


Chokla

SRRC Mannavanur


B.Merino

NTRS Garsa


Avikalin


Synthetic

NWPSI Units

ARC Bikaner


Magra


Marwari

CIRG Makhdoom


Muzaffarnagri

MPKV Rahuri


Deccani

LRS Palamner


Nellore

PGRIAS Kattupakkam


Madras Red

MSSP Units

CSWRI Avikanagar


Malpura

RAJUVAS Navania

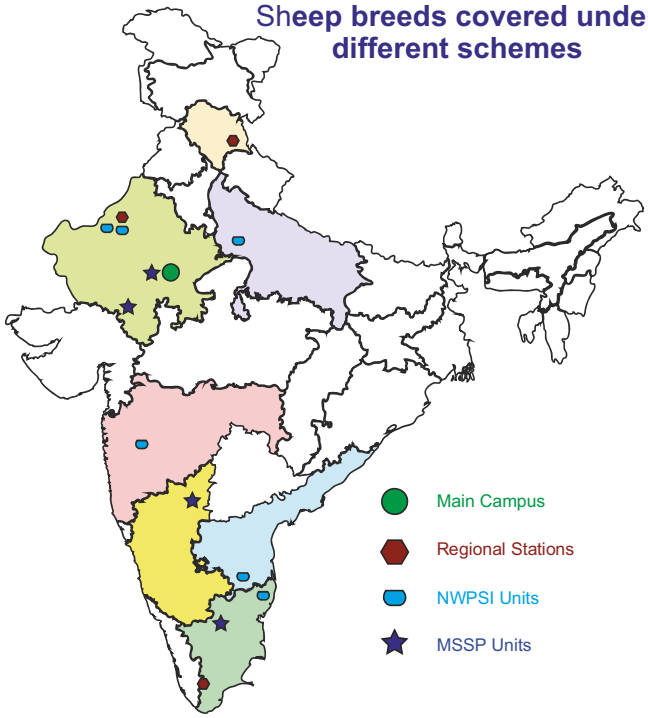

Sonadi

KVAFSU Bidar


Mandya

TANUVAS Salem


Mecheri



Important Milestones of the Institute

1962	-	Establishment of Institute at Avikanagar
1963	-	Establishment of NTRS, Garsa, Kullu
1964	-	Introduced Romney Marsh, South Down and Rambuillet sheep
1965	-	Establishment of SRRC, Mannavanur
1967	-	Office cum Laboratory building
1968	-	Wet processing and spinning plant
1969	-	Constructed Post Graduate Hostel building
		Introduced Corriedale sheep at SRRC, Mannavanur
1970	-	Constructed Medical Dispensary
1971	-	Introduced Soviet Merino sheep
1972	-	Constructed Animal Health laboratory
1974	-	Establishment of ARC, Bikaner
		Introduced Dorset and Suffolk sheep
1975	-	Introduced Karakul sheep at Bikaner
1977	-	Evolved Avikalin and Avivastra sheep
1978	-	Introduced rabbits at NTRS Garsa
1981	-	Constructed New Administrative Building
1982	-	Introduced rabbits at CSWRI, Avikanagar and SRRC, Mannavanur
1983	-	Evolved synthetic strains of Mutton, Nali and Chokla
1985	-	Constructed NPB building
1986	-	Developed disease data information system for organized sheep farm,
		Evolved Bharat Merino sheep
1988	-	Constructed Administration cum Laboratory Building at Bikaner
1989	-	Constructed model rural slaughter house and rabbit sheds at Avikanagar
		Implemented planned flock health calendar
1990	-	Lambs born using pelleted frozen semen
1991	-	Developed protocal for freezing of ram semen in straws
1992	-	Lambs born through embryo transfer technology
		Established Asian Small Ruminant Information Centre

CSWRI-60 Years of Resarch Contributions

1995	-	Constructed Central School building at Avikanagar
		Construction of Office cum Guest house at Jaipur
1996	-	Introduction of Awassi sheep
1997	-	Introduction of Garole sheep
		Transfer Goat Unit of WRRC, CIRG to CSWRI, Avikanagar
		Establish VSAT facilities at Avikanagar
1998	-	Developed protocol for cryopreservation of embryos
		Implemented one anthelmintic drench per annum in sheep at Avikanagar
2002	-	Complete feed block for scarcity feeding
		Developed lamb feeding protocol
2004	-	Constructed Guest house at Avikanagar
		Recovered 24 embryoes in single flushing in Garole sheep
		Implemented region specific worm management programme for sheep flocks in Rajasthan
2007	-	Constructed Biotechnology building
		Constructed Auditorium
		Developed FROGIN
		Developed area specific mineral mixture
		Impregnated intra vaginal sponge Avikesil-s for estrus synchronization
2009	-	Introduced Patanwadi sheep at Avikanagar
		Established model micro watershed management system
2010	-	Introduced Kendrapada sheep at Avikanagar
2011	-	Constructed ATIC centre at Avikanagar
2013	-	Introduced Dumba sheep at Avikanagar
2016	-	Launched prolific Avishaan sheep
		Developed Memnaprash- a milk supplement for lambs
		Developed Avikhad- an organic manure from wool waste
2018	-	Creation of state-of-the-art Artificial Insemination Laboratory
		Introduction of Patanwadi sheep as a dairy sheep
2019	-	Establishment of Agri-Business Incubation Centre
		Launch of woollen Rajai (Jaipuri)/comforter
		Launch of Yoga mat on International Yoga Day
2020	-	Patent awarded for identification of Pashmina fibre by PCR-based technique
		Patent awarded for indigenous cradle for restraining of sheep for pregnancy diagnosis

Animal Genetics and Breeding

Animal Breeding was one of the important foundation stone on which the ICAR-Central Sheep and Wool Research Institute (CSWRI) was established. Sheep Genetics Section was formally established in 1966 with the objective to conduct research on improvement of indigenous breeds of sheep for wool and meat production. The section was upgraded to Division of Animal Genetics and Breeding in 1975. During 1960's the sheep improvement programme through crossbreeding was started by importing Rambouillet sheep from Texas (USA). Subsequently, during 70's Soviet Merino sheep were imported from Stavropol (erstwhile U.S.S.R.) for crossbreeding the indigenous medium wool producing sheep for fine wool production. Dorset and Suffolk sheep were imported for crossbreeding the indigenous sheep to evolve new mutton type breeds. Malpura and Jaisalmeri sheep were crossed with exotic Rambouillet. Several crossbreds of different grades were produced and evaluated for their growth performance, wool yield and quality traits. In 1971 projects for fine wool and mutton production were initiated in the form of All India Coordinated Research Project. Later the two projects were merged into a single project on Sheep Breeding with fine wool component and mutton component. In Mutton component, the crossbreeding of local Malpura and Sonadi sheep with exotic Suffolk and Dorset was initiated in 1974 to evolve mutton type sheep to attain body weight of 30kg at 6 months of age. In the fine wool component, Chokla and Nali sheep were crossed with Rambouillet as well as Soviet Merino to produce a good quality apparel wool bearing sheep. The biochemical polymorphic studies were also undertaken to study the inheritance of various blood constituents and to determine the possible association of these biochemical parameters with economic traits. Marwari, Sonadi and Malpura breeds were crossbred with Karakul to produce lambs for pelt production. Research was also carried out with indigenous goat breeds to evolve a crossbred goat capable to attain 25kg body weight at 6month of age. Studies on cytogenetics were initiated in 1982. In 1994, Awassi sheep was introduced in the mutton project with the aim to improve milk and body weight. Awassi was crossed with native Malpura sheep. In 1997, Garole - a prolific micro-sheep of West Bengal was introduced for increasing prolificacy of Malpura sheep. In 2008, Patanwadi inheritance was introduced into prolific project to improve the milk yield and mothering ability. In 2010, Kendrapada, another prolific sheep from Odisha was introduced into the prolific sheep project. The important achievement milestones of the Division are summarized below:

1963 : Import of Romney Marsh, Southdown and Rambouillet sheep

1966 : Establishment of Sheep Genetics Section

1971 : All India Coordinated Research Project on sheep started. Import of Soviet Merino sheep from Stavropol (erstwhile U.S.S.R.), ¾ Rambouillet crosses of different indigenous breeds produced

1974 : Import of Dorset and Suffolk sheep

1975 : Sheep Genetics Section upgraded to Division of Animal genetics and Breeding Import of Karakul from USSR

1976 : Avikalin and Avivastra strains of sheep evolved

1983 : Avimaans, a Mutton Synthetic strain of sheep evolved

1986 : Bharat Merino strain evolved

1992 : Conversion of AICRP into Network Project on Sheep Improvement (NWPSI)

1994 : Introduction of Awassi sheep

1995 : Awassi X Malpura half-bred sheep produced

1997 : Introduction of Garole sheep

1998 : Garole X Malpura half-breds produced

2005 : GMM and MGM crosses (¾ Malpura ¼ Garole) produced

2008 : Introduction of Patanwadi inheritance in prolific sheep project

2009 : Three breed crosses ("A"=GMM X Patanwadi and "B"=Patanwadi X GMM) produced Mega Sheep Seed Project (MSSP) started

2010 : Introduction of Kendrapada sheep in prolific sheep project

2016 : Prolific Avishaan sheep was developed and released for field evaluation

2018 : Work on Patanwadi sheep was initiated to develop it as dairy sheep

Crossbreeding with exotic germplasm was used as a tool for faster genetic improvement in mutton and wool production. A number of new strains for mutton, fine wool, superior carpet wool and pelt production have been evolved through breeding and selection strategies. Crossbreeding results indicated that the superiority in body weight, greasy fleece weight and fleece quality of newly developed strains over the indigenous purebreds involved in crosses. But, the same level of performance was not achieved in the extensive system of management in farmers' flock. Performance of synthetic strains was satisfactory in favourable sub-temperate climatic conditions. At present indigenous breeds like Malpura and Patanwadi sheep, and Sirohi goats are maintained for improvement of their production potential through selective breeding. “Avishaan” prolific sheep was developed by crossing of three indigenous breed (Garole-Malpura-Patanwadi) and released on 04th January 2016 and is capable of producing more lambs per lambing, more live weight, more milk to sustain the multiple lambs and high survivability in semi-arid condition. Research achievements show that Avishaan has a very promising future in fulfilling the target of doubling the income of the farmers. 'Resistant' and 'Susceptible' lines of sheep against Haemonchus contortus were developed in Malpura and Avikalin breeds.

Carpet wool production

Avikalin: Avikalin was evolved in 1977 with the objectives to produce 2kg annual greasy fleece yield (GFY) with ~30µ fibre diameter and ~30% medullation. A crossbreeding experiment for improving wool production was initiated at CSWRI, Avikanagar in 1964-65 involving exotic fine wool breed (Rambouillet) and native extremely coarse wool breed (Malpura). Since the beginning of 1975 the half bred have been pooled and interbred and the new strain arising out of this base having 50% Rambouillet and 50% Malpura inheritance was named as Avikalin (Avi- Sanskrit word for sheep and Kalin- a Persian word for carpet). During the initial years and up to 1992 ram lambs/breeding rams were selected following the sequential selection based on weaning, 6- and 12-month weights, 1st six monthly GFY and six monthly GFY and wool quality traits (viz. staple length at 6 month of age and diameter at yearling stage). The objectives of wool quality traits were achieved and since 1993 efforts were made to fully exploit the production potential of Avikalin sheep and to develop incorporating 6-month body weight and 1st six monthly GFY. Under the project “Improvement and testing of Avikalin sheep”, available Avimaans ewes were mated with Avikalin rams for upgrading and subsequent merging with Avikalin flock. Avikalin X Avimaans (CM) was further upgraded with Avikalin and 3CM having 87.5% of Avikalin was produced. Progeny from the crosses of 3CM and Avikalin were merged with Avikalin.

The quality of wool produced by Avikalin sheep is of carpet quality. Wool has been found useful even for preparation of serge and blending with other fibres for superior quality hosiery. Avikalin is more superior in economic returns through the sale of wool alone compared with Malpura. Annual greasy fleece yield (GFY) in Avikalin sheep was achieved up to 2.51kg. Avikalin produces wool with average fibre diameter and medullation of around 30µ and 30%, respectively; with a staple length of 4.5cm. The least square means of body weight at birth, weaning, 6 and 12 months were 3.03, 15.07, 26.56 and 33.56kg, respectively. The annual tupping and lambing (available basis) were 93.67 and 84.39%, respectively. Overall survivability was above 90%. This indicates that the Avikalin sheep was well adapted to the local climatic conditions. Performance of Avikalin sheep was also tested in arid climatic conditions in Bikaner. Body

weights at 6 and 12 months were 20.83 and 26.00 kg, respectively. Lambing percentage was 72.9. GFY at spring and autumn clip was 814g and 1202g, respectively. It showed that Avikalin has adapted to arid conditions with performance similar to semi-arid conditions.

To evaluate its performance in sub-temperate climate, a small flock of Avikalin was transferred to SRRC, Mannavanur (Tamil Nadu). Growth and GFY performance are much higher than the performance of Avikalin sheep in semi-arid climate. Body weights at 6 and 12 months were 25.23 and 37.5kg, respectively. Adult annual GFY was 2.512kg. Compared to Malpura, Avikalin had shown 12.5% improvement in 6-month weight and 90% in annual GFY. Higher average daily gain (ADG) in pre- and post-weaning phase indicates good mothering ability in Avikalin sheep. Avikalin can be used as an improver breed for cross breeding the coarse wool breeds of sheep to increase carpet wool production. Results clearly indicate that Avikalin sheep has surpassed the performance of Malpura sheep in all the traits of economic importance and it can be very well used as dual type sheep for carpet and mutton production.

Chokla: A fine carpet wool sheep breed of Rajasthan primarily reared for its superior quality carpet wool. The AICRP on sheep breeding was initiated in 1971. Since then, Chokla was used for cross breeding with exotic animals for developing different crossbred such as Avivastra and Bharat Merino. During 1991, AICRP on sheep breeding was converted into Network Project on Sheep Improvement and the project "Evaluation and improvement of Chokla sheep for carpet wool" was started in April 1992 and still continuing to improve the wool yield. Overall, least-squares mean during the start of the project (1992-95) for body weight at birth, weaning, 6 and 12 months of age were 2.77, 11.81, 16.51 and 21.35kg, respectively. Corresponding growth performance during the period 2004-08 were 2.76, 13.90, 19.58 and 25.33kg, respectively. Over the period under semi-intensive management there is significant improvement in the body weight at different ages and reflects the effect of selection in the flock. Six- and 12-month body weights of 24.83 and 30.29kg, respectively were achieved with change in concentrate supplementation regime during the period 2009-11. The first six monthly, adult six monthly and adult annual GFY were 0.780, 1.056 and 2.212kg, respectively, in 2012-13. The fibre diameter, staple length and medullation were of 32.52µ, 5.47cm and 20.20%, respectively, in adult and 31.74µ, 5.98cm and 35.11%, respectively, in hoggets. It was removed from the Network project platform from 1st April, 2013 and all Chokla sheep were transferred to ARC, ICAR-CSWRI, Bikaner.

Fine wool production

Bharat Merino: Bharat Merino is a strain of fine wool sheep evolved by crossing the half-bred ewes of Chokla, Nali, Malpura and Jaisalmeri with Rambouillet and/or Russian Merino rams and stabilizing the population at 75% exotic fine wool inheritance. Native sheep viz. Chokla- a fine carpet wool breed, Malpura -a coarse and hairy wool breed and Jaisalmeri- a medium carpet wool sheep breed was mated with Rambouillet for production of half-bred. Half bred ewes were backcrossed with Rambouillet rams for production of 3/4th Rambouillet. A similar project involving crossbreeding of native Chokla and Nali ewes with Rambouillet and Russian Merino rams from USSR was in progress under AICRP since 1971 in the Institute. The 3/4th crosses of both the projects were merged in1982. After merging these were inter bred and named as Bharat Merino. Performance of Bharat Merino sheep was satisfactory with regards to production and reproduction except that in semi-arid condition it has not been possible to obtain more than 5cm staple length at six monthly shearing. Keeping this in view, in 1987 Bharat Merino sheep were transferred to SRRC, Mannavanur to evaluate its performance in sub-temperate climate. The performance of Bharat Merino was significantly improved with regards to production and reproduction and the problem of short staple length at six month was overcome by shearing animals annually. The performance of Bharat Merino sheep with respect to production,

reproduction and adaptability were significantly higher in sub-temperate climate of Mannavanur than semi-arid climate of Avikanagar.

The strain has the potential as an import substitute for Rambouillet and Merino rams to be used as improver breed for improving the indigenous breeds for carpet wool and fine wool production. Improved rams of Bharat Merino sheep are in demand in states of Himachal Pradesh, Haryana, Tamil Nadu, Karnataka and Jammu and Kashmir.

Comparative performance of Bharat Merino sheep

Parameter	Avikanagar	Mannavanur
Wool trait		
Greasy fleece yield (kg)	2.05±0.10	2.61±0.11
Staple length (cm)*	3.24±0.05	8.11±0.07
Fiber diameter (μ)	17.94±2.25	19.38±0.10
Medullation (%)	2.66±0.33	0.79±0.13
Body weight (kg)		
Birth	3.38 ± 0.01	4.10±0.01
3 months	15.97±0.07	18.40±0.09
6 months	23.36±0.09	25.33±0.13
12 months	30.60±0.11	32.30±0.35
Reproductive performance (%)		
Tupping	89.68	91.48
Lambing (available basis)	71.63	82.31
Survivability (%)		
0- 3 months	93.18	97.17
3- 6 months	96.29	98.40
6- 12 months	92.00	98.72
Adult	94.10	97.91

** At Avikanagar staple length at six month and at Mannavanur annually*

Avivastra: Chokla ewes were crossed with Rambouillet rams to produce half-breds - 5/8th and 3/4th. Rambouillet x Chokla F1, F2 and 5/8th was grouped together and given name of Avivastra in 1977. The half-breds were interbred to stabilize exotic inheritance at 50% and further improvement in greasy fleece weight and quality was brought through selection. The half-breds and 5/8th crossbreds of Rambouillet and Merino with Chokla and Nali were interbred. It resulted in Chokla and Nali Synthetic strains in 1983. The performance of both the strains was similar. During the year 1989-90 the groups of Avivastra and fine wool synthetics (Chokla and Nali Synthetic) sheep were merged together into a single group 'Avivastra' after comparing groups for greasy fleece weight, staple length, medullation percentage and economic traits. Production performances with respect to birth, weaning, 6- and 12-month weight were 3.04, 14.77, 19.80 and 24.43kg, respectively. Adult annual GFY was more than 2.5kg. Breed possessed all the parameters best fit with fine wool quality. Survivability in pre-weaning, post-weaning and adult sheep was 92.78, 97.85 and 95.28%, respectively. Wool quality parameters of Avivastra and Bharat Merino crosses are quite comparable except the medullation %, which was higher than the Bharat Merino. Avivastra sheep meet most of the requirements for apparel wool traits although medullation percent is slightly higher. Due to poor acceptability and reduced reproductive performance of Avivastra sheep in the field it was decided to upgrade Avivastra sheep by crossing with rams of Bharat Merino and merging with Bharat Merino. All the upgraded Avivastra sheep were merged with Bharat Merino in year 2000. After upgrading Avivastra sheep using Bharat Merino, upgraded rams can be used as an improver germplasm for improving coarse fibre breed for wool quality. The crossbred wool is suitable for processing on worsted system.

Mutton production

Avimaans: The Avimaans strain of sheep has been evolved through crossbreeding of Malpura and Sonadi ewes with imported Dorset and Suffolk rams. AICRP on sheep breeding for mutton production was initiated in 1970-71 with the objective to evolve new mutton breed(s) suitable for semi-arid conditions of the country, which would have an average body weight of 30kg at 6 months of age. Against this objective, an average weight of about 34kg could be achieved in Mutton synthetic subsequently named as 'Avimaans'. Overall means for birth, 6- and 12-month body weight were 3.31, 20.50 and 28.45kg, respectively. Most of the feedlot trials indicated higher body weight gain and efficiency of feed conversion in Avimaans compared to native breeds (viz., Malpura and Sonadi). On an average, Malpura lambs took 122 and 138 days to achieve 20 and 25kg body weight whereas mutton synthetic lambs took 108 and 122days, respectively. Mutton synthetic lambs had better ADG (179g) than Malpura (158g). In Avimaans, the tupping was low as compared to the natives and it varied from 55.98 to 86.9% in different years. Annual lambing on the basis of ewes available was 58.2%. The first 6 monthly and adult 6 monthly GFY were 0.64 and 0.57kg, respectively. However, due to higher fat percent in carcass, the objective was revised to attain 25kg body weight at 4 to 4½ months of age. In view

of relatively poor reproductive performance of Avimaans, its further multiplication was stopped.

Awassi x Malpura (AM): Considering the importance of heavy body weight and milk yield in economic mutton production, a pilot project on crossbreeding of Awassi rams with Malpura ewes was started in 1994, at CSWRI, Avikanagar. AM half-bred lambs exhibited improvement over Malpura lambs at birth, 3, 6 and 12-month weights. These crossbreds produced more 1st six monthly wool yield compared to Malpura lambs. Crossbred wool was found to have better wool quality compared to Malpura wool. AM ewes produced 29% more milk than that of Malpura ewes. Farmers were fascinated by fat tail of Awassi and they showed interest in crossbreeding of native Malpura ewes with Awassi rams. Least-square means for birth, 3-, 6-, 9- and 12-month body weight were 3.42, 14.71, 22.12, 26.01 and 29.43kg, respectively. Results revealed that AM crossbreds exhibited 18.75, 27.05, 19.56, 19.59 and 14.92% improvement over their native counterparts of Malpura breed. The superiority trends of AM lambs observed at weaning stage could not be sustained after weaning despite having production potential which, indicated that the crossbreds require more inputs in terms of feed and fodder to maintain the superiority trend. Feed conversion efficiency was higher (19.8%) in AM than Malpura lambs (15.7%). The Awassi crosses had better growth performance (150g ADG) than the Malpura (115g ADG) lambs.

The overall least-squares means for 1st six monthly, adult six monthly and annual adult GFY were 0.794, 0.561 and 1.022kg, respectively. AM crossbreds produced 37% more 1st six monthly GFY compared to Malpura lambs. The AM wool was found to have better wool quality with 36µ diameter and 45% medullation compared to 45µ diameter and 60% medullation in Malpura wool. Crossbred wool was also lustrous and could be used as carpet wool. Awassi x Malpura ewes produced 42% more milk than that of Malpura ewes. Average daily milk yield was 501g. The annual tupping and lambing on tupped basis were 86.21 and 71.79%, respectively. AM crossbred were phased out in year 2002 due to non-availability of Awassi rams. Awassi is a milch breed in its native country and the purpose of crossing was to produce a milch sheep breed although milk from sheep is not of any commercial importance in the country at present. But there is a great scope of using sheep milk for producing speciality cheese and other dairy products having scope for more value addition.

Malpura: Malpura, an indigenous sheep, is well adapted to harsh climatic conditions of semi-arid region. It is an important mutton type breed with coarse wool texture and found in Jaipur, Tonk and Sawai Madhopur districts of Rajasthan. Ewes have sufficient milk to sustain their neonates. Malpura being a native breed has been used in almost all the crossbreeding programs being run in the CSWRI to produce various crossbred for mutton, fine wool and carpet wool improvement like Avimaans, Avikalin, Bharat Merino, Awassi x Malpura crosses and Indian Karakul. Selective breeding in Malpura sheep is going on to genetically improve the breed for mutton production. Simultaneously, an elite flock of pure Malpura is also being built up. The rams of Malpura are supplied to the farmers for improving their sheep flock. There is always a high demand of superior rams in local sheep farmers to improve their own flock. Previously, the young rams were ranked and selected on the basis of an index incorporating six-month weight and 1st six monthly GFY. Selection index has been revised to give due advantage to the animals having better growth. At present Selection index is based on index incorporating six month body weight, pre and post weaning average daily gain. Several studies have been carried out to improve the criteria of selection for Malpura sheep and it was found that single trait selection on the basis of 6 month live weight (6WT) is best. After initiation of Mega Sheep Seed Project (MSSP) platform of ICAR, this ongoing Malpura sheep improvement program was shifted to MSSP, during year 2014. The objective of the MSSP-Malpura unit is to supply 50 to 70 breeding rams in field to cover nearly 2500 breeding females.

The performance of Malpura sheep at farm level indicated that the least squares mean (LSM) of weaning weight (3 month) is 16.00kg which is about 76.60% improved over that of inception of the project (9.06 vs 16.00). Tremendous increase of marketable age of Malpura at 6month body weight (26.14kg), which is about 89.831% improved over the inception of the project (13.77 vs 26.14). Similarly, at 12month body weight is 35.55 kg, which is 93.20% improved over the inception of the project (18.40 vs 35.55). The adult survivability was 96.30% which was improved by about 21.79% over the inception. The lambing percentage also increases on available basis was 82.32% improved over that of inception about 16.50%. The wool yield and quality performance at present is improved over the inception by 20.75 % (0.771 vs 0.931kg in adult annual GFY) and modulation % also decreased by 15.50% (82.70 vs 71.60). The genetic trend of 6month body weight was upward and positive. The genetic gain was 25.3g per year. The high R^2 (0.696) indicates genetic selection was very effective in improving growth performance of Malpura Sheep and the inbreeding coefficient was 2.04% which was well within the acceptable limit.

Performance improvement in Malpura sheep over the years

Trait	1974 - 1977	2020 - 2021
Growth (kg)		
Birth weight	2.52±0.03	3.17±0.03
Weaning weight	9.74±0.17	16.00±0.20
Six month weight	13.84±0.29	26.52 ±0.27
Twelve month weight	19.46±0.39	35.55±0.40
Greasy fleece yield (kg)		
First six monthly	0.506±0.04	0.560±0.01
Adult annual	0.771±0.02	0.939±0.02
Wool quality		
Average fibre diameter (μ)	39.41±0.41	42.60±2.56
Medullation (%)	82.70±0.21	71.60±2.96
Staple length (cm)	5.76±0.06	5.80±0.21
Reproduction (%)		
Tupping	94.07	91.71
Lambing (Available basis)	70.87	82.57
Survivability (%)		
0-3 month	91.21	86.73
3-12 month	92.14	96.48
Adult	79.07	96.30

The project is also operational in the adopted farmers' flock in research mode and performance Malpura sheep indicated that the least squares means for these body weights were 3.34±0.01, 14.55±0.05, 20.62±0.09, 24.83±0.13 and 29.91±0.17kg at birth, 3, 6, 9- and 12-months, respectively. Earlier reports reveal that the live weights have increased over the time. Earlier scientist reported from the data 1994 to 1996 in field flocks, live weight at birth, 3 and 6-months were 3.16, 9.86 and 15.58 kg, respectively. For the period 1999-2000 also reported BWT (3.50), 3-month weight (13.52) and 6-month weight (18.94 kg), respectively in field flocks. In year 2010, reported BWT, 3 and 6-month weight of 3.55, 14.01 and 21.05 kg, respectively for the data recorded during 2008-2009. Similar live weights were recorded for birth (3.01±0.05) and 3-month weight (15.08±0.21), whereas higher 6-month weight was recorded (24.44±0.50 kg) in Malpura sheep for data recorded during 2012-2013. The increasing trend for weaning weight has been observed. The current data size is most accurate and huge as compared to the earlier reports owing to accurate ear tagging, tattooing and recording of live weights on target dates to capture target age live weight and reflects the true picture for the population in the field breeding tract.

The lambing pattern in field flocks from six year lambing data showed that there was a certain trend of higher lambing in the second half part of the year (August to December and January) as compared to first half (February to July). The lowest lambing was recorded in the month of June and May; however, the highest lambing was recorded in the month of September and December, with little variation over the years between months. Photoperiod is crucial factor which actually drives the seasonality of reproduction in sheep as it controls the reproductive cycles by the intermediary of the hypothalamo-pituitary axis. Sheep in the temperate climate is typically seasonal, owing to selection pressure for better survival of lambs in favourable period of the year, i.e. early spring. European breeds of sheep have shown active breeding during decreasing day length that ends in winter. However, being tropical and semi-arid region, there was always a plenty of sunlight across the year, with little reduction in the daylight photoperiod post monsoon for the data under study. The month of October to February has minimum photoperiod as compared to rest of the months. Sheep being round the year breeder in this region, we hypothesized that we will not observe such a

pattern of breeding dependence on daylight length. The Malpura sheep was seen to have tendency for major lambing (>70%) in the post monsoon and winter period, owing to better resource availability for newly born lambs and their dams. The sheep flocks recorded under the MSSP, Malpura sheep project has a great possibility to work as a successful community-based breeding program (CBBP) model owing to the defined breeding objective of increased growth, similar need of all the sheep breeders in the region, sizable genetic variability for growth traits and potential of the breed to meet the demands of the stakeholders. The present model of Malpura sheep CBBP, where CSWRI works as facilitation center (a nucleus) with data collection and prophylactic support may be slowly shifted to the local breeding community co-operative for self-help such as decision making, breeding and marketing. For the genetic improvement of the animals in the farmers' flock a total of 709 superior breeding rams/ram lambs were supplied/sold to the Govt. Agency/ registered Farmers/NGO/ Developmental agency. The comparative growth performance between progeny of distributed rams and farmer's rams showed that progeny of project rams excelled over the progeny of farmers' rams.

Prolific sheep

Improved animal genetic resources with versatile characteristics are the need of the day to meet the growing human demand. India is endowed with wide diversity of sheep genetic resources, which forms the backbone of its rural livelihood security systems. Sheep rearing now faces a dilemma to produce more mutton and wool for the growing human population against the reality of shrinking grazing resources, creating a major constraint to the further growth of sheep population. In the present scenario, the demand for meat in India has increased rapidly and the emphasis has shifted from wool towards mutton as the main produce from sheep rearing. As per BAH&FS (2019), total meat production in India is 8114.45 m kg, out of which sheep contributed 677.99 m kg amounting to 8.36% of total meat production in the country. In an estimate, the demand of mutton in India would be around 986 million kg in 2030 and 1408 million kg in 2050. As per recommendations of Indian Council of Medical Research, minimum of 30 grams meat per day per head should be taken which makes about 11.00 kg of meat/head/annum but current availability of meat in India is only about 5.5 kg/head/annum. Thus, there is a wide gap between demand and availability of meat and it would further widen in future with the increasing demand of meat from different parts of the country. The gap between the demand and production of mutton could be bridged by augmenting the reproductive rate of low producing Indian sheep breeds. Improving prolificacy in sheep flock can increase the profitability of sheep production. Lamb production has become a most important source of income for sheep keepers. In order to improve the fecundity of sheep, incorporation of genetic material of prolific sheep is an ideal approach to evolve a large size breed capable of multiple births for economic and remunerative mutton production.

Realizing the importance of FecB mutation, extensive work has been done all over the world including India for improving prolificacy in sheep. ICAR-CSWRI, Avikanagar, also took the opportunity to conduct the research on prolificacy introgression from Garole sheep into native Malpura sheep. A cross breeding scheme was initiated in 1997 to introgress the FecB gene from India's most valuable germplasm “Garole sheep” of a hot and humid environment into the non-prolific and large size mutton sheep breed “Malpura” best adapted of a semi-arid tropical environment to produce the Garole x Malpura (GM) crossbred carrying FecB gene. Encouraging results have been obtained in GM half-breds in terms of twinning rate and growth of quarter-breds (GMM; backcross of GM with Malpura).

Garole x Malpura (GM): There was a tremendous increase in multiple births and in other reproductive efficiency traits in GM ewes compared to Malpura ewes. The results provided the first evidence for increased litter size in GM, with the possibility of further exploitation using appropriate breeding and selection strategies. The average litter size at birth was 1.56 with highest litter size of 1.68 was rerecorded in year 2008 and 2010. There was significant improvement in multiple births in GM crosses compared to Malpura. The GM ewes had 49% (1.56 vs 1.05) advantages over Malpura for litter size at birth. Average twinning and triplet in last 6 years was 40.09% and 9.80%, respectively in GM. The growth

performance of GM in terms of body weights recorded at birth, 3-, 6-, and 12-months age were 1.87, 10.13, 15.27 and 20.59 kg, respectively. It was obvious that on crossing the small sized Garole rams with large sized Malpura ewes the half-bred progenies would weigh less than the dam parent and higher than the sire parent. Two reasons contributed to these differences; the one that the cross contained genes from a significantly lighter breed; the second, many of the crossbred lambs were born twins or triplets which are mostly lighter than single-born lambs. The pre-weaning survivability ranged from 87.94 to 93.36%. Overall survivability of the GM over the years was greater than 89.90%. These results further indicated that the progenies of GM crossbred were inheriting traits of adaptation from Malpura sheep and the prolific genes from Garole. In January 2009, a GM female (ID 504) weighing 27.4 kg at lambing gave birth to triplets, (two males and one female lamb). Litter weight of 6.40kg at birth, 36.40kg at three month and 62.60 kg at six month of age was achieved. Subsequently, the triplet lambs born to this dam attained 12-month age in January 2010 with an amazing litter weight of 95.0 kg. It clearly indicates that prolific sheep can be successfully reared / launched in the semi-arid region and it has great potential in augmenting mutton production in our country.

Backcrosses- GMM / MGM: Having developed prolific GM half-bred sheep, there was scope to exploit the prolific GM sheep for relatively better growth by backcrossing with native Malpura. Backcrossing of GM with Malpura was employed to make gain in body weights and growth performances and at the same time maintaining the prolificacy level comparable to GM sheep. In the backcrossing programme the FecB gene carrier GM rams were used as sires and Malpura ewes as dam breed to produce the GM x Malpura (GMM; 75% Malpura and 25% Garole) and reciprocal crosses were also attempted to produce MGM. Percentage of multiple births ranged from 6.7 to 40 in GMM and from 14.3 to 27.3 in MGM. The litter size at birth ranged from 1.07 to 1.42 in GMM and 1.14 to 1.29 in MGM crosses. The incidence of multiple births is low compared to GM mainly due to lower FecB gene frequency in population and retention of a greater number of non-carrier females in flock. Once a sizeable population of GMM ewes are reached more rigorous selection for FecB gene will be carried which will further increase the prolificacy. The survivability of the back crosses (GMM/ MGM) is better than the GM and at par with the native Malpura sheep. Least-squares means for body weights at birth, 3, 6 and 12 months were 2.54, 13.68, 20.00 and 26.15 and 2.13, 12.16, 16.59 and 21.10kg, respectively in GMM and MGM crosses. The results indicate that there is pronounced higher gain in the body weight and growth rate of lambs produced after backcrossing of GM rams with Malpura ewes. This also reflects the major role of large uterine capacity of Malpura ewes in producing heavier GMM lambs compared to lighter MGM lambs borne by GM ewes. At present inter se mating in GMM is in progress and production of MGM has been stopped.

Avishaan: A crossbreeding scheme was initiated during the year 1997 to introgress the FecB gene from small sized prolific sheep breed 'Garole' of Sunderban area of West Bengal into non-prolific large sized mutton sheep breed 'Malpura' of Rajasthan and Garole x Malpura halfbreds were produced. Increased twinning percent to the tune of 50% in Garole x Malpura half-breds was observed. At the same time a need was felt to improve the body size of prolific halfbred sheep through backcrossing with dam parent Malpura sheep. In the backcrossing, the FecB gene carrier Garole x Malpura halfbreds were used as sire and Malpura as dam breed to produce the GMM crosses having 25% Garole and 75% Malpura inheritance. The 3/4th crossbreds GMM ewes were capable of producing more than 60% multiple lambing and also have higher body weight compared to half-breds but problem of low milk yield in dam persisted and body weights of GMM lambs were also need to be improved further. To overcome the problem of low milk yield in the 3/4th crossbreds dams and to enhance the live weights of lambs, Patanwadi inheritance (a heavy sheep breed of Saurashtra region of Gujarat and famous for milk yield) was introduced during the year 2008. In this crossbreeding programme, GMM having *FecB*^{BB} gene was used as sire and Patanwadi was used as a dam

breed to produce triple indigenous breed crosses (Garole-Malpura-Patanwadi). With the implementation of structured breeding plan and FecB gene detection, a high performing sheep strain “Avishaan" in terms of high prolificacy, more litter weight, more milk per dam and adaptable to harsh climatic conditions was developed and released by CSWRI on 04th January, 2016 for field evaluation. This developed prolific Avishaan strain is a composite cross possessing 12.5% Garole, 37.5% Malpura and 50% Patanwadi inheritance in which FecB gene has been introgressed successfully. Avishaan is a large sized sheep with long legs. It inherited typical Roman nose and long tubular ears of Patanwadi breed. Face is mostly light to dark brown extended to neck and the body coat colour is off white. However, some lambs born with complete dark brown/ light brown or even black coat colour and also few lambs were found to be having large spots of black or dark/ light brown on their face and body. The ears are medium to large and tubular. Tail is thin and medium in length. Both male and female of Avishaan sheep are polled and produces coarse type wool. The gist of trait wise performance of Avishaan is given below:

During the period from 2011 to 2019, multiple births and litter size at birth was observed to be 22.2 to 74.4%; and 1.3 to 1.8, respectively which indicated that FecB gene has been introgressed successfully in Avishaan strain. Prolificacy and litter size at birth in Avishaan sheep over the four generations has been ranged from 58.09 to 71.70% and 1.63 to 2.33, respectively which indicated that breeding and selection procedure adopted for introgression of FecB gene have been in right perspective. This genotype will definitely be helpful in enhancing the lifetime production and productivity of sheep. Reproductive soundness of sheep play significant role in multiplication of germplasm and become helpful in enhancing the productivity of animal. The tupping percentage in Avishaan ranged from 90.2 to 100 and lambing percentage on tupped basis varied from 90.0 to 99.2 which indicated that Avishaan is a reproductively sound genotype.

Multiple birth and litter size of Avishaan over the years (2011-2019)

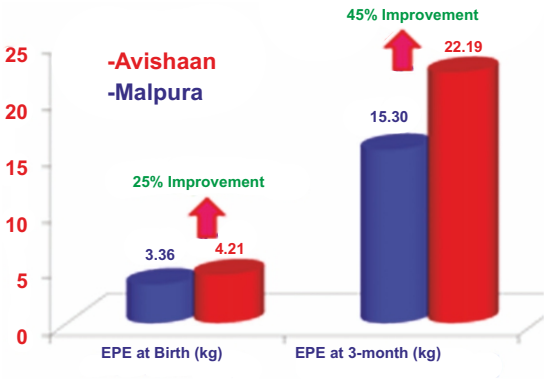
Year of lambing	Ewes lambed	Lambs born	Multiple birth %	Litter size at birth	Type of birth (%)			
					Single	Twins	Triplets	Quad
2011-12	18	23	22.2	1.3	77.78	16.67	5.55	-
2012-13	27	35	29.6	1.3	70.37	29.63	-	-
2013-14	35	44	25.7	1.3	74.29	25.71	-	-
2014-15	37	53	40.5	1.4	59.46	37.84	2.70	-
2015 16	133	214	57.1	1.6	42.86	54.14	2.26	0.75
2016-17	100	153	49.0	1.5	51.00	45.00	4.00	-
2017-18	146	264	69.2	1.8	30.82	58.90	8.90	1.37
2018-19	170	317	74.1	1.8	25.88	62.94	10.00	1.18
2019	172	319	74.4	1.8	25.58	63.95	9.88	0.58

Overall least squares mean(s) over the generations were 2.51, 14.76, 23.50 and 30.99kg at birth, 3, 6 and 12-months of age, respectively.

Least squares means (±S.E.) for body weights of Avishaan lambs over the generations

Particular	Birth wt	3- month wt	6- month wt	12- month wt
Overall mean	2.51±0.04	14.76±0.29	23.50±0.57	30.99±0.36
Generation	**	**	**	**
1	2.57±0.03	14.70±0.21	22.50±0.30	30.00±0.42
2	2.69±0.03	16.03±0.19	24.90±0.27	31.99±0.33
3	2.40±0.06	15.16±0.42	24.56±0.63	30.97±0.89
4	2.36±0.15	13.16±0.99	21.96±2.09	-
Sex	**	**	**	**
Male	2.57±0.05	15.55±0.31	25.18±0.59	34.56±0.47
Female	2.44±0.05	13.98±0.31	21.82±0.60	27.41±0.41
Type of birth	**	**	**	**
Single	2.85±0.05	16.95±0.36	25.64±0.65	32.24±0.52
Multiple	2.16±0.04)	12.58±0.28	21.37±0.56	29.74±0.73

Ewe productivity efficiency (EPE) is a very important economic parameter in mutton production as it indicates the potential of an ewe in terms of harvesting the quantum of litter weight at particular age of the lambs. The overall EPE of Avishaan ewes at 3-month over a period of nine years (2011-2019) was 22.19kg whereas, corresponding figure for the same period in respect of monotocus Malpura ewes was 15.30kg, thereby, Avishaan excelled local Malpura sheep by 45% in live weight production efficiency. These results suggested that rearing of prolific Avishaan sheep is relatively more beneficial in terms of more sheep per sheep as compared to monotocus sheep.



Sufficient availability of milk with the dam is very essential in sustaining the twins/ triplets during the early age of neonates. To assess daily milk yield with Avishaan ewes, test day milk recording by lamb suckling method on single as well as twin bearing ewes was initiated from 15th day and continued up to 90 days of lactation. Overall average daily milk yield in Avishaan sheep over a period of five years (2017 to 2021) was 721g. The ewes belonging to 1st parity produced comparatively lesser milk than the ewes of latter parities and maximum yield was observed during 3rd parity during the period of study. Results indicated that Avishaan sheep have good milk potential to feed twins.

Survivability is an indicator of adaptation of a genotype in prevailing climatic and managemental conditions. The survivability of Avishaan sheep at different ages over the years has been in satisfactory range; in adult it ranged from 96.4 to 100%; in growing lambs (3 to 12-month age group) 95.3 to 98.2% and in suckling lambs 92.7 to 99.3% which indicated that this genotype is well adapted.

Avishaan sheep were supplied to the sheep owners and government agencies for field evaluation. Data were recorded from the flocks of local farmers and also feedback was obtained through phone/ E-mails from the sheep owners of distant places. During the last eight years CSWRI has provided around 800 prolific Avishaan sheep to the farmers and government agencies of ten states viz. Rajasthan, Haryana, Maharashtra, Jharkhand, Telangana, Karnataka, J&K, Punjab, Uttrakhand and Uttar Pradesh for breeding purposes. Field results analysed so far are encouraging as 60-70% multiple lambing have been obtained at farmers' door and this igniting a new way ahead for profitable sheep husbandry. Avishaan prolific sheep may prove as a boon towards doubling the income of farmers. We are receiving huge demand of Avishaan sheep from different corners of the country. Considering the utility of Avishaan sheep, we are receiving huge demand from different parts of the country.

Patanwadi sheep as milch breed: Patanwadi sheep is known for its ability to produce significant amount of milk, besides potential for higher growth and wool production. Some ewes were reported to produce 1.5kg or more daily milk yield. More milk from sheep enables the lambs to be comparatively healthier resulting in low mortality/morbidity in neonates. In this context, ICAR-CSWRI initiated a project on the genetic improvement and development of Patanwadi as dairy sheep in 2018.The average daily milk yield (ADMY) and total lactation milk yield (TLMY) during the year 2019-20 for 1st, 2nd and 3rd month of lactation were 0.887 and 26.61 kg, 0.862 and 51.71 kg and 0.752 and 67.35kg, respectively. About 17% Patanwadi ewes produced more than one kg ADMY and 27% ewes produced ADMY of 750g to 1.0kg. Collection of data on udder measurements of Patanwadi ewes also started and will be correlated with ADMY. The overall body weights at birth, 3, 6 and 12 months of age were 3.54±0.05, 19.52±0.31, 32.34±0.40 and 38.17±0.61kg, respectively. Annual tupping and lambing (on tupped basis) was 94.94% and 75.74%, respectively. The six monthly and annual GFY was 0.747±0.02 and 1.15±0.04kg, respectively. There is high demand of Patanwadi sheep among the farmers and 53 elite male

germplasm were sold to the farmers of Rajasthan for breed improvement purposes. The overall survivability of Patanwadi sheep was more than 97%.

Milk composition of Patanwadi sheep revealed that the fat percentage of Patanwadi milk increased as the lactation progressed, though there were not much variation in protein and SNF percentages over the weeks. The detailed composition of Patanwadi milk in different weeks of lactation is given below:

Compositional analysis (Mean±S.E.) of Patanwadi sheep milk

Week	Fat (%)	SNF (%)	Density (%)	Protein (%)	Lactose (%)	Freezing point (°C)	Conduc-tivity	pH	Salt (%)
1	3.73±0.27^{h}	12.55±0.14^{a}	42.75±0.74^{a}	4.60±0.05^{ab}	8.20±1.33^{a}	.0.78±0.01^{c}	5.28±0.09	6.57±0.02^{ab}	1.03±0.01^{a}
2	4.43±0.32^{fgh}	11.80±0.21^{abc}	40.28±1.42^{ab}	4.32±0.08^{ab}	6.5±0.11^{ab}	-0.78±0.01^{abc}	5.08±0.07	6.48±0.12^{ab}	0.97±0.02^{ab}
3	4.25±0.44^{gh}	11.76±0.20^{abc}	39.58±1.23^{abc}	5.26±0.95^{a}	6.47±0.11^{ab}	-0.78±0.01^{abc}	5.14±0.10	6.59±0.03^{a}	0.96±0.02^{abc}
4	4.71±0.48^{efgh}	11.52±0.30^{bcd}	37.85±1.47^{abcd}	4.17±0.11^{ab}	6.32±0.16^{ab}	-0.78±0.01^{abc}	5.32±0.20	6.52±0.06^{ab}	0.95±0.02^{abc}
5	6.13±0.67^{cde}	10.82±0.45^{cd}	34.02±2.23^{def}	3.91±0.16^{b}	5.99±0.24^{b}	-0.70±0.02^{aa}	5.10±0.10	6.29±0.12^{b}	0.91±0.04^{bc}
6	5.66±0.40^{defg}	11.65±0.24^{abc}	37.34±1.29^{bcde}	4.27±0.09^{ab}	6.42±0.13^{ab}	-0.71±0.02^{ab}	5.36±0.06	6.53±0.11^{ab}	0.96±0.02^{abc}
7	5.86±0.37^{def}	11.54±0.30^{bcd}	36.77±1.53^{bcde}	4.25±0.13^{ab}	6.39±0.19^{ab}	-0.76±0.01^{c}	5.16±0.06	6.38±0.07^{ab}	0.97±0.03^{abc}
8	6.08±0.41^{cde}	11.97±0.21^{ab}	37.99±1.19^{abcd}	4.39±0.08^{ab}	6.57±0.12^{ab}	-0.76±0.01^{bc}	5.07±0.08	6.37±0.04^{ab}	0.99±0.01^{ab}
9	6.49±0.38^{cd}	11.44±0.36^{bcd}	35.75±1.60^{bcde}	4.15±0.17^{ab}	6.33±0.20^{ab}	-0.76±0.01^{c}	4.74±0.21	6.45±0.08^{ab}	0.92±0.05^{bc}
10	7.07±0.72^{bcd}	11.40±0.42^{bcd}	35.59±1.53^{bcde}	4.28±0.10^{ab}	6.47±0.14^{ab}	-0.76±0.01^{c}	5.12±0.26	6.36±0.04^{ab}	0.96±0.03^{abc}
11	7.57±0.54^{abc}	11.13±0.36^{bcd}	35.03±1.20^{cde}	4.19±0.08^{ab}	6.29±0.12^{ab}	-0.77±0.01^{c}	4.89±0.10	6.45±0.04^{ab}	0.96±0.02^{abc}
12	8.34±0.45^{ab}	11.05±0.23^{bcd}	32.33±1.28^{ef}	4.06±0.09^{b}	6.12±0.12^{ab}	-0.75±0.01^{abc}	4.89±0.06	6.44±0.04^{ab}	0.94±0.02^{bc}
13	8.67±0.51^{a}	10.60±0.18^{d}	29.37±1.35^{f}	3.84±0.07^{b}	5.83±0.09^{b}	-0.74±0.01^{abc}	4.98±0.13	6.48±0.05^{ab}	0-89±0-01^{c}

Means bearing different superscripts are significantly different (P<0.05)

Network project on sheep improvement

The Network project on sheep improvement (NWPSI) was started on 1st April, 1990, after converting all the centres of AICRP on sheep breeding into NWPSI centres. AICRP on sheep breeding was mainly focused on crossbreeding of genetically low yielding indigenous sheep breeds with high yielding exotic sheep breeds viz. Rambouillet, Dorset, Suffolk etc., whereas, in NWPSI emphasis has been given on the survey, evaluation, conservation and improvement of indigenous sheep genetic resources. Under NWPSI different breeds of sheep are being genetically improved through selection and inter-se mating for mutton and wool production. Presently, there are 6 cooperating units of NWPSI (4 farm-based and 2 field-based) located in different parts of the country with its coordinating unit at Avikanagar. The project aims at improvement of indigenous sheep breeds under farm and field conditions. In farm, the male lambs are first ranked using selection index based on body weight (mutton breeds), and body weight and wool yield (carpet wool breeds) at six months of age. Best lambs are selected and mated at around the age of 18 months. Subsequently these rams are again evaluated based on their progeny performance and best 2-3 rams are selected and used for breeding. Selected male lambs from improver flocks are supplied to the base flocks for breeding purposes. The project has established nucleus flocks of around 300-350 genetically improved breedable females and required number of elite rams of Marwari, Muzaffarnagari, Deccani and Nellore breeds in their respective breeding tracts. The genetic selection and planned breeding programme supported by timely healthcare and other scientific managemental interventions have resulted in significant improvement in live body weight at marketable age (6 month), higher wool yield, improvement in reproductive performances and drastic reduction in mortality in different breeds of sheep. Obviously, these project measures are actively contributing to produce a greater number of lambs with better overall performances leading to higher income to the farmers from sheep husbandry. Further, the project is continuously catering to the need of genetically improved germplasm of different breeds in the field. A total of 10070 elite rams comprising of 2270 Marwari, 1645 Muzaffarnagari, 1010 Deccani, 1964 Nellore, 1444 Magra and 1737 Madras Red sheep have been distributed in the field in their respective breeding tract since 1992 for

genetic improvement of sheep in the farmers' flock. The project also includes capacity building of stakeholders. Different cooperating units organizes training programmes, exposure visits (On and off campus), health camps etc. for the sheep farmers of their respective regions. These activities were immensely beneficial to the farmers for easy adoption of scientific sheep rearing practices in terms of proper breeding, feeding, healthcare and management of their animals. NWPSI also assist the farmers from the marginalized communities. Under Tribal Sub Plan (TSP) and Scheduled Caste Sub Plan (SCSP), the poor farmers belonging to the Tribal/scheduled caste categories were provided with different inputs/training/exposure visits related to sheep husbandry for their social and financial upliftment.

Improvement in live weight (kg) in different breeds over the years

Breed	Particulars	Birth	3-month	6-month	12-month
Marwari	Base population	2.50	12.90	17.30	19.50
	2018-19 population	3.20	17.20	25.30	31.70
	Weight gain	0.70	4.30	8.00	12.20
	Percent improvement	28.00	33.33	46.24	62.56
	Response (kg/yr)	+0.027	+0.165	+0.307	+0.469
Muzaffarnagri	Base population	-	-	17.09	20.81
	2018-19 population	-	-	24.57	32.51
	Weight gain	-	-	7.48	11.7
	Percent improvement	-	-	43.77	56.22
	Response (kg/yr)	-	-	0.29	0.45
Deccani	Base population	3.16	13.73	19.39	24.32
	2018-19 population	3.18	14.01	23.8	28.56
	Weight gain	0.02	0.28	4.41	4.24
	Percent improvement	0.63	2.08	22.74	17.43
	Response (kg/yr)	0.00	0.01	0.17	0.16
Nellore	Base population	2.94	11.56	17.78	23.38
	2018-19 population	3.29	15.07	22.75	26.75
	Weight gain	0.35	3.51	4.97	3.47
	Percent improvement	11.90	30.36	27.95	20.52
	Response (kg/yr)	0.015	0.146	0.210	0.145
Madras Red (Field)	Base population	2.16	8.73	13.02	19.08
	2018-19 population	2.79	10.3	14.17	20.33
	Weight gain	0.63	1.57	1.15	1.25
	Percent improvement	29.17	17.98	8.83	6.55
	Response (kg/yr)	0.03	0.06	0.05	0.05
Magra (Farm)	Base population (1998-2000)	2.92	14.63	19.58	23.06
	2018-19 population	3.27	18.44	25.51	32.31
	Weight gain	0.35	3.81	5.93	9.25
	Percent improvement	11.98	26.04	30.28	40.11
	Response (kg/yr)	+0.0194	+0.211	+0.329	+0.513
Magra (Field)	Base population (1998-2000)	-	-	21.16	29.12
	2018-19 population	-	-	22.83	29.51
	Weight gain	-	-	1.67	0.39
	Percent improvement	-	-	7.89	1.34
	Response (kg/yr)	-	-	0.36	0.06

Mega sheep seed project (MSSP)

Mega Sheep Seed Project (MSSP) was started on 1st April, 2009 with the main objective to produce around 80 breeding rams of each breed annually to cover about 8000 breedable ewes by the end of XI plan. The aim of the project was enhancing quantity and quality of meat and/or wool production, capacity building in SAUs /ICAR institute/

NGOs to produce improved breeding rams, linking small holders with organized market and paving the way towards public-private partnership. The project was initially sanctioned with four cooperating units namely, KVAFSU, Bidar for Mandya Sheep, MPUAT, Udaipur for Sonadi Sheep, TANUVAS, Chennai for Mecheri Sheep and BAU, Ranchi for Chhotanagpuri Sheep with ICAR-CSWRI, Avikanagar as Coordinating unit. Later, in 2014 another unit at ICAR-CSWRI, Avikanagar for Malpura sheep was added. But, Chhotanagpuri unit was closed in 2017 and presently there are four cooperating units only. The main objective of the project is improvement of indigenous sheep breeds by propagation of superior germplasm in the farmers' flock. During XII Plan, the objective was revised to produce and distribute 50 superior breeding rams to cover at least 2500 breedable ewes annually by each unit. The present target is distribution of 70 elite breeding rams of each breed. Each cooperating unit of the project consists of two interlinked components-Institutional nucleus farm and associated field flocks.

Nucleus flocks of genetically improved five important indigenous sheep breeds have been established in the breeding tracts of respective breeds. However, due to closure of Chhotanagpuri sheep unit, BAU, Ranchi in 2017, presently nucleus flocks of around 300 superior breedable females of four breeds, namely Mandya, Mecheri, Sonadi and Malpura are being maintained at different Institutional farms. Since inception of the project a total of 2570 genetically superior rams comprising of 631 Chhotanagpuri, 490 Mandya, 614 Mecheri, 514 Sonadi and 321 Malpura breed were produced and distributed/sold to the registered and other farmers. The total ewe coverage in the field by these ram was 84794 comprising of 14767 Chhotanagpuri, 16697 Mandya, 25030 Mecheri, 16251 Sonadi and 12049 Malpura sheep. The supply of free elite breeding rams to the registered farmers' flock followed by necessary healthcare and other managemental interventions from the project has resulted in improvement of production and reproduction of the farmers' sheep. The growth performances in terms of live body weight at 3, 6 and 12 month of age in Mandya sheep was improved by 31.78, 30.14 and 5.56%, respectively, since inception. The same for Mecheri sheep was 5.87, 15.95 and 4.06%, respectively. In Sonadi sheep, these traits were improved by 4.08, 8.53 and 8.69%, respectively. The same performances in Malpura sheep were improved by 17.12, 9.96 and 3.28%, respectively. The tupping and lambing percentages (on available basis) were also significantly improved in farm as well as in field flocks as a result of use of genetically improved breeding ram and scientific breeding and management practices. The survivability of the nucleus flock of different breeds was more than 95%. The availability of timely healthcare interventions in terms of vaccination, regular treatment, dipping, deworming etc. to the field flocks covered under the project has drastically reduced the mortality leading to prevention of financial loss to the farmers and adding up extra to their income from sheep husbandry. The registered farmers in the breeding tract of the breeds covered under the project are provided hands on training on profitable sheep husbandry practices like use of purebred genetically improved rams, better feeding, healthcare and other managemental aspects. They are also taken for exposure visits to other places for increasing their awareness, better acceptance and easy adoption of scientific sheep rearing practices. MSSP also provides assistance to the sheep farmers from marginalized communities. In Tribal sub Plan (TSP) and Scheduled Caste sub Plan (SCSP), the sheep farmers belonging to Tribal/scheduled caste categories are provided with different inputs including breeding animals, training and exposure visits related to sheep husbandry for their social upliftment and economic betterment. The project activities are helping in filling up the gap of short supply of superior germplasm in the breeding tract of different breeds, increasing farmers' awareness to choose true to breed animals, adoption of scientific sheep husbandry practices, keeping rural youth and attracting peri-urban youth to maintain/adopt sheep husbandry as a viable source of income.

AICRP on Sirohi Goat

The unit of AICRP on Goats at Avikanagar came into existence on 24th December, 1976. Then the objectives were to develop a new breed of goat suitable for agro-climatic conditions of Rajasthan and capable of attaining 25 kg live weight at 6 months of age with 45-50% dressing percentage under intensive feeding. It was recommended to

cross the local Sirohi goats with exotic Anglo-Nubians and indigenous Beetal goats. As Anglo-Nubians could not be procured, the studies were restricted to pure breeding of Beetal and Sirohi and crossbreeding of Sirohi with Beetal upt o March 1984. The objective of attaining 25kg live weight at 6 months age was achieved. The crossbreds were, however, found only marginally superior to purebreds. The objective of the project was then modified to study the "Production performance of Sirohi, Beetal, Jakhrana, Marwari and Kutchi indigenous breeds" and the technical program was accordingly changed with effect from 1st April, 1984. In 1986, the objective was again changed to compare the purebred performance of Sirohi, Marwari and Kutchi breeds for meat production under semi-intensive and intensive management systems and the Beetal and Jakhrana breeds were dropped from the technical program. Selective breeding of Sirohi is running as existing unit of AICRP at Avikanagar. Presently, bucks used for breeding purpose are selected based on 9-month weight and dam's 1st lactation 90 days milk yield. There is literally no selection practised in females except disposal of low performers at different stages due to small flock size. Controlled seasonal breeding through nominated hand mating is followed in the flock. There is remarkable overall improvement in growth, milk, reproduction and survivability traits of Sirohi goats since inception as a result of continuous genetic selection and selective breeding. The least squares mean(s) of live body weight at 3, 6, 9 and 12 month of age were improved to the tune of 24, 33, 67 and 39%, respectively, during 2020 since inception. The lactation milk production was improved to 43% in 2020 compared to that of 1983. Similarly, survivability and reproductive performance were also improved significantly. There was decline in performances of different traits in some years which may be attributable to changing environmental conditions including inconsistency in availability of nutritional inputs and disease incidences. There is huge demand for Sirohi goats among the farmers from all over the country. A total of 2679 genetically improved Sirohi germplasm, mostly males, have been sold/distributed to the farmers, Govt organizations and NGOs for breed improvement purposes in last 20 years. There are visible differences in the flock profile and improved performances in the farmers' flock leading to enhanced income of the farmers as a result of infusion of good germplasm from the project.

Performance improvement in Sirohi goats over the years

Trait		
Growth (kg)	1977	2020
Birth wt	2.58	3.07
3 Month wt	9.03	11.18
6 Month wt	14.11	18.71
9 Month wt	17.13	28.60
12 Month wt	21.94	30.40
Milk production	1983*	2020
90DMY (lit)	68.10	76.06
150DMY (lit)	86.09	109.47
TLMY (lit)	83.48	119.19
LL (d)	147.00	176.83
Survivability (%)	1977-84**	2020
0-3 Month	93.35	97.14
3-6 Month	97.11	97.46
6-12 Month	98.59	100.00
Adult	88.55	97.97
Overall	92.97	96.47
Reproduction	1986***	2020
Tupping %	72.77	97.30
Kidding% (Available)	54.54	98.06
Kidding% (Tupped)	75.00	100.80
Kidding rate	116.67	122.82

Major Histocompatibility Complex Genes: Two separate projects by Department of Biotechnology (DBT) and Department of Science and Technology (DST-SERB) have been executed. In DBT funded project, MHC variability at DRB, DQA and DQB loci in sheep and goats, and associated the genetic variation with variability in PPR and sheep/goat pox vaccine response were targeted. Environmental determinants affected the response to vaccine. Great variability between the animals for vaccine response was observed. T cell responses revealed non-significant association of CD4+, CD8+ and interferon-gamma levels *in vivo* in blood serum post vaccinated (with PPR) in sheep. Further 29 SSCP patterns for DRB-1 gene in sheep were observed with homozygosity and heterozygosity of 17.24 and 82.76%, respectively. DQA-2 locus had rich diversity with 19 and 20 alleles in Malpura and Avikalin sheep, respectively. Further in Sirohi goats, a total of 18 DRB-1 and 15 DQB-1 alleles were observed. In DST-SERB funded projects the Ovar-MHC variation in DRB, DQA1 and DQA2 loci across 22 sheep breeds were explored. A total of 391 sequences were submitted to NCBI and 19 new alleles were discovered. Huge genetic (structural) variation at allelic level and at peptide binding pockets across breeds and evolutionary significance is observed for the MHC region in sheep. An online DBMS was developed for depositing and retrieving the polymorphic immune database in sheep, goat and camels, where, the SNP variation data, clean sequence data from PCR or cloned DNA sequencing posted separately.

Animal Nutrition

The Sheep Nutrition Section was established in 1965 with the objectives to determine nutritive value of locally available feeds and fodder for sheep, to work out the nutrient requirements for maintenance, growth and production in sheep, to develop suitable feeding and grazing practices and to recommend efficient economic rations for sheep production. During the VI Five Year Plan, the Division of Nutrition including Grassland and Forage Agronomy (GFA) was created to conduct research on various aspects of feed and fodder resource development for sheep and rabbits, the nutritive evaluation and performance of sheep and rabbits on various feeding systems and to develop feeding systems. Later, GFA was separated and again remerged during 2015. Presently, the division is having well equipped lab for mineral estimation, proximate analysis, rumen microbiology and biotechnology, methane estimation and analysis. Apart from existing laboratory facilities division has experimental sheds with well-equipped metabolic trial facilities, feed technology unit for producing mash, pellet, complete feed block and silage, climatic chamber, herbal garden, fodder/forage demonstration unit and silvipastures. The thrust areas of research in this Division are:

* Developing feeding strategies for harnessing the inherent potential of small ruminants for functional meat and meat products
* Determining nutritional requirements for sheep at various production stages
* Developing sustainable and eco-friendly feeding strategies for sheep, goat and rabbit production
* Expanding feed resource base by evaluating and including newer feed resources- pasture (grasses, legumes), top feed resources, agro-industrial by-products and non-conventional feeds
* Identifying various anti-nutritional factors and methods to reduce them in feed and low-grade roughages for including them in the diet of small ruminants

The component-wise major research achievements of the Division are as under:

Nutritional interventions for increasing production performance: Initially, detailed surveys were conducted to assess the prevailing feeding practices, available feed resources and production performance at farm level. Based on survey data, limiting nutrients were recognized and various feeding modules/strategies were devised for balanced feeding practices to enhance production performance of small ruminants. The benefits of concentrate supplementation in term of weight and economic gain were documented and demonstrated to the farmers in the villages. To increase pre-weaning growth in lambs, concentrate mixture supplementation (@1.5% of body weight) was demonstrated in the farmer flocks which improved weight gain by 24% and fetched 25-33% more price through sale of lambs in the market. Like-wise, concentrate supplementation (@1.5% of body weight) during post-weaning phase resulted in increased body weights by 22-24% and lambs fetched 30-35% more price in the market. Planned supplementation of 300g of concentrate mixture during pregnancy and lactation stages was demonstrated in field flocks. Use of cheaper protein sources such as mustard cake in place of costlier groundnut and cotton seed cake was also demonstrated in field.

Maximizing pre-weaning growth performance in lambs through dietary interventions: Lambs meet their nutrient requirements from dam's milk; hence a positive relationship exists between milk yield of the dam and pre-weaning growth. It has been observed that native sheep breed does not produce enough milk to support rapid growth of pre-weaner lambs moreover; condition becomes more crucial when twins and triplets are born. “Memnaprash”, a nutritious liquid milk formulae developed by the Division for pre-weaning lambs/kids for gaining higher weight and survivability. Feeding of this supplement as milk replacer by diluting it with lukewarm water (six times) resulted in an additional body weight of 4-5kg at 3 month of age which increased market returns by Rs. 800-1000 more

and net return to the farmers was around Rs. 600-800 per lamb in 3 months. In pre-weaning lambs, Memnaprash feeding resulted in 100% survivability of lambs born as twins and triplets. Combination of milk replacer and creep mixture feeding was observed as the best suited technique to harvest highest average daily gain during pre-weaning phase. The cumulative profit was 13 and 25% higher in twins and triplets reared on Memnaprash compared to singlet. However, studies revealed that weaning lambs at 60 days of age on milk replacer allowance impaired growth performance and nutrient utilization whereas, rearing of lambs on milk replacer and weaning at 90days improved weight gain by 12% during pre-weaning phase. Economic analysis depicts that by investing a unit price, farmer can harvest about 2.5 times more output from lambs reared on milk replacer. Hence, raising lambs on milk replacer feeding and late weaning is economically beneficial for harnessing desired pre weaning body weight and maximizing finisher output in lambs under semiarid conditions. Gelatinizing of starch and protein in milk replacer resulted in higher weight gain and better feed conversion ratio than non–gelatinized milk replacers. Single time milking of ewes and feeding milk replacer to lamb(s) results in higher gain and lower production cost per kg weight gain. Different strains of probiotics (Kluyveromyces marximanus, Saccharomyces cerevisiae, S. uvarum) were supplemented at 0.1% body weight (1.5 - 2.0 ×1010 live cells/ ml) to pre-weaned lambs supported ADG up to 177g.

Finisher lamb production for quantitative and qualitative mutton production: Mutton synthetic (MS), Malpura (M) and Sonadi (S) weaner (90 days) lambs could achieve 170, 150 and 118g ADG with 1:5 to 1:7 feed efficiency ratio under intensive feeding on 50:50 roughage (Ziziphus leaves) and concentrate based ration. In intensive feeding, out of 99 MS lambs used, 90% animals achieved finishing weight of 30kg in record time of 56 days (total age of 146 days) and out of seven Malpura lambs, 71% achieved 30kg live weight in 66 days (total age of 156 days). To avoid higher deposition of carcass fat and to improve the efficiency of feed conversion lambs were weaned at 60th day of age and intensively fed to achieve target finishing weight of 25kg. The MS, M and MC lambs achieved finishing weight of 25kg in 73, 91 and 136 days of intensive feeding with 162, 135 and 112g ADG and 18, 16 and 14% feed efficiency, respectively. To sustain the gain the lambs consumed 75g DM, 5.5g DCP and 42.1g TDN/kg W0.75.

Weaner lambs (Avivastra) and kids (Marwari) were provided intensive feeding with composite ration having 50:50 roughages and concentrate. In 90days of intensive feeding, the weaner lambs (19.2kg) and kids (17.2kg) achieved finishing weight of 35.9 and 23.0 kg with ADG of 185.0 and 64.0 g and feed efficiency ratio 1:8.9 and 1:14.3, respectively. Nali, Chokla, and their crosses with Merino/Rambouillet weaner (90days) lambs maintained on 50:50 roughage concentrate based ration achieved average daily gain of 111 to 135g with 1:12-15 feed efficiency ratio. The mutton synthetic male lambs maintained on creep ration up to 60 days, 70:30 concentrate: roughage ration from 60 to 100 days and 50:50 ratio for 100-130 days reached a live weight of 30kg with a daily gain of 204g/ head. These lambs consumed 11.5, 9.3 and 8.0g DCP and 55, 56.4 and 57.5g TDN/kgW0.75/day, respectively. Body weight of 20-22kg in indigenous and 24-25kg in cross breeds were achieved by supplementary feeding of creep ration (150 and 200g/day) in addition to suckling up to weaning and 250 to 350g/day concentrate mixture in addition to grazing up to 6 months of age. Experiments with lambs fed on various levels of digestible energy and protein indicated that they required 70g DM, 5g DCP and 50g TDN/kg W0.75 to support 100gADG. Supplementary feeding along with grazing have the potential to expand the animal performance by increasing pre-weaning, post-weaning and mature body weight, quickening the reproductive cycle, increasing number of offspring and producing a greater number of finishing lambs/kids at an early marketable age. However, the cost of creep mixture vis-à-vis grower/finisher ration may also have significant bearing in commercial livestock farming. For harvesting better finishing weight Khejri, Ardu, Pala leaves, conserved cultivated grasses and crop residue are better roughage sources.

For economical finisher lamb feeding maize, barley, jowar, bajra, broken wheat or rice grains as energy and groundnut cake, mustard cake, til cake, cotton seed cake, gour korma based complete feed can be used for intensive mutton production. Finisher lambs may attain an ADG @200-250g if provided adequate energy and protein in balanced diet. Weaned lambs on an average require 32-35g DCP/ Mcal DE intake for achieving as ADG ranging from 130-160g. Under field conditions feeding of lambs with concentrate supplementation at 2.5 % of their body weight with routine grazing management seem promising because of reasonable feed cost, better growth and satisfactory fat and lean meat. Experiments conducted in the division revealed that for maintenance lambs require 120 kcal DE and 3g DCP per kgW0.75/day. Alternate energy and protein sources such as damaged wheat, damaged rice, mustard cake etc. can reduce cost of feeding if used judicially. On high concentrate diets supplementation of 1.5% sodium bicarbonate helps to maintain rumen pH near neutrality, which enhance growth by 35%. The post weaning diet should be rich in energy and should contain 18-20% protein (as fed basis) for the first three weeks and then 14 to 17% protein, thereafter. Inclusion of fat in ruminant diets may improve energy efficiency due to lowering of enteric methane production and long chain fatty acids are used for direct synthesis of fat without the need for acetate and glucose. However, the use of conventional fat is generally discouraged in weaner lambs as it reduces voluntary intake and fibre digestibility. Thus, inclusion of by-pass fat is a promising technology which can provide high energy to finisher lambs without altering the rumen environment. A simple method was developed in the division where industrial grade oils were converted to calcium soap of fatty acids. The final product consisted of 63% fat and 37% mineral matter and its cost was in between Rs.50-60/kg. Adding of bypass fat at 4% level in finisher lamb's diet increased weight gain by 26.7%. Lambs fed yeast culture containing Saccharomyces cerevisiae had significantly better performance in terms of total gain and ADG followed by mixed yeast culture and Saccharomyces uvarum culture fed lambs. Supplementation of commercial microbial feed additives containing both Saccharomyces cerevisae + Lactobacillus sporogenes to growing lambs improved growth performances and feed intake by 125%.

Nutrition for quality mutton and wool production: Inclusion of Ca-soap at 4% level and linseed at 10% in the diet of finisher lambs resulted in enhanced content of desirable fatty acids in both muscle and adipose tissue. Dietary inclusion of 10% mature curry leaves (Murraya koenigii) has dual impact on environmental sustainability and meat quality (higher C18:2c9t11 conjugated linoleic acid and lower C18:0 content). Similarly, in adult ewes feeding complete feed blocks containing Methi (Trigonella foenum-graecum) straw resulted in higher proportion of conjugated linoleic acid and polyunsaturated fatty acid content in meat. Addition of 10% aniseed (Pimpenella anisum) straw in post-weaned lamb's ration enhanced weight gain, improved feed conversion ratio, increased desirable fatty acid content in meat, improved oxidative stability of meat and meat products. Therefore, aniseed straw can be considered as a promising unconventional feed supplement for modulating ruminal biohydrogenation and augmenting proportion of functional fatty acids in meat which benefits human health. Prosopis cineraria (Khejri) leaves incorporated as a source of polyphenols improved meat quality but lowered growth performance. Carcass and wool quality were improved in lambs with supplemental protected fat and vitamin E. For wool production it was revealed that sulphur supplementation @0.3% in concentrate did not improve performance or wool quality parameters. However, an increase in wool yield (around 450g) with a reasonable increase in fibre diameter and decrease in hairy and medullation percentage was observed with the supplementation of sulphur (0.3% S as Na2SO4) in concentrate mixture along with grazing.

Restructuring of culled animals for quality meat production: The animals which have outlived their reproductive life (>6yr of age) are culled. These animals are not cared by the farmer which ultimately leads to loss of body condition score. The meat of such aged animals is tough and fibrous and not preferred by consumers. Improvement in body

condition and carcass characteristics were also recorded in cull ewes fed high energy diet @2.5% of body weight for a period of 90 days. Furthermore, feeding of compound feed blocks with urea as a cheaper nitrogen source and rumen protected fat improved performance, nutrient utilization and enhanced carcass traits for better marketability and returns from cull ewes. Therefore, a short duration (45-90d) feeding strategy with minimum feed input and maximum output (live weight gain) may fetch a higher price for the animals, which will compensate the feed and rearing cost and cancel out the recurring expenditure on these animals. In cull ewe's inclusion of 4g rumen bypass fat per kg feed made from industrial grade rice bran oil improved nutrient digestibility, body condition and carcass traits.

Researches on nutrient requirement: Requirement of nutrients (energy, protein) for sheep mainly depends on body weight of animal, its interaction with environment, and level of different production. The body weight gain of crossbred hogget on a ration with 65% TDN and 8% DCP was 140g/day. TDN and DCP requirement of hogget weighing 20kg and gaining 140g/day was 617 and 65g, respectively. Lambs weighing 15kg consumed 889g DM, 457g TDN and gained 89g/day. Lambs weighing 25kg weight consumed 990g DM, 675g TDN and 74g DCP/day and gained 95g/day. Consumption of TDN and DCP in the ratio of 8.5 at an intake level of 3g DCP/kg live weight produced highest growth in weaner lambs. Dry matter consumption was 3.5 to 4.0kg/100 kg body weight. Fine wool crossbred lambs averaging 15kg body weight consumed 617g DM, 422g TDN and 48g DCP and gained 70g/day. Avikalin lambs gained 151g/day when fed a complete feed containing 50% concentrate and 50% roughage (ground cowpea hay) with an intake level of 1100g DM, 642g TDN and 156g DCP. DM intake worked out to be 46g/kg body weight in lambs. TDN (36g) and DCP (5g) per kg metabolic weight have been recommended as the requirement for maintenance. Rams weighing 32kg maintained weight with intake of 397g TDN and 34g DCP/day. For maintenance, approximately 10g of TDN and 1g of DCP are required per kg live weight. For young lambs, more than 14% protein in the diet had no additional advantage. Pregnant ewes during their advanced pregnancy required 7.8g of DCP and 58.7g of TDN per kg metabolic weight for producing lambs with 3.5-4.0kg birth weight. These lambs attained 14.0kg body weight at two months of age. Nutrient requirements of sheep at various physiological stages were estimated as under:

Stage	Requirement/kgW $^{0.75}$			
	TDN (g)	DE (kcal)	ME (kcal)	Digestible protein (g)
Maintenance	27.30	120.12	98.50	3.0
Growth (per g gain)	1.79	7.87	6.46	0.2
Pregnancy	50.90	223.96	183.65	7.0
Lactation	53.00	233.20	191.22	8.5
Wool production	35.00	154.00	126.28	4.2

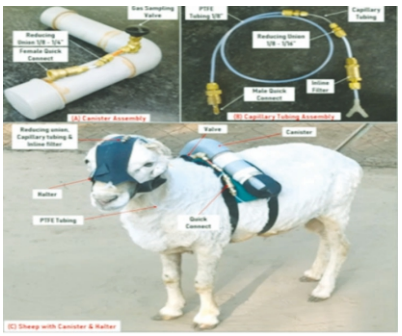
The study on measurement of energy expenditure in sheep indicated that a housed sheep spent 4.16 MJ energy/day. The energy expenditure of grazing animals was 43% higher than that of stall-fed sheep. The expenditure of energy was 4.85MJ/day during winter, which increased to 6.70MJ/day during rainy season. The animals exposed to heat stress required more energy to meet their enhanced requirements for thermoregulation and maintenance. The extra requirement by suitably increasing the energy density of the diet improved production traits of weaner lambs and adult sheep.

Optimum nitrogen-sulphur ratio in the diet of wool producing sheep was found to be 5:1. Sulphur concentration of 0.24% in the diet produced maximum quantity of wool i.e.1392g in 6 months clip with a scouring yield of 80%. On increasing the feeding level by adding 20% concentrate along with cenchrus fodder, wool production was increased from 671g to 1393g and staple length was increased from 3.7 to 5.6cm. The effect of dietary levels (18, 22 and 27%) of crude protein on pre-weaning gain in lambs indicated that even the lowest protein level was optimum for

their pre-weaning growth requirement and the weaning weights were 11.1, 11.3 and 11.4kg on diets with 18, 22 and 27% CP, respectively. These lambs, on intensive feeding, on a diet containing pala (50%) and concentrate (50%) had similar finishing weight of 21kg. Maintenance requirement of protein in adult Marwari rams weighing 30kg was 6% CP. The optimum level of CP and TDN in the ration for wool production was 10 and 50%, respectively. The nutrient intake and digestibility in dry, pregnant and lactating sheep were significantly higher during winter in all the three physiological stages as compared to monsoon and summer. On the basis of nutrient availability, requirement and possible supplementary feeding a strategic supplementary schedule is developed to have optimum production from flock, *viz*. 330g ground maize to dry non-producing animals (30kg) only during summer, maize+ oil cakes at 300+100g, 0+115g and 240+200g to pregnant (30kg) and 0+125g, 0+190g and 220+250g to lactating animals during monsoon, winter and summer, respectively.

Nutrient requirement studies of multiple foetus bearing Avishaan sheep: Avishaan ewes given 18% higher nutrition than ICAR (2013) resulted in comparatively better peri-parturient performance in terms of ewe body weight, milk production and lamb growth than those given 12% higher nutrition. Despite better peri-parturient performance at 18% higher nutrition in Avishaan ewes, there was protein insufficiency. Hence, modifying ingredient composition of concentrate with protein rich supplements and quality roughage enable optimum production performance. In case of gestating prolific ewe(s) supplementation of 400g concentrate mixture along with grazing provided 4.1g of DCPI (g/kgw$^{0.75}$) and 0.73MJ of MEI (MJ/kgW$^{0.75}$) which was comparable to ICAR (2013) requirements i.e.5.0 g DCPI (g/kgw$^{0.75}$) and 0.79MJ MEI (MJ/kgW$^{0.75}$). In lactating ewes with multiple fetus, supplementation of 600g concentrate mixture along with grazing provided 6.1g of DCPI (g/kgw$^{0.75}$) and 1.1 MJ of MEI(MJ/kgW$^{0.75}$) which provided 6% lower protein and 17% higher energy in comparison ICAR (2013) requirements i.e. 6.5g DCPI (g/kgw$^{0.75}$) and 0.96MJ MEI(MJ/kgW$^{0.75}$). In multiple fetus bearing ewes providing 10% higher nutrient requirements than ICAR (2013) i.e. 8.0g DCPI/kg W$^{0.75}$ and 0.9ME (MJ/kgW$^{0.75}$), was sufficient to provide energy and protein requirements. To meet the requirements in Avishaan, supplementing 450g concentrate mixture (CP-11.5%, DE- 2700 Kcal)) to ewes bearing single fetus provided 60.4g DMI/kgW$^{0.75}$, 3.6g DCPI/kg W$^{0.75}$ and 0.52ME (MJ/kgW$^{0.75}$). In case of multiple foetus bearing ewes supplementation of 600g concentrate and 500g concentrate + 1.0kg green provided 65.9 and 67.1g DMI/kg W$^{0.75}$, 4.1 and 4.3g DCPI /kg W$^{0.75}$ and 0.55 and 0.59MJ ME (MJ/kgW$^{0.75}$), respectively.

Livestock feeding and environmental concerns: In ruminants, methane production result in energy loss between 10-13% of energy intake. Besides this methane is also a potential greenhouse gas. The Division developed a feed product named 'Avi-Batika' which is palatable, improves feed intake, modifies rumen fermentation and sustains adequate livestock production. It reduces methane to the tune of 17.5% in growing lambs. As a result, an increase of 19.8% weight gain was recorded in lambs fed 'Avi-Batika'. *Blepharis scindica* herbage and *Trigonella foenum-graecum* straw, added at 40% in CFB conserved 5.2 and 2.4% energy, respectively by reducing methane emissions. Feeding of 10% mature curry leaves lowered methane emission by 12% and increased weight gain by 9.9%. Addition of *Prosopis cineraria* and *Ziziphus nummularia* at 20% level resulted in methane mitigation to the tune of 15.5 and 10.7% respectively per unit of digestible organic matter. Total mixed ration when offered as complete feed block conserves more energy (3.6% of ME) through reduced CH_4 emission compared to that offered in mash form. Feeding of Moringa leaves in total mixed ration at 30% level increased weight gain by 15% and lowered methane emission by 3.70% per unit of energy intake. Supplementing aniseed



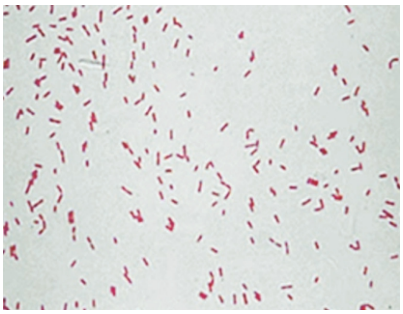
(*Pimpenella anisum*) straw at 10% level reduced daily methane emission by 17.5% and increased growth performance in lambs by 9%. Among cereals methane production potential per 100mg of digestible organic matter was lower in pearl millet (1.41ml) and higher in guar grains (1.83ml) whereas, in cakes it was higher in cotton seed (1.72 ml) and lower in mustard cake (0.56 ml) and in case of byproducts the values were higher (2.04ml) as compared to grains and cakes. Methane production per g of samples was highest in the leaves of kala siras (13.99ml) followed by shisham (10.44ml) and siras (9.70ml) leaves. The Tree leaves producing less methane were of khejri (2.27ml), mango (3.58ml), tamarind (3.83ml) and sagwan (3.86ml). Total methane production per g of sample in available crop straws in descending order was as til straw (12.25ml), jowar straw (9.79ml), wheat straw (7.86ml), barley straw (7.79ml), saunf straw (7.33ml), guar straw (6.55ml), gram straw (6.20ml), groundnut straw (5.38ml), jeera straw (4.19ml) and bajra straw (2.21ml). Methane emission per 100mg of digestible organic matter was reduced with bypass supplementation. Several spices straws (5, 10 or 15%) were tested in complete diet with different concentrate and roughage ratio (60:40 or 40:60 or 25:75 or 75:25) *in vitro* to assess their methane mitigation potential. Among the spice's straws, Ajwain, fenugreek and fennel produced lower methane up to 15% level of inclusion. Amongst the tree leaves, Khejri, Neem and Ardu up to 20% level of inclusion lowered *in vitro* methane production and improved digestibility to a significant extent.

Under heat stress, the growing lambs require additional energy to support the priority functions of thermoregulation and growth. Adult animals fed 115 and 130% above their maintenance requirement during summer under hot sun not only sustained their weight but could increase it at 130% of maintenance suggesting that the animals had enhanced energy requirement during summer. When subjected to graded nutritional stress Malpura and Chokla sheep and Sirohi goats, compared to Avikalin and Avivastra, with their lower body reserve lost more weight and took longer period to regain the lost body weight and the effect was pronounced in winter as compared to that in summer. The crossbred Mutton Synthetic lambs despite their higher energy expenditure in thermolysis, grew faster, utilized feed efficiently and therefore had better productive performance. Two housing systems were evaluated, under shed and open corral with panipula shelter in 20% of the area. No apparent difference in feed intake and digestibility of nutrients, blood-biochemical profile, body weight changes and wool yield and quality was observed under the two housing systems. Provision of the desert cooler in sheep sheds created a better microenvironment and improved physiological responses to heat stress. Inclusion of fruit and vegetable waste up to 10% in sheep diet improved nutrient utilization and antioxidant status along with reduction in GHG emissions. Level of selenium enriched yeast has limited potential to ameliorate heat stress. The umbrella-type portable lamb incubator could provide adequate shelter management to new-born lamb. In Avishaan rams, under heat stress conditions, the availability of earthen pot cold drinking water reduced their body weight loss, improved metabolic activity and their welfare.

Nutrition-reproduction interaction: Inclusion of *Prosopis cineraria* at 40 % level in diet revealed positive effect on male reproduction with higher semen volume. Supplementation of *Moringa oleifera* leaves in the diet of ewe lambs increased their antioxidant status and improved conception rate (67%) compared to *Morus alba* (36%) and control (27%). Supplementation of herbal pellets (*Asparagus racemosus*) and mineral pellets to grazing ram lambs increased testosterone concentration as compared to non- supplemented lambs. Milk-replacer feeding during pre-weaning and Ca-soap during the post weaning period enhanced growth, testicular development and semen quality. The

supplementation of pellet mineral mixture to sheep (@5g/day for 5 months) increased wool yield by 8-9%, milk yield by 10-15% and supplementation to anoestrus sheep brought 60% of sheep into oestrus within 15-21days and remaining 40% after 42days of supplementation.

Rumen metabolism, microbiology and biotechnology: Ruminants harbours a diverse microbial population in their fore stomach, rumen and the diet of the grazing ruminants consists of mostly poor-quality roughages and contains higher structural polymers (cellulose, hemicellulose and pectin). Because the feed they eat, such as grass, leaves, and hay are not very nutritious, they have to get the most out of what they eat. The major species involved in cellulose degradation are *Bacteroides succinogenes, Ruminococcusalbus, R. flavefaciens* and *Eubacterium cellilosolvens*. Isolation, identification and functional characterization of 50 cellulose degrading bacteria and 34 tanninolytic bacteria from rumen contents of sheep were done with the help of biochemical and molecular techniques. Different bacterial colonies were separated and different isolates were morphological characterized on the basis of different colour and size of their colonies, and then the isolates were biochemically characterized. The isolates showed varied characteristics with respect to biochemical characterization. Mostly the isolates are Gram -ve and varied morphologically from cocci to bacillus or coco-bacillus. Isolates were mostly obligatory anaerobes. Characterization of *in vitro* fibrolytic and dry matter degradability potential of tannin degrading isolates for identifying promising isolates to be used as direct fed microbial in sheep.



Studying of rumen protozoal population suggests that among sheep and goat under controlled feeding, dry-matter intake was lower while digestibility of fibre fraction was higher in goats, which could be partly due to the greater number of total ciliate protozoa as well as holotrichs and spirotrichs in rumen of goats. Sodium lauryl sulphate can effectively be used as a defaunating agent and it had no apparent adverse effect on the performance of sheep as evident from similar nutrient digestibility, plane of nutrition, rumen fermentation pattern and ciliate protozoal population between defaunated and faunated sheep. A simplified cultural test using Fe^{2+} medium to detect mimosine degradation by the mixed rumen microbes of sheep and goat was performed. Mixed rumen microbes of sheep and goats degraded mimosine up to 19 and 26%, respectively on 30th day of incubation. The influence of live yeast culture namely *Saccharomyces cerevisiae*, *S. uvarum*, *Kluyveromyces marximanus* and a mixed yeast culture of above three in a ratio of 1:1:1 was assessed in weaner Malpura lambs. Among the three yeast strains, lambs fed yeast culture *S. cerevisiae* had significantly better performance in terms of total gain and ADG followed by mixed yeast culture and *S. uvarum* culture. Yeast culture feeding improved growth performance by 5 to 8%, feed efficiency by 3 to 9% and reduction in cost of feed inputs per kg live weight gain by 6 to12%. Fermented yeast feeding (@ 30-50g) also reduced incidence and duration of diarrhoea in lambs. Feeding of fermented yeast product as probiotic supplement fermented product improved growth performance. Optimum dose of probiotics for better growth, health and mutton production was assessed in pre-weaner lambs and it was reported that lambs drenched with liquid culture @1ml/ kg body weight of *Lactobacillus acidophilus* containing $3.6x10^9$ cells/ml improved average daily gain and intake. With *L. acidophilus* feeding faecal *E. coli* count was also lower. The incidence of diarrhoea was lowered and faecal consistency improved in *L. acidophilus* supplemented groups.

Nutrition of grazing sheep: The main pasture species was *Cenchrus ciliaris* and grass legume mixed pasture of cenchrus and dolichos. Cenchrus - dolichos mixed pasture could produce growth of 45 to 100g/day in lambs. The CP % in the native pasture varied from 4.3 to 10.3% and remained below 7.0% during September to March. The DM and CP contents of pasture during lush and lean seasons were 31.5%, 8.0% and 76.2%, 4.5%, respectively. TDN intakes by rams on available pasture were low (20 to 50% lower than NRC requirements). The DCP intake was adequate

during July to September only. Phosphorus intakes were also not adequate for most parts of the year. Vitamin A level declined gradually from September to December and June. A stocking rate of 5ewes/ha on cenchrus gave satisfactory performance in Avikalin and Avivastra ewes. When ewes were allowed to graze on such pasture at a stocking rate of 5, 6 and 7sheep/ha, forage availability during July was reduced to 5.1, 4.5 and 1.1q/ha, suggesting that 6 sheep could be carried per hectare on cenchrus pasture. Mutton synthetic sheep grazing 8hr/day on cenchrus dominant pasture performed well with annual lambing 83.5%, adult mortality 5.5% and lamb mortality 6.5% and the body weight of lambs at birth, weaning (3 months) and at slaughter (9 months) was 3.0, 11.5 and 20.0kg, respectively with dressing percentage of 40. Wool yield was 2.1kg/annum/sheep.

Dorset x Sonadi cross-bred ewes at the stocking rate of 6ewes/ha performed well in cenchrus based silvi-pasture. The average body weights and lambing rate of ewes were higher with stocking rate of 5 ewes/ha, however, average wool production in ewes were higher with stocking rate of 6ewes/ha. Six-month body weight was higher with stocking density of 4ewes/ha. Cenchrus produced maximum fodder under more stocking rate (6 sheep/ha) due to maximum plant height as sheep dropping increased the organic carbon content on surface soil and reduced soil pH. Avivastra ewes and Marwari does at stocking density of 4animals/ha (2 ewes + 2 goats) grazing on *Cenchrus ciliaris* pasture consumed 37.2 and 28.5g DM/kg body weight and DM digestibility of 60.8 and 51.0% during lush season and they consumed 28.5 and 27.3g DM/kg body weight with DM digestibility of 45.3 and 40.3% during lean season. Birth, weaning (3 months) and 6 monthly weights of grazing lambs and kids were 3.3 and 3.2; 18.5 and 16.3 and 27.5 and 26.6kg, respectively. In male hoggets, grazing on three, two and single tier silvi-pasture plots and under routine sector management (the biomass availability in this pasture ranged from 21.72 - 28.91q/ha) the live weight gain was higher in the silvi pastoral plots (7.3kg) compared to sector management (3.4kg). Nutritional studies at north temperate region revealed that body weight gain in crossbred (Rambouillet x Gaddi) hoggets was highest with white clover (*Trifolium repense*; 4.19kg) and lowest with native grass (Cymbopogan family - locally known as Kanja; 2.30kg) and intermediate with Tall fescue (*Festuca arundenacea*). Finishing weight of 20-22kg was achieved with ADG of 53-61g/day in lambs and 93-102g/day in kids. Grazing sheep (Malpura and Mutton Synthetic) revealed that silvipastoral system of range management could successfully maintain 4ewes with followers round the year. Average milk yield (ml/day) of ewes in three, two and single tier silvi-pasture and natural rangeland were 467, 365, 310 and 285 respectively with milk protein content of 5.0-5.4g%.

However, to obtain the desired production traits, the surplus biomass available on pasture had to be harvested to avoid losses in natural cycle and fed to the animals during lean season and critical physiological stages. Fallen tree leaves formed the major portion of diet during summer months and its preference by the grazing animals increased from February (30.0%) to March (47.3%). Grazing sheep found to prefer *Eluecina indica*, *Commenlina forsakalaei*, *Eriochloa polystachyca* and *Crotalaria burhia* during onset of monsoon. Marwari ewes could be maintained on pasture grazing alone throughout the year when not bred. Dry matter intake was highest during October to December, but digestibility of nutrients was lowest during this season. Body weight gain of sheep in one year period was better on improved pasture (7-8kg) compared to natural (5.6kg), improved natural (5.4kg) and reseeded cenchrus pasture (6.1kg). In goats, however, gain in weight was higher in reseeded cenchrus pasture (8.4kg) compared to natural (8.3kg), improved natural (8.2kg) and improved (7.9kg) pasture. Performance of kids was better than lambs when grazed on silvi-pasture system.

While estimating DM and DE intakes using different diet collection methods e.g. composite pasture sampling (CPS), mouth grab (MG), hand plucked (HP) and oesophageal extrusa (OE), and faecal collection methods e.g. use of collection bags and chromic oxide indicator; it was observed that the CPS, HP and MG methods over estimate DM and DE intake. The OE method, however, had limitation of salivary nitrogen contamination, alteration in grazing behaviour due to surgical trauma and artifact lignin formation in drying process. The double indicator method has been successfully modified to reduce errors. In the process oesophageal cannula was also fabricated and fitted in sheep for collection of representative samples of diet of grazing animals. The DMI estimated by extrusa and total faecal collection was 665g/head/day and was significantly lower than that estimated by composite (1265g/head/day),

mouth grab (847g/head/day) and handpicked (1095g/head/day) method. Nutrient selectivity studies using oesophageal cannulated sheep, suggested that animal could preferentially select moderately high protein (CP-13%) diet, even during lean season, when pasture contained about 3-4% CP.

The biomass yield of community grazing land in the month of September, January and May is around 4.92, 1.36 and 1.93 DM q/ha. Most of the native grass species were sprouted immediately after rain and constituted of.

Tribulus terrestiris (8.90%), *Indigo feracardifolia* (16.24%), *Crotolaria burhia* (12.64%), Satha (16.91%), *Zizyphus nummularia* (11.40%), *Dactylo cteniumaegyticum* (21.18%), *Melilotus indica* (9.31%) and other native grasses. Pasture yield of cenchrus (q DM/ha) was higher in monsoon (40.7) than October (24.6) and December (10.8). The DM was higher in December (82.9%) and lowest in August (46.5%) with reverse trend in CP showing the lowest value (6.01%) in December. The fibre composition was in line with DM. The chemical composition of other components such as NDF and ADF content of the pasture was higher in June and lower in August. With a DM intake of 737, 656 and 681g/d in the month August, October and December, respectively, the digestibility of DM, OM, CP, NDF and ADF of ewes were high in August (54.7, 54.1, 60.6, 56.5 and 59.3%) and low in December (50.8, 50.2, 47.7, 21.3 and 34.6%). The digestible crude protein (DCP %) also varied among seasons ranging from 5.72% in December, 6.61% in October and 8.48% in August. The ME intake during August, October and December were 35.1, 22.6 and 35.5 MJ/d, respectively which supported higher live weight gain in December versus August and October. The biomass yield of community grazing area and fellow land was 6.2q DM/ha. Pasture sample collected from community grazing land mainly comprised of Chidichawla, Bekariya, Doodhi, congress grass and Doob. Four major contributors were Doodhi (32.6%) followed by Bekaria (19.4%), Chidichawla (15.71%) and Congress grass (12.15%). The DM, CP, NDF, cellulose and lignin content of the pasture samples were 52.6, 9.4, 55.6, 26.2 and 6.8%, respectively. The CP content of individual vegetation samples ranged from 11.38-13.89% and lignin 4-7%. Preference index for DM and CP was 0.66 and 1.32, respectively indicating animals prefer to consume succulent material from pasture having high nutritive value.

Supplementary feeding: Grazing alone could hardly produce satisfactory growth in lambs. Supplementation with concentrate in addition to 8 hr/day grazing on cenchrus dominant pasture increased carcass yield by 55%. Crossbred weaner lambs on an average getting 600g concentrate per day in addition to grazing gained @130g/day compared to 108g/day on 50% concentrate and 50% roughage diet in stalls. Supplementation of 200g concentrate or cowpea hay produced weight gain of 70g/day. Supplementary feeding, (concentrate, hay and green) over grazing to kids, resulted in an increase of 45% in live weight and 14% in dressing percentage. A daily gain of 37, 87 and 73g from 3 to 6 months and 63, 139 and 120g from 6 to 9 months age was obtained in Beetal × Sirohi kids maintained on browsing, browsing with concentrate supplementation and on complete stall feeding, respectively. Supplementation of formalin treated GN cake (1% v/w) did not produce any significant effect on overall weight gain of lambs but wool production increased by about 10%. Experiment on weaner lambs for mutton production under intensive and supplementary feeding management indicated that under both the systems of feeding lambs achieved 23kg body weight. The average daily gain (g) 98 and 106 and feed efficiency (kg/kg gain) 11.2 and 12.0 with DMI (g/kg W0.75) of 100.6 and 92.9 was observed under intensive and supplementary feeding systems, respectively. Groundnut cake in sheep ration can be effectively replaced by cotton seed cake on equal nitrogen basis. Addition of cotton seed cake at lower levels (up to 20%) did not

affect body weight gains in lambs. Guar korma, a locally available agro-industrial by product may be mixed as a protein source in the ration of adult sheep in place of cakes without any adverse effect on wool production and health, while it may replace groundnut cake nitrogen in the concentrate mixture for Marwari hoggets to the level of 35% without any adverse effect on weight gain, wool production and health. However, dietary inclusion of damaged wheat by replacing maize at 75 and 100% levels depressed growth without any adverse effect on immunity.

Feed resource evaluation and utilization: The nutritive value of various feeds-grasses, legumes, top feeds and pastures available during different seasons were evaluated. *Alianthus excelsa* (Ardu) leaves were found to be the best in term of palatability and nutrient contents among the top feeds for sheep. Nutritive value and animal performance of artificially grown barley fodder (Fometa) was also assessed in sheep. The average yield of Fometa fodder was 10.4q/day containing 86.95% moisture, 15.74% CP, 9.37% CF, 1.97% EE and 70.27% NFE. The digestibility of DM and proximate principles ranged between 75-90%. Hoggets maintained on sole Fometa fodder consumed 840g DM, 105g DCP and 659g TDN/day and gained at 34g/day. When Khejri leaves (*Prosopis cineraria*) as dry or as fresh lopping were fed to sheep and goat, sheep lost 28g/day weight, whereas goats gained 46g/day. Incorporation of khejri leaves in the ration of weaner lambs (20% by weight in the concentrate), lowered the digestibility of organic constituents. Pala leaves (*Zizyphus nummularia*) had 5.6% DCP and 49.7% TDN with a nutritive ratio 1:7.9. Dry matter intake from green pala leaves was 2.3% of body weight in growing lambs. An *ad libitum* ration containing 30% Pala, 40% maize, 20% groundnut cake, 7% molasses, 2% mineral mixture and 1% common salt was sufficient to produce an average daily gain of 100g/day in weaner lambs.

Pala leaves should be fed in combination with other feed but not as a sole feed to obtain satisfactory performance. Treatment of pala leaves with 1.2% PEG (Polyethylene glycol- 4000) significantly increased dry matter intake and dry matter digestibility. The body weight increase in yearling rams was also higher in PEG treated group than untreated group. The dry leaves of Mopane (*Colophospermum mopane*) had poor preference in the sheep while green leaves and twigs were consumed. The ground ripe Siris (*Albezzia lebbeck*) pods could be mixed in the concentrate mixture for adult Marwari sheep to the level of 40% without any deleterious effect on health and wool production. Fallen tree leaves can be incorporated in the diet of sheep up to 20% in the feed block. Feeding trials revealed that dried leaves of *Prosopis juliflora* can replace guar straw up to 20%, whereas pods could replace up to 50% of guar straw. Sun dried ground pods of *P. juliflora* can replace 30 - 40% concentrate mixture fed to rams @1% of their body weight along with *ad libitum* cenchrus hay. Replacement of concentrate with dried pods of *P. juliflora* did not affect the nutrient intake, rumen fermentation characteristics and nutrient utilization. Dried *P. Juliflora* leaves can replace concentrate mixture, guar straw and cenchrus straw up to 10-20%. However, dried pods can replace concentrate mixture, guar straw and cenchrus straw up to 40-50%.

Complete feeds have been developed for sheep and goats incorporating roughages and concentrates. Roughage components used in these feeds were ground cowpea hay, ground cenchrus hay, *Zizyphus nummularia* (pala) leaves, *Ailanthus excelsa* (ardu) leaves and *Prosopis cineraria* (khejri) leaves. Such complete feeds can be used for lambs and kids for meat production. Feeds containing 50% concentrates and 50% roughage have been found satisfactory; although high energy feeds can be prepared for higher growth with 60:40 or 75:25, concentrate to roughages ration. Feed conversion ratio of 5 to 8 with DM consumption of 3.5 to 5.0% of body weight has been obtained in lambs fed

complete feed blocks. On a complete diet containing 40% siris pods, the digestibility of nutrients (DM, OM, CP, TCHO, NDF, ADF) and retention of nitrogen was significantly higher in goats than sheep. Complete diet was prepared with cenchrus straw (38.6%), dried ardu leaves (37%), wheat bran (14%), mustard cake (7.4%), common salt (1%) and mineral mixture (2%) and its performance was evaluated in Malpura rams and Kutchi bucks. It was concluded that complete diet could sustain the animals but goats did not prefer feeding of complete blocks. Preparation of complete feed blocks by mixing roughage and concentrate in 70:30 ratios with 5.0% molasses as binder reduced the cost per kg gain by 38% in sheep and goat as compared to feeding of grass hay and concentrate separately. Complete feed block with tanniniferous forages (e.g. *A. nilotica, Z. nummularia*) at the 30% levels can be successfully and safely utilized in feeding of weaner lambs without any adverse effects. A large number of monsoon herbage species grow rapidly after rain viz., *Achyranthus aspera* (Andhajhara), *Amaranthus* sp. (Cholai), *Boerhavia diffusa* (Satha), *Commelina diffusa* (Bokharu), *Crotolaria medicaginea* (Jhojhru), *Oxalis corniculata* (Khatari), *Indigofera cardifolia* (Bekaria), *Trianthema portulacastrum* (sabuni) and *Tribulus terrestris* (Gokharu) in arid and semi-arid region. On average they contain 15-30% DM, 14-20% CP, 2-3% EE, 55-75% NDF, 30-65% ADF, 6-15% lignin and 10-15% ash. Complete feed blocks were prepared by incorporating concentrate, monsoon herbage, hay and molasses. Feed blocks contained 10% CP and 55% TDN which is sufficient for sheep feeding during scarcity period.

Prickly pear cactus or opuntia, [*Opuntiaficus-indica* (Linn.) Mill.] from semi-arid regions in India contain CP, 92-126g/kg DM, which is higher than the commonly used dry roughages (straw, stover and grasses) in ruminant feeding. Although opuntia feeding with conserved fodder maintained adult sheep but a high N loss in urine is the principal concern and may require additional N supplementation. Sheep offered opuntia in combination with cenchrus (*Cenchrus ciliaris*) hay had low feed intake, apparent digestibility of DM, CP and energy, nutritive value, plane of nutrition and N balance, but when supplemented with 50g groundnut meal, there was improvement and values were similar to cenchrus plus 200g concentrate supplemented diet. Furthermore, one kg fresh opuntia feeding to a sheep provides 0.88L of water thus it can compensate mild water restriction by 1.00L without effecting feed intake during summer. During summer, cactus could be an important source of water to sheep besides nutrient supply in hot arid regions. The feeding of 8.80kg cactus provides about 7.50 litre water to 10 sheep or 75 litre of water from 880kg cactus to 100 sheep.

Utilization of agro by-products in feed: Water soaking of mustard cake reduced its glucosinolate, (6.53% in untreated) content to the extent of 12, 23, 29 and 36% at 1, 2, 4 and 6h, respectively, whereas 8 and 12h of soaking did not have added advantage. Lactating sheep fed on mustard cake incorporated concentrate feed found to contain 10-14.8µg/ml of thiocyanate in milk and 5.2-6.5µg/mL of thiocyanate in serum. Cotton seed cake could replace groundnut cake on equal nitrogen basis in lamb ration. Complete feeds have been developed containing de-oiled rice polish and urea for maintenance purpose; wheat bran has been used with pala leaves in 50:50, 75:25 ratio for lambs which have gained 50 to 70g/day. Sugar beet pulp @53%, sea weed meals @0% and wheat bhusa @25% can replace expensive ingredients like maize, barley in the rations for lambs. Replacement of barley at the rate of 50 and 75% by molasses resulted in 235 and 157g body weight gains. Guar korma may replace groundnut cake up to 35% in concentrate ration without any deleterious effect.

Improvement of low-grade roughage: Ammonia-sulphuric acid treatment of wheat bhusa increased dry matter digestibility in sheep. Supplementing urea @1% in molasses liquid drink to crossbred lambs grazing on cenchrus pasture resulted in better body weight gains than urea-salt-licks supplementation. Commercial grade urea could be fed to growing lambs in the concentrate mixture containing barley and groundnut cake up to 2.6% of the concentrate mixture. The growth performance was about 84% of the control lambs. Enrichment of harvested cenchrus grass by ammoniation with 4% urea improved DCP value from 2.7 to 7.1 and TDN value from 47.3 to 55.8%. Feeding of treated cenchrus alone could maintain empty adult ewes. Hogget fed on chaffed and ground pearl millet stover alone or both

the material ammoniated as such or ammoniated along with molasses indicated that the digestibilities of CP and fiber improved significantly by ammoniation alone as well as ammoniation with molasses. The DCP value of the roughage increased from 4.5 to 11.0 and 3.6 to 13.0% by urea treatment alone and urea molasses treatment respectively. The treatment improved the DMI and energy value of roughage. Wool yield also increased from 1.1 to 1.4kg by these treatments. Ewes fed on untreated and 4% urea treated cenchrus grass along with 150 and 300g babool pods improved in body weight gain. The animals receiving 4% urea treated cenchrus hay with 300g babool pods showed better weight gain (14%) than their counterparts receiving only urea treated cenchrus hay which lost their body weights by 19%.

Treatment of bam grass (*Sorghum helepense*) with 4% urea and subsequent stacking for 28 days improved the DCP and TDN values of the grass. Treated and untreated baru grass fed with or without 6g Na_2S0_4 per day indicated that sole bam feeding resulted in negative sulphur balance, whereas addition of Na_2S0_4 maintained the animals in positive sulphur balance. Ewes maintained on varying levels of sulphur (0.09 to 0.23% of DM) indicated that addition of sulphur improved the digestibility of DM, CF and EE thereby increasing DCP and TDN content. The sulphur balance was positive in animals fed 0.23% sulphur and negative in all others indicating that for optimum sulphur balance in sheep the diet should contain a minimum of 0.2% sulphur.

Mustard straw has 2.5% crude protein and is not commonly utilized for sheep feeding. Ammoniation and stacking (21days) of mustard straw with 4% urea improved its CP content to 9.85%. Wool yield (90days clip) was 585.0g in untreated mustard straw fed ewes and 747g in treated mustard straw fed group. Weaner lambs fed on 50:50 concentrate and untreated and 4% urea treated mustard straw indicated that DM, DCP and TDN intakes in both the groups were far below their requirements for growth and in 100days feeding period lambs fed untreated mustard straw-based diet gained 3.0kg live weight whereas the treated mustard straw-based group had negative gain. Mustard straw fed with pearl millet, *Cenchrus* grass and pala leaves along with 1% urea indicated that CP content of the feed combination ranged between 7.0 and 8.2%. Animals fed on 50:50 combination of mustard straw with pearl millet, cenchrus and pala leaves lost weights, whereas, all the four roughages in 25% incorporation were able to sustain the animals. Urea treated mustard straw supplemented with either 200g concentrate or 25% tree leaves can maintain the sheep.

Fungal (*Coprinus fimatarius*) treatment of ammoniated mustard straw improved its nutritive value and 5% urea with 75% moisture and 11 days incubation at 30^{0}C was found to be ideal treatment for the straw. *In vitro* fungal culture techniques were standardized and various white rot fungi used were *Ganoderma applanatu, Ganoderma lucidum, Longyites strata, Phanerochaete chrysosporium, Pleurotus ostreatus, Pleurotus sajorcaju, Polyporus adustus, Polyporus arcularius, Polyporus sanguineus-154, Polyporus sanguineus-970, Polyporus versicolor, rametes hirsute.* Amongst these species *Pleurotus* and *Polyporus* spp. are the potential lignin degrading fungi which can be exploited for the improvement of feeding value of mustard straw (low grade roughages) in sheep. Submerged system was set up using *P. sanguineus* and mustard straw (1%) in 0.02 M sodium acetate buffered medium pH 4.5 with an incubation period of 29 days. *P. sanguineus* produced good amount of lignin degrading enzymes. The substrate having 70% moisture with supplemental 0.25% single super phosphate and incubated with white rot fungi at 35^{o}C for 14 days improved IVDMD. Addition of urea found to have inhibitory effect on fungal growth. *C.*

versicolor was found to be most suitable for bio-delignification of mustard straw under solid-state fermentation and it improved CP content by 26% and DM digestibility (*in vitro, in sacco*) by 16%. Autoclaving of straw/roughages could be replaced by dipping straw in formaldehyde (500ppm) and carbendazim (35ppm) solutions for 8h for sterilization. To improve the nutritive value of mustard straw it was soaked in either boiling water or 2% NaOH solution for 6 or 12h. NaOH treatment reduced NDF, ADF and Cellulose significantly as compared to the water and boiled water soaking. The tenacity of structural fibre (g/tex) was found to be lower in NaOH treated mustard straw indicating structural changes brought about by NaOH treatment. When Mustard straw treated with different levels of urea (0, 3, 4, 5%), moisture (55, 65, 75%) and incubated at different levels of temperature (30, 40 and 500 ºC) for 7, 14 and 21 days.

The results indicated that there was a reduction in hemicellulose and lignin content of straw after treatment with urea, linearly. When urea treatment was done using alternate layers of urea treated and untreated straws the ammonia produced was diffused to untreated layers, increasing concentration of nitrogen (% DM) in straw from 0.78 (untreated) to 1.74-2.06% (treated straw). The technique saved water and labour requirement. The hydrolyzation of urea to ammonia, during treatment in conventional method was 75-85%, which was similar in layer method whereas urea could not be hydrolysed when concentrated urea solution was either poured or placed in the form of lump inside the straw. Spraying of urea solution on the sewan and drying it was found to be better method of feeding urea as compared to urea in drinking water. Urea:starch ratio 1.5:13 was adequate and safe for maintenance of adult Marwari Sheep when sewan stover was fed as roughage. *In vitro* nutrient digestibility was lower in H_2O_2 treated than NaOH treated mustard straw. The contents of OM, CP, ADF and cellulose slightly reduced and the per cent NDF, hemicellulose, lignin and *in vitro* digestibility marginally increased when the MS was soaked for different hours. On the other hand, non-significant differences were observed among periods of soaking for OM, CP, cell wall constituents and *in vitro* digestibility. The period and NaOH/ H_2O_2 treatment did not have their combined effect on the nutritive value of mustard straw. Alkaline H_2O_2 treatment of mustard straw improved DM and digestible DM intake, decreased the N excretion in urine, higher N balance and these effects were more pronounced in 2% NaOH + 1.5% H_2O_2 treated mustard straw. Exogenous enzymes fortification with concentrate did not significantly alter nutrient intake and utilization and the rumen fermentation attributes in rams fed cenchrus hay-based diets. However, pre-treatment of roughages at 30% moisture level showed promise through improvement in nutrient digestibility (OM, NDF, ADF and CP).

Processing of tanniferous feeds for their increased utilization: Fodder/feed obtained from trees are an integral part of diets of small ruminants in arid and semi-arid regions of India. Top feeds serve as good quality forages but presence of large quantity of tannins hinders their utility. Leaves from *Acacia nilotica, Ailanthus excelsa, Zizyphus nummularia, Z. maruitiana, Calligonum polygonoides, Prosopis cineraria, Dichro stachysnutans, Ficus bengalensis, F. religiosa, Bauhinia racemosa* and *Leucaena leucocephala* were analysed for their tannin content and biochemical nature of tannins. It was observed that except *A. excelsa*, all other leaves contained tannins. Although concentration of tannins varied with the season and age of the leaves, but pattern of change was not uniform with all the tree leaves studied. Tannins were also present in the cell wall fraction of tree leaves; hence presence of tannins leads to over estimation of lignin in tannin rich tree leaves. Tannin content and its protein precipitating capacity were mainly responsible for adverse nutritional effects. Tannins in *P. cineraria* and *Z. nummularia* had higher protein precipitating capacity than *A. nilotica*. Tannins may combine with dietary and enzyme proteins and reduce digestion. Casein complex with tannic acid was less degraded by sheep rumen microbes.

Practical feeding experiments with *P. cineraria* + urea also showed that animals performed better in comparison to *P. cineraria* alone. Similar to tannic acid, *Z. nummularia* tannins also inhibited proteolysis of casein by rumen microbes. Looking at the role of tannins in nutrition, a simple method for the determination of tannins in intact tree leaves was developed for the use of feed industry. The method is based upon protein precipitating capacity of tree leaf tannins. Deleterious effects of tannins depend upon its ability to form complexes with protein and other macromolecules. Polyethylene glycol- 4000 binds preferentially to tannins in comparison to proteins. Experiments with *Z. nummularia* and *P. cineraria* showed that treatment with PEG-4000 not only increased the feed intake and digestibility of nutrients but also the productivity of animals. *In vitro* studies also showed that the inhibitory effects of *P.*

cineraria tannins on trypsin, chymotrypsin, amylase, ruminal cellulase were recovered in the presence of PEG-4000. The beneficial effects of PEG-4000 were also visible in the status of iron, protein and albumin in the serum of sheep. Attempts to reduce the tannins content in tree leaves by NaOH and $FeSO_4$ treatments were found to be impractical. High cost of PEG-4000 prohibits its application in routine feeding. Tannin resistant rumen microbes were isolated from the sheep rumen. Its growth was observed under strict anaerobic condition and in the presence of 0.5, 1.0, 2.0, and 3.0mg tannins in broth. Growth was slow and in presence of 3.0mg and higher amount of tannins in the culture tube, bacteria did not grow. The degradation of tannins of *P. cineraria, B. racemosa, F. bengalensis, L. leucocephala, Z. nummularia and D. nutans* have been shown by the isolated bacterial isolates.

Micronutrient profile and supplementation strategies: The results of AICRP on improvement of feed resources and nutrient utilization in raising animal production under existing feeding practices and gaps in feeding systems for livestock of different agro-climatic zones of Rajasthan has been documented. The micronutrient profile of macro (Ca, P and Mg) and micro minerals (Cu, Fe, Zn and Mn) and intakes of cattle, buffaloes, sheep and goats in different physiological stages have been worked out from the actual mineral contents of feeds and fodders fed to animals in different agro-climatic zones and compared with standard requirements for identifying the mineral deficiencies. The prioritization of these nutrients in livestock feeding has been identified and a suitable strategy for their supplementation has been developed. Area specific mineral mixture consisting of calcium, phosphorus, zinc, copper and cobalt minerals in different proportions for different agro-climatic zones of semi-arid Rajasthan has been developed based on deficiencies of these minerals in the diets or rations of animals during different physiological stages. Mineral mixture pellets were prepared for supplementation to sheep and goats. It has been found that mineral mixture helps in bringing anoestrus sheep into estrus after 15-20days of supplementation. The supplementation of mineral mixture at the rate of 5g daily for 5 months increased the wool yield from 400g to 433g in supplemented lactating and 440g in supplemented dry sheep. Chelated copper and zinc in place of inorganic minerals used in mineral mixture for supplementing to Malpura lambs under field conditions. Growth of lambs on roughage and supplementary concentrate feed containing conventional and chelated copper and zinc minerals were almost similar, however, copper and zinc in chelated form were required in 56.4 and 25.9% lesser quantities than conventional inorganic source to achieve same level of growth in lambs.

Conservation of feeds and fodders: Cowpea silage was prepared at the flowering and pod stage with or without molasses and fed to Malpura rams, palatability and dry matter digestibility of the silage was increased by the addition of molasses. Ensilage at flowering stage was better than at pod stage. Cowpea mixed with pearl millet crop (50:50) was harvested at pod stage and ensiled as chaffed untreated or treated with 5% molasses and 1% common salt by weight. Rams on an average consumed 2.52 and 2.34kg dry matter/100kg body weight from untreated and treated silages, respectively. There was no significant effect of molasses-salt treatment on dry matter intake and digestibility of nutrients except that of crude fibre which declined significantly. Silages from green neem leaves as such or with (super mindif; 2% dry basis) or with molasses (10%) and green oats with or without pala leaves can be fed to sheep. When green pearl millet fodder was ensiled with or without 0.50% biuret, ammonia-N concentration increased fivefold. Although the crude protein

content increased from 5.20 to 7.60, the palatability of the biuret-treated silage was decreased. The TDN value of the treated silage was also low.

Feed toxins and food safety: Feed ingredients used at CSWRI Avikanagar for feeding of animals including the rations prepared from local market were tested for aflatoxin contents. The aflatoxin contents in all the ingredients are within the permissible limits of sheep feeding, however maize had highest aflatoxin content (337ppb) compared to other ingredients. Mould infestation was least in DORB, adult pellets and lamb rations showing total aflatoxin content of 31.9, 29.0 and 29.0ppb, respectively. Therefore, mycotoxicosis is not a problem for our livestock. Interestingly pellet feed and lamb ration obtained from local manufactures were also safe for aflatoxin content. Profile of different aflatoxin showed that aflatoxin B1 content ranged from 6.9 to 37.9ppb and aflatoxin B2 from 10.8 to 120ppb. Aflatoxin G1 was detected in til cake (45ppb), GNC solvent (38.96ppb), maize (217ppb), wheat bran (9ppb) and rabbit pellets (74ppb), while aflatoxin G2 was detected only in til cake, GNC solvent and adult pellet feed.

Animal feeding trial on bio-safety studies with of Bt cotton crop using seed meal stated that nutrient (OM, CP and fiber fractions) and mineral (Ca, P. Mn, Co and Zn) contents were identical in Bt-cotton and non-Bt cotton seeds. The growth performance of lambs was similar on control, non-Bt cotton seed and Bt-cotton seed included diets. The growing lambs consumed 168g Bt-cotton seed per day and did not have apparent adverse effect on dry matter intake, nutrient utilization and nitrogen balance. Similarly, Bt-cotton seed intake of @19.5% of dry matter intake did not produce deleterious effect on performance and dry matter intake. Thus, palatability and growth performance were not a problem for Bt-cotton seed feeding in lambs even under high plane of nutrition. Also, feeding of Bt cotton seed to lambs did not alter immunity and allergen status.

Rabbit nutrition: For maintaining adult rabbit, a diet containing 13% CP and 2.20Mcal/kg DE is recommended. Normally, adult rabbit usually consumes 30-35g DM/kg body weight. To avoid gastro-intestinal problems diet should contain 20-25% ADF and 12-15 CF%. For growing kits, a diet containing 18-19% CP and 2.5-2.8Mcal/kg DE is required to achieve a commercially viable growth rate of 28-30g/d. The gestation length in a doe is 1 month and since the litter size at birth ranges from 7 to 10, a pregnant doe requires continuously high energy and protein in her diet. A 15% increase in DMI is generally observed during gestation over non pregnant stage. A diet with 18% CP and 2.4Mcal/kg DE was found sufficient to achieve desirable litter size. Litter weight accounted for about 12% of body weight of doe at kindling. A healthy kit grows about 8-10g per day. To maintain this growth, lactating doe has to produce enough milk. The DM intake of lactating doe was about 35-50% higher in comparison to dry stage. For achieving desirable weight, a feed should contain leguminous green fodder and concentrate.

Nutrient requirement of rabbit

Physiological stage	Requirement/kgW $^{0.75}$			Nutrient concentration	
	DM (g/d)	DCP (g/d)	DE (kcal/d)	CP%	DE (kcal/kg)
Maintenance	42.6	3.80	94.7	13.0	2200
Growth*	91.0	**13.0**	**25.5**	**19.0**	**2700**
Gestation	45.0	5.9	105.5	**18.0**	**2400**
Lactation	64.0	9.0	170.0	**18.0**	**2700**

Optimization of protein levels for various physiological stages in rabbits: Adult British and Russian Angora rabbits (more than 6-month age) were fed for 9 months, 14.4, 16.2, 17.1, 18.1, 19.4, 22.0 and 23.1% proteins in their diets respectively. Wool yield was highest on 17.1% protein diet (0.60g/day), followed by 14.4% protein diet (0.58g/day). The digestibility of nutrients for crude protein increased with increasing protein content. There was no effect of fibre characteristics on wool production and quality. Animals almost maintained their body weight throughout

the experimental period. It was concluded that 17% CP is required in the diet of Angora rabbit for wool growth. Six-week-old male Angora rabbits were fed with basal diet of concentrate pellets at 60% of the total daily feed requirement and the rest 10% through green tree leaves of biul (*Grewia opositifolia* Rorb), Kachnar (*Bahunia variegata*) and Winter/Kashmiri willow (*Salix* species) up to 12 weeks of age. No significant difference in weight gains, efficiency of feed utilization and wool yield was observed. The wool yield/kg body weight ranged between 14.79 and 17.60g. Feeding rabbits on complete concentrate diets during pregnancy and lactation resulted in higher birth weights of kits and body weights subsequently at 6 and 12weeks of age than those on concentrate + roughage (50:50) diets. Rabbits on completely roughage diets attained the lowest body weights. Both broiler and Angora breeds of rabbits on concentrate gained more than their counterpart on concentrate + roughage diets. Grey Giant gained more than Angora rabbits on concentrate diet. There was no significant difference in weight gains of Angora rabbits on concentrate + roughage-based diets. For grower meat rabbit protein contents of diet should be around 20%. Feed efficiency was also highest at 19.4% crude protein diet. Cowpea hay fed broiler rabbits expressed higher gain, consumed more feed and had higher feed efficiency than those fed Kudzu vine and Robinia leaves. Dried tomato pomace can be incorporated in the diets of growing rabbit up to 20%. Rice-phak at 20% level along with barley 11% do not form a successful replacement of maize + wheat bran + rice polish in the feeding regime of Angora rabbits.

Methionine supplementation resulted in higher gain, better feed conversion and dressing percent in rabbits. Adult Soviet Chinchilla rabbits could be maintained on paper mulberry leaf-based ration having 18% crushed barley. Robinia leaves could be added @ 25% for improving gains in Soviet Chinchilla broiler rabbits. Kudzu vine may be included up to 25% level in adult White Giant broiler rabbit ration. For Soviet Chinchilla kits weaned at 28th day of age 4% fat as palmolene oil for growth is recommended in the feed. Ground leguminous fodder (20-25%) along with a mixture of cake, bran, molasses, salt and mineral mixture can be used as pellet complete diet. Cowpea hay, lucerne hay and berseem hay can be used interchangeably in the complete diet. Bam, khejri, pala, mango, pipal, bargad and ardu, tree leaves can be used with 15% in complete diet for satisfactory performance of rabbits. Maximum gain can be obtained on mulberry-based concentrate feed. Best average daily gains were achieved when green leguminous fodder was fed *ad lib* along with concentrate pellets containing 20-22% CP and 3.0Mcal/kg DE. The feasibility of replacing pellet feed with soaked soybean and maize without and with heat treatment in broiler rabbit was studied. No ill effect of feeding soaked, and soaked and boiled soybean feeding was observed on rabbit's health. In rabbit diets, pellets containing moringa leaves at 70% level lowered feeding cost, yielded better fatty acid profile and improved the shelf life of rabbit meat and its products. Hence, for better growth performance and improved meat quality level of moringa leaves should not exceed beyond 50% in complete feed pellets. Feeding of urd (*Vigna mungo*) crop residue and *Stylosanthes hamata* hay at 25% level improved feed conversion ratio and keeping quality of rabbit meat. Their incorporation also modified the fatty acid profile of meat with lower SFA and thrombogenic index, and higher PUFA and n-3 fatty acids.

Animal Physiology and Biochemistry

The Division of Animal Physiology and Biochemistry was initially started as Physiology Section in the year 1965, though the work on ovine physiology and reproduction was initiated two years after the inception of the institute. Then, in 1975 the section was upgraded to division to carry out both the basic and applied research in the areas of adaptive and reproductive physiology in sheep. The division was subsequently renamed in February 2003 as the Division of Physiology and Biochemistry after merger of Biochemistry Section. Over the last six decades the division has emerged as one of the leading research centres in the country. A number of externally-funded projects from DBT, DST, NATP, NIAP, NAFBSRA and NICRA have been successfully completed in the division. The division is well equipped with advanced research facilities such as PCR, real-time PCR, Western blot apparatus, gel doc system, HPLC, fluorescent microscope, gamma counter, cell culture laboratory, programmable cryofreezer, computer assisted semen analyser (CASA), ultrasonography etc. The major programmes undertaken were on ram semen preservation, artificial insemination and adjudging the physiological adaptability of different strains developed at the institute. During the IX and X plan periods, the main emphasis was geared up on research on developing advanced reproductive technologies pertaining to cryopreservation of ram semen, embryo technology, control breeding in ewes and adaptation of sheep and rabbits to hot semi-arid environment. Recently research has been initiated on sheep milk with aim to evaluate and validate of sheep milk bioactive potential as human health promoter. The division is credited to report for the first time in the country the birth of lamb following transfer of frozen-thawed embryo in 1998 and IVM-IVF-IVC produced embryo in 1999. The division has also been successful in producing 240 elite lambs through ETT and cryo-conserving 263 *in-vivo* produced embryos from various sheep breeds.

A number of protocols have been developed to enhance the reproductive efficiency of native sheep. The notable research contributions are development of techniques pertaining to cost-effective indigenous progesterone impregnated intra-vaginal sponges, laparoscope aided embryo transfer and intrauterine artificial insemination, superovulation, ram semen freezing and transcervical artificial insemination. The two technologies namely, '*Artificial insemination of sheep using short-term preserved ram semen'* and '*Estrus induction and synchronization in sheep'* have been successfully demonstrated and transferred in to the field. The Avikesil-S sponge developed for *'Estrus synchronization in sheep and goats'* has also been commercialized. The scientists of this division have filed six patents through ICAR*, out of these*, one patent has been awarded and two are under review. The division has been conferred with prestigious awards from ICAR, ISCA, NAAS and other scientific societies and in several national and international seminars. The two research contributions of the division have been published as *records* in the *Limca Book of Records*. The salient research achievements of the division on different aspects of sheep physiology such as male and female reproduction, adaptation to climate stress, growth and lactation during last six decade are highlighted below:

Male reproduction

Biochemistry of semen: Calcium, Sodium, Potassium, Inorganic Phosphorus, Chloride and Alkaline phosphatase activity in semen do not vary between breeds. Electrolytes in the semen did not affect the physical attributes. Creatinine value of semen is 4 times higher than the serum. Glutathione level in blood of Malpura animal is double than Nali and Chokla. Acid phosphates activity in semen is inhibited by the excess of phosphate ions and RNAse by the acetate ions. Amalyse activity depends on breed and season with highest activity during spring followed by autumn.

Semen production: Rams of native breeds start donating semen at 6-7 month of age. Hot weather has deteriorating influence on semen quality of exotic rams. It could be overcome by acclimatizing the rams for three generations. Exotic rams donate good quality semen at the rate of one ejaculate per day up to 19 days. Second collection of the ejaculate within 10 min interval increases the volume of semen and number of spermatozoa. Semen of exotic rams at 2-3yr of age is best and limit is up to 5yr. Foot and Mouth Disease, Sheep Pox and Blue Tongue even at sub clinical

level affect the semen quality. Stresses like dipping, vaccination etc., also affect the semen quality, adversely. Saxome (Indian herbs) at 7g/day along with 150g concentrate for 40 days improve the libido of the rams through its aphrodisiac, general stimulant and spermatogenic action. Intensive feeding of lambs increased the testicular development to donate semen at 7 months of age and attain the puberty at 9 months of age in females. The influence of *FecB* gene introgression on sperm production and quality was reported for the first time.

Isolation, culture and biochemical characterization of ovine spermatogonial stem cells: A single-step enzymatic digestion of testes tissue with collagenase-I plus trypsin-EDTA was found to be effective for isolation of ovine spermatogonial stem cells (SSCs) and two rounds of attachment culture on gelatine-coated plates significantly enriched the SSCs.

Use of Hydroxytyrosol for short-term preservation of ram semen: Application of a potent antioxidant Hydroxytyrosol (HT) as an additive during short-term preservation of ram semen was studied. HT at the rate of 150 µM was found to be optimal in terms of motility parameters for chilled liquid semen preservation for 24 h. A fertility trial in Malpura ewes was conducted with 24h-stored chilled liquid semen with EYCG-HT (with 150 µM HT) and observed that conception rate based on lambing was higher than the control EYCG diluent (50.00 vs 30.76).

***Purification of sperm motility-inhibitory proteins of ram cauda epididymal plasma*:** Two motility-inhibitory polypeptides of about 80 and 65 kDa were purified from ram cauda epididymal plasma. The 80 kDa peptide also exhibited anti-capacitating activity on ram sperm.

A novel membrane stabilizer for preservation of semen: A novel membrane stabilizer to replace egg yolk in semen extender was synthesized and tested in ram semen preservation. It was found superior to egg yolk both in liquid preservation of ram semen at 5°C up to 120 h as well as in cryopreservation. Sperm total motility (70-75% vs. 40-50%), rapid motility and velocity were significantly higher in presence new membrane stabilizer as compared to that of the egg yolk. Fertility rates of liquid-preserved ram semen were comparable between EYCG and novel membrane stabilizer-based extender up to 48 h of storage. A patent in this regard has been processed and filed.

Effect of pre-freezing equilibration period on post-thaw quality of cryopreserved ram semen: Equilibration of semen prior to freezing helps in entry of cryoprotective glycerol into sperm. The effect of different equilibration periods on post-thaw qualities of ram semen was investigated. Equilibration for 22 h significantly improved post-thaw sperm viability, rapid motility and plasma membrane integrity, and reduced sperm acrosome reaction. The post-thaw sperm membrane cholesterol and mitochondrial membrane potential were significantly higher in 22 h equilibrated samples compared to those having 3 h equilibration.

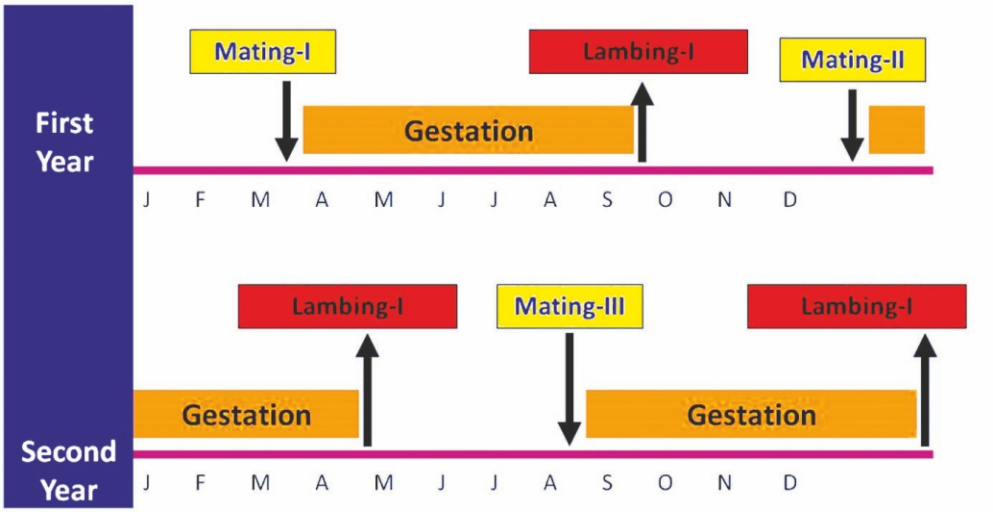
Female reproduction

Reproductive efficiency of Patanwadi sheep: The twining rate achieved in Patanwadi sheep were 30.7 and 25.0% in the ewes mated in natural and induced estrus, respectively. After first lambing, second breeding was successfully performed in 58.3% ewes with in targeted eight months period (232.7±2.14 days). All the ewes were mated second time within inter-service period of 271±9.68 days.

Flushing of ewes: Feed supplementation @1.5% of body weights affected the estrus and ovulation responses in the ewes. Feed supplementation during summer season improved ovulation rate (1.2±0.20) compared to control group (0.7±0.15).

Production of 3 lamb crops in 2 years: In present scenario of growing demand for mutton and shifting towards intensive sheep rearing, accelerated mating system to target three crops in two years has been studied with respect to its feasibility and success rate in sheep maintained under organised management and feeding practices. For production of 3 lambs in 2 years, 30 Malpura ewes were bred by natural mating strictly within 90 days post lambing either at natural estrus or induced estrus. The induction of estrus was done by using indigenously developed progesterone impregnated intra vagina sponges and PMSG protocol. A total of 66.7% (16/24) ewes completed fifth lambing within targeted days of 3 lamb crops in 2 years protocol. Fifth mating and lambing was achieved within

923.41±15.59 and 1075.77±15.72 days, which were targeted within 966 and 1116 days, respectively from the day of first mating. Adoption of accelerated lambing system yielded 32.58 and 26.92% more lambs in Malpura and Patanwadi sheep, respectively.



Accelerated lamb production (schematic view)

Potential of Dopamine antagonist to induce cyclicity in anoestrus ewes: For assessing the role of Dopamine antagonist to improve upon the LH pulse frequency in anoestrous ewes, 12 Malpura ewes (3-4yr old) were equally divided into two groups. Ewes in treated group were injected Dopamine antagonist (@ 0.6 mg / kg, subcutaneously) twice a day (7:00 am and 5:00 pm). Five out of the six ewes in the treatment group exhibited clear signs of oestrous on variable days (2-7 days after the start of the treatment) while one ewe was observed in silent heat. LH surges were observed in the animals on the day of detection of estrus or the day following it. It was found that dopamine antagonist as such can cause ovulation in anoestrus ewes.

***Molecular identification and characterization of melatonin receptors gene*:** On molecular characterization of the entire melatonin receptor gene of nearly 10 breeds of sheep showed 10 important SNPs in the coding sequence of the gene, three of which were non-synonymous. Frequency of 'r' allele was found to be dominantly higher in seasonal than non-seasonal sheep breeds. M allele was not found to differ significantly between the seasonal and non-seasonal sheep breeds.

Synthesis of recombinant ovine Kisspeptin: For induction of early puberty in sheep, ovine kisspeptin-14 (Kp-14) was synthesized and studied for its conformational properties. Functional in-vivo validation of the peptide was done and administration of Kp-14 peptide @20µg/ewe (single bolus, intravenous) resulted 8-10 times increase in LH levels at 15min after the injection. *Further,* recombinant kisspeptins were engineered and recombinantly produced to have an increased therapeutic half-life in blood vascular system of sheep model. The half-life of the kisspeptins which is known to be in minutes has been increased for maintenance of in -vivo functionality. A patent in this regard has been processed and filed by the inventors.

Characterization of BMPR-1B associated with high prolificacy in sheep: The full coding region of Bone Morphogenetic Protein Receptor-1B (BMPR-1B) gene from prolific GMM (*FecB*^{BB}) and non-prolific GMM (*FecB*$^{++}$) sheep was characterized and mutations identified. The *FecB* mutation was observed to alter the expression of BMPR1B and SMAD signalling genes in the ovaries of homozygous carrier GMM ewes. Antisera against extracellular domain of BMPR-1B was raised in rabbit. The anti-sera showed positive reaction at 57kD with purified BMPR-1B protein and specifically downregulated the expression of BMPR-1B and BMPR-II receptor genes in cultured granulosa cells of both prolific and non-prolific sheep.

Cloning and expression of olfactory marker protein (OMP) in sheep: Olfactory marker protein is widely recognized as a molecular marker for mature OSNs in other species. The primers for amplification of OMP gene in sheep were self-designed and the gene was successfully amplified and cloned. Hyperimmune sera were raised in a rabbit using purified OMP protein. *In-vitro* localization of OMP protein in the epithelia covering the vomero-nasal organ (VNO) and endoturbinates tissues was done by Western blotting.

Identification of novel PLP transport mechanism in E. coli: PLP is a biological active form of Vitamin B_6 and is essentially required for carbohydrates, amino-acids and fatty acid metabolism. The effect of supplementation of PLP in the media on the expression of PLP dependent model protein in *E. coli* was studied. Soluble recombinant protein could be purified from each of the culture vials grown with variable amount of PLP [0 mM (Group I), 0.01mM (Group II), 0.025mM (Group III), 0.05mM (Group IV) and 0.1mM (Group V)]. There was approximately 4.2%, 7.2%, 10.5% and 18% increase in purified protein yield in Group II, III, IV and V respectively in comparison to group I. The relative incorporation of PLP into the purified protein by scanning the changes in internal fluorescence of purified proteins revealed a significant quenching of tryptophan fluorescence emission in groups supplemented with PLP in culture media.

Documentation of de-novo pathway of cysteine synthesis in multicellular nematodes: In order to determine whether the parasite uses a de-novo pathway of cysteine synthesis or not, ssuccessful directional cloning of the CS gene was done in pET303 champion vector using restriction sites XbaI and XhoI. The CS protein catalysed the reactions of de novo pathway by using O-acetyl serine as substrate which was validated both by a biochemical assay as well as by FTIR by tracking upon the cysteine transmittance at wavenumber 2357 nm^{-1}. Cysteine synthase activity by de-novo pathway was also observed in the homogenate extract of the parasite, further corroborating to the finding. The expression of CS gene was found to be highly up- regulated in adult worms and was found to be lowest in L3 larval stage of H. contortus. It confirmed that the de-novo pathway of cysteine synthesis is an active process of cysteine production in parasite and the expression of the cysteine synthase enzyme is modulated at different stages of parasite's life cycle reflecting and conforming to the microenvironment and physiological survival needs of the parasite in the host.

Improvement in prolificacy through n-3 PUFA supplementation: It has been observed that ewes with low body condition score only had improved ovulation rate on increasing the level of nutrition. The supplementation of n-3 Polyunsaturated fatty acids (PUFA) rich fish oil at 0.6 ml/kg body weight for 2 months improved the proportion of Malpura ewes having multiple preovulatory follicle and ovulation by 60 and 48%, respectively as compared to the ewes fed with isocaloric diet rich in palm oil. The twinning percent in fish oil supplemented ewes was 3 times higher than those of palm oil fed ewes which are otherwise single foetus bearing (27.27 vs 9.09%).

Stress and adaptation

Nutritional stress: Animals under energy crisis experienced greater degree of stress. Nutritional stress had an adverse effect on physiological responses, blood parameters and reproductive efficiency of ewes. Thermal stress has greater effect on depleted sheep than *ad libitum* fed sheep. *Ad lib*itum feeding and exercise increases greasy fleece production. Nutritional stress has more effect than thermal stress and when both these stresses are coupled, it has more severe effect. When nutrition is not a limiting factor, then ewes are able to better cope up with thermal stress.

Effect of water deprivation: Offering water at intervals of 48 h for 6months and 72 h interval for a prolonged time affected lamb growth, pregnancy, lactation and carcass yield. However, it did not affect non pregnant, non-lactating and non-growing animals. There is no body weight loss in Chokla sheep when watered at weekly intervals. During winter watering at intervals of 48 h improved digestibility of DM, CP, EE and CF. The animals avoid intake of high protein materials during restricted watering. Watering at intervals of 72 h reduces intake of DM and consequently body weight. Restricted watering, increases concentration of salt in urine.

Effect of heat stress on adaptability and reproductive performance of Avishaan rams: No significant effect of heat stress was found on testosterone level, reaction time, number of mounts for first and second ejaculation, time taken for first and second ejaculation. Moreover, comparison of circadian rhythms of newly developed prolific

Avishaan sheep and native Malpura sheep during summer and winter indicated that newly developed prolific sheep had similar adaptability to this environment as compared to Malpura breed when shelter and nutrition is optimum.

Effect of heat stress on expression of HSP70 gene and biochemical markers: Partial coding sequence of the HSP70 gene in the Malpura sheep was submitted to NCBI. Heat shock protein gene HSPA1A (inducible HSP70) gene expression acts as a specific marker of heat stress but not a marker of cold stress in sheep as it increased significantly on all 4 hourly diurnal time points in summer in peripheral blood mononuclear cells of adult Malpura Rams during grazing but not during winter. Under controlled thermal exposures in climate chambers, HSPA1A expression pattern is highly sensitive to temperature changes. Circulating cortisol changes diurnally in relation to climatic changes in both the seasons. During summer, the cortisol levels decrease in the afternoon to rise again in the evening in grazing rams. Breed wise variation has been observed in the circadian rhythm of physiological responses of Avishaan, Avikalin and Malpura rams. Avishaan rams are also able to tolerate solar radiation and availability of cold drinking water reduces the magnitude of heat stress. Average daily gains (three to six gram) of the post weaning period and from six months to one year for all the Avikalin lambs born in this institute farm since last 1976 revealed that the most comfortable THI for Avikalin sheep is 25-27.

Indexing of the climatic stress and development of climate resilient housing systems for commercial sheep farming: The study has been initiated to develop climate resilient shelter system for commercial sheep farming in semi-arid and arid climate. For sheep, the majority of climatic stress occurs during the summer season rather than winter season in the semi-arid region. The native Malpura and synthetic prolific Avishaan rams have shown similar physiological responses and blood biochemical stress indices, which indicates that winter was well tolerated by both the breeds. Comparative evaluation of sheep during summer and in controlled climatic conditions with specific increments and indexing with respect to the various physiological and blood biomarkers, will help index the climate stress in sheep. Further evaluation of several indigenous shelters in the areas are in progress which help identify their thermal insulation characteristics to determine the efficiency of climate resilience of such shelter systems.

Growth performance

Fat-tailed Dumba sheep: The small ruminant production systems are mainly subsistence-oriented but in view of the rising demand for meat, there is a great scope for commercial sheep farming. In this scenario large body size with rapid growth efficiency is the current need of the sheep farming in the country. As an alternate option for enhancing meat production and bridging the gap between demand and availability of meat in the country, performance of Dumba sheep (Fat-Tail/rump) has been evaluated in semi-arid climate prevailing in the institute. The overall survivability of Dumba sheep was 92.63% (0-3 months, 3-12 months and adult groups as 88.19, 100, and 82.92%, respectively). The performance of the animal for growth, reproduction and production is presented below:

Mean (±S.E.) body weight (kg) and average daily gain (g) of Dumba lambs

Particular	Body weight				
	Birth wt	3M wt	6M wt	9M wt	12M wt
Overall	4.49±0.09	27.65±0.65	42.39±1.06	51.81±1.61	62.37±2.00
Male	4.65±0.12	28.94±0.88	47.01±1.41	58.69±2.36	74.41±2.39
Female	4.28±0.11	25.83±0.87	38.26±1.26	46.31±1.71	53.09±1.89
	Average daily gain				
	0-3M		3-6M	6-12M	
Overall	256.43±65.79		161.31±58.94	110.02±65.58	
Male	267.87±9.04		188.49±7.51	149.56±8.03	
Female	240.30±9.00		136.98±6.89	79.52±5.98	
Singleton	270.85±6.10		166.86±6.44	110.71±7.37	
Twin	185.92±17.09		130.50±11.15	105.99±13.32	

Reproductive and lactation performance of Dumba sheep

Reproductive performance	
Age of puberty (males) (days)	283.38±18.51
Age at first lambing (days)	589
Inter - lambing period (days)	320
Lambing (%)	85.4
Twinning (%)	9.7
Lactation performance	
Total lactational yield (kg)	74.24±0.72
Daily milk yield (kg)	0.885±0.01
Fat %	8.89±0.62
Protein %	3.68±0.16
Lactose %	5.59±0.23
Salt %	0.85±0.03
SNF %	10.06±0.43
Total Solid %	18.95±0.25

Physiology of growth: Malpura lambs require 6.5 kg of milk to produce one kg live weight. Crossbreds are more efficient in milk utilization. Weaning of lambs at 45 days or 75 -90 days result in similar body weights at 6 and 9 months of age. Administration of thyroxin improves body weight and fertility in ewes. Castration at birth does not improve weight gain up to 6 months and dressing yield. Castration at 3 or 9 months do not affect carcass yield. Body condition score (BCS) of 3.0-3.5 of ewes is optimum at mating and during gestation for achieving higher lambing and birth weight of lambs. Rams kept under the conditions of a hot, semi-arid environment should be maintained at moderate (3.03.5) BCS during breeding stage to ensure maximum reproductive efficiency.

Group feeding strategy for optimum growth: A mild competition is required for feed and water intake, minimum feed wastage in addition to space for individual feed intake and free movement so as to result in optimum body gain in lambs which is exhibited in group feeding the lambs in troughs with fenced line with optimal head space.

Lactation and Milk

Characterization of sheep milk and lactation: Malpura ewes produce maximum milk (65 kg) in 90 days of lactation whereas Chokla yielded 24% less than Malpura. Milk yield of Rambouillet and crossbred is similar to Malpura. Peak milk yield is achieved during 2nd week of lactation. Dumba ewes have the potential to produce 75-90 kg milk in 90 days lactation.

Assessment on sheep milk production potential and its utilization: Survey data of questionnaire on 90 sheep farmers of 32 villages of Malpura to assess sheep milk production potential, its utilization and social attributes of respective sheep farmers was analysed using Garrett ranking technique. The incomes of farmers from sheep produce as per Garrett ranking scale (1-5) were ranked as lamb (3-4 month), sheep (adult), manure, milk, and wool, respectively. Most farmers involved in marketing of the milk in the area were illiterate, middle aged (30-60 yrs), having a family size of 5-9 and flock strength of >50.

Evaluation of inherent bioactive sheep milk constituents: Inherent calcium, phosphorous and chloride content in sheep milk was 219 mg/dl, 92.46mg/dl and 253 mMol/l, respectively. The activity of gamma glutamyl transferase was comparatively higher in sheep milk plasma than in blood plasma while the lactate dehydrogenase activity was lower in sheep milk plasma. Bioactive peptides from sheep milk were produced by proteolytic hydrolysis of total milk protein with pepsin for half an hour followed by periodic tryptic hydrolysis. Production of 3kd molecular weight peptides was achieved within 2h using peptic digestion followed by tryptic digestion. The peptides produced (3kd) exhibited positive response in *in-vitro* anti-hemolytic assay.

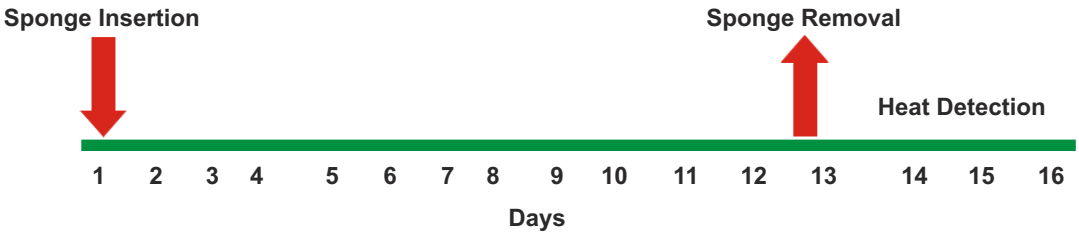
Technologies developed

The important technologies emerged out of the research conducted in the division include intra-vaginal sponge (Avikesil-S) for estrus induction and synchronization, superovulation protocols for sheep, laparoscopic aided embryo transfer, artificial insemination with chilled semen, validation of computer-aided semen analysis technique, protocol for ram semen freezing using programmable cell freezer, cryopreservation of ovine embryos and birth of lambs, transcervical artificial insemination (TCAI) in sheep using frozen semen and laparoscopic artificial insemination with frozen semen.

Intra-vaginal sponges for estrus induction and synchronization: Progesterone impregnated intravaginal sponges (Avikesil-S) have been developed indigenously for estrus induction and synchronization in sheep and goats. The synchronization kit has been commercialised since 2006. The sponge is easily inserted into vagina with the help of a vaginal plastic/glass speculum and a plunger used to push the sponge from speculum to the vagina. On withdrawal, it can be easily pulled out with the help of a thread attached to the sponge which is left hanging outside the vagina at the time of insertion. The sponge is being used in sheep and goat farms belonging to various government animal science research institutes, universities, state animal husbandry departments, NGOs, entrepreneurs, small farmers pan India with very good success rate in estrus synchronization and induction. More than 52000 sponges have been supplied to these organizations and progressive farmers of more than 18 states, so far. Every year indigenous vaginal sponges are being prepared and supplied for use in TOT area of our Institute and in organised sheep and goat farms. These sponges had been utilized for fertility management and artificial insemination (AI) programme. A standard protocol has been developed for estrus synchronization of crossbred and native sheep breeds through progesterone impregnated vaginal sponges.

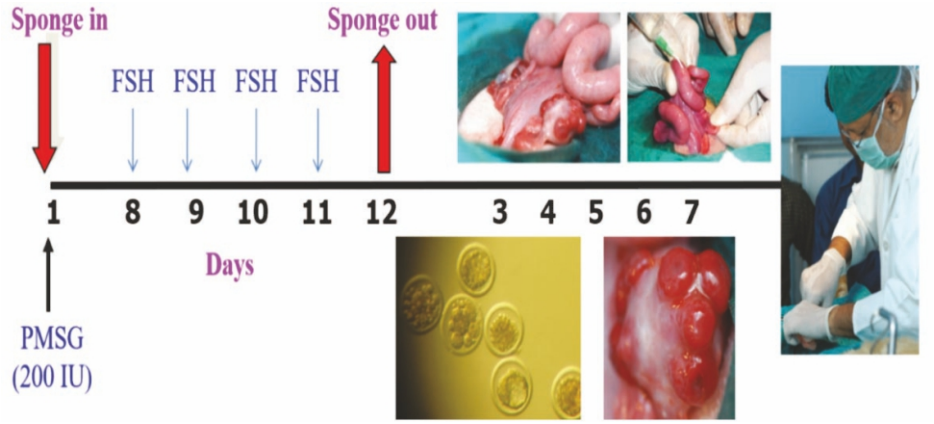
Indigenously developed progesterone impregnated vaginal sponge (Avikesil-S)

Insertion of Avikesil-S sponge



Estrus synchronization protocol using vaginal progesterone sponge

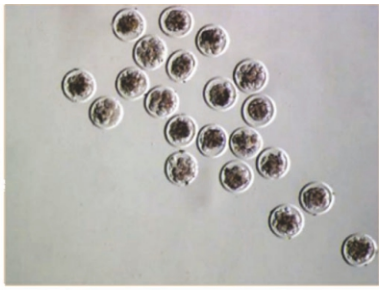
Superovulation protocol for native and crossbred sheep: To reduce the cost of superovulation and to minimize individual variability in response, a unique protocol consisting of FSH and PMSG combination was developed, standardized and validated for inducing superovulation in native and crossbred sheep. Ovagen (5.4 mg) in 8 doses over 4 days (12 hr apart) in conjugation with PMSG (200 IU) resulted in acceptable superovulatory response (>8- 10 CL/ewe) in donor ewes.



Superovulation protocol for sheep

Laparoscope aided embryo transfer in sheep: A quick and easy method of laparoscope aided embryo transfer was developed at the Institute. A special designed cradle was fabricated for easy restraining and positioning of ewe (suspended at 45^0 angle) subjected to laparoscopy. The recipients having synchrony with donor are fasted for 24-36 h before laparoscopy. Sedation is induced with intramuscular injection of xylazine. Xylocaine is administered subcutaneously as local anesthetic. Abdominal area anterior to udder is shaved and sprayed with 70% alcohol. Uterine horn ipsilateral to corpus luteum is gently grasped with the forceps (modified in our laboratory) and lifted through the puncture site to expose a loop of horn. A blunt needle is used to make a small aperture in the loop of horn and tom-cat catheter loaded with embryo is introduced into lumen of horn. Embryo is pushed into the lumen and horn is again put into abdomen. Skin is sutured or sealed with wound clippers. This technique does not require costly equipment for inflating abdomen for laparoscopy and special imported atraumatic forceps and other equipments. A total of 222 lambs belonging to Bharat Merino, Malpura, Kheri, Chokla, Munjal x Malpura crosses and Garole breeds were produced through *in vivo* derived embryos.

Location of uterine horns through laparoscope



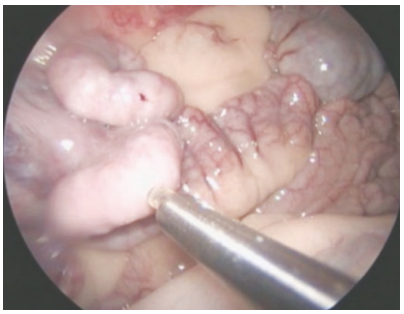
In vivo produced transferable sheep embryos

Transfer of embryos by tom-cat catheter into lumen of horn

Large size Awassi X Malpura recipient ewe and small size Garole donor ewes (A) Garole lambs produced after in vivo derived embryo transfer (B)

Artificial insemination in sheep with liquid chilled semen: The techniques for fixed time AI in sheep have been developed, simplified and improved during the last few years. Nevertheless, AI has not yet received universal acceptance in sheep industry due to several technical and economic reasons. However, with the advent of recent advances in reproductive technologies, the efficiency of AI in terms of conception and lambing rate has improved. To date the success of AI in sheep is limited to liquid semen. The main methods of short-term preservation of ram semen in a liquid state are based on storage at reduced temperature (0-5 or 10-15°C) by reversible inactivation of spermatozoa. The lambing rate following use of liquid semen stored for one, two and three days are50-60%, 25-30% and 15-20%, respectively.

***AI at farmer's flock*:** Institute launched an AI programme for improving rural sheep of semi-arid region using liquid semen of exotic Awassi and native Patanwadi and Malpura rams. Semen is obtained daily in the morning from adult rams. Ejaculates having good semen quality are diluted 1:1 with EYCG diluent and stored in ice containing semen shipper. AI was done daily in estrus ewes for one cycle by depositing 0.1 ml containing 100 million sperm per os. AI with More than 2000 ewes from farmer's flock have been inseminated at fixed time following estrus synchronization using Avikesil-S sponge, with overall lambing of approximately 60%.



Laparoscope aided intrauterine artificial insemination: Unlike cattle, buffalo and goat, sheep has a tough cervix to pass AI gun. Hence, results of transcervical AI (TCAI) are very poor and inconsistent. As intrauterine insemination induces greater pregnancy rates, a simple method of laparoscope aided intrauterine artificial insemination using frozen semen was developed in sheep. This procedure requires approximately 5-7 minutes for single insemination. Lambing rate of 50-70% has been achieved following intrauterine deposition of frozen-thawed semen in Malpura ewes.

Validation of computer-aided semen analysis technique for assessment of motion characteristics of ram spermatozoa: The computer-aided semen analysis (CASA) technique was standardized and validated for objective assessment of sperm motion characteristics of ram spermatozoa. The precise results obtained by this technique were useful to evaluate sperm motion characteristics, which are not apparent by routine subjective evaluation of semen but are useful in assessing the fertilizing ability of ram sperm for its use in AI. The technique has been used for assessment of sperm motion characteristics and track dimensions of growing ram lambs; *FecB* carrier prolific rams and rams of different native, exotic and crossbred breeds during breeding and non-breeding season. The technique has also been applied to determine the influence of short-term preservation, freezing and thawing on motion characteristics of ram spermatozoa.

Cryopreservation of ovine embryos and birth of lambs: *In vivo* derived embryos from native and crossbred sheep were cryopreserved using standard protocol. Embryos at the stage of morulae and beyond with good and fair morphology were selected for cryopreservation. Total number of sheep embryos (Bharat Merino, Malpura, Kheri, Chokla and Garole breeds) frozen and cryopreserved at CSWRI were 263 (220 by slow freezing and 43 by vitrification). In a major breakthrough our team of scientist from CSWRI was successful in producing a lamb from cryopreserved embryo for the first time in the country. Detail of lambs produced from frozen thawed embryos is as under:

Breed (Donor)	Days of embryo storage	Breed (Recipient)	Lamb	
			Sex	Birth wt (kg)
Bharat Merino	260	Kheri	M	3.9
Malpura	565	Malpura	M	3.8
Bharat Merino	191	Malpura	M	3.8
Malpura	180	Malpura	F	2.4

Development of protocol for ram semen freezing using programmable cell freezer: A common protocol has been developed for cryopreservation of ram semen of exotic, crossbred or native breed packaged in medium (0.5 ml) and mini (0.25 ml) size French plastic straws. The schematic flow diagram of various steps involved in cryo-processing of ram semen by this protocol is as follows:

Raw semen

↓ **1 x 10^9 sperms/ml with Ey-TEST-G**

Dilution

↓ **2 h at 5°C**

Equilibration

↓ **@-25°C/min in cell freezer**

Freezing

↓ **-50° (0.25 ml) or - 60°C (0.5 ml straw) for 10 sec**

Thawing

↓ **Computer-aided semen analysis technique**

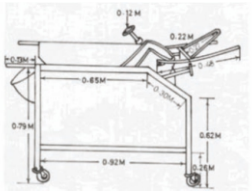
Objective Assessment

The freezing protocol is based on controlled cooling and freezing, directly in the programmable cell freezer and CASA techniques. The steps involved are as follows:

Start temperature	:	+25°C
Step 1	:	Hold for 10 minutes (rate is zero and the temperature is maintained at +25°C), no seeding selected
Step 2	:	-0.15°C/min to +5°C
Step 3	:	Hold for 10 minutes (rate is zero and the temperature is maintained at +5°C)
Step 4	:	-25°C/min to -125°C
Step 5	:	Hold for 10 minutes (rate is zero and the temperature is maintained at -125°C)

The application of this protocol in all the breeds tested at the Institute gave 70 % average mean post-thaw motility of spermatozoa. The high post-thaw recovery is attributed to the criteria of processing only those ejaculates for cryopreservation which have thick consistency, rapid wave motion, i.e. having 90% initial motility and $\geq$3000 x 10^6 spermatozoa per ml.

Transcervical artificial insemination (TCAI) in sheep using frozen semen: Insemination cradle is a pre-requisite for TCAI technique. A simple cradle was designed and fabricated locally to ideally suit TCAI of native sheep breeds with frozen semen. The simple and cost-effective design of this cradle makes it ideal and economic for large scale production to meet future demands and can also serve as a valuable import substitute. In this cradle, ewes exhibiting oestrus are restrained with hind quarter elevated so that the vulva is positioned at an angle of 80 to 90° i.e., vertically. Other insemination devices suitable to native sheep, such as speculum with plunger, catheter with bent tipped needle and miniature light source for TCAI were also fabricated in our laboratory.

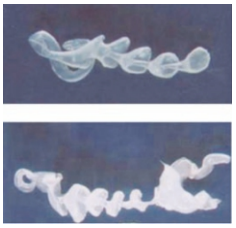


A prototype of cradle designed and fabricated for TCAI

Sketch of the operator performing TCAI in sheep

Equipment fabricated for TCAI

Location of os-cervix with the aid of light and introduction of needle for deep deposition of semen into uterus



Silicon mould of vaginal canal maiden ewe Adult ewe

To initiate the insemination the speculum with plunger is lubricated with a small amount of medical gel and introduced into the vagina. Following TCAI with frozen ram semen progressive success has been achieved for the first time in this country in terms of lambs born and the results obtained in our laboratory are at par with the leading research teams of the World. Out of 293 sheep inseminated with frozen semen through TCAI technique, a total of 51 lambs (17.41% lambing) were produced.

Animal Health

The Division of Animal Health has its origin from the Sheep Husbandry Section initiated since inception of the Institute in 1962. In 1970, the Sheep Husbandry Section was renamed as Sheep Health Section. Up to 1978, the main role of section was to provide health cover to the flocks of the Institute. The section initiated a long-term research project on the epidemiology of sheep and goat diseases in 1978. The section has provided valuable insight on the various diseases and health related problems that occur when the production potential and genotypes of animals are progressively altered. With the passage of time, the diagnostic laboratories were also developed to fit into the requirement of the Institute. The pathological and parasitological diagnostic work gained precedence to provide initial. Later, the bacteriological and virological diagnostic work was initiated. The Animal Health Section was re-designated as Division of Animal Health in 1987.

Microbiology and Molecular Biology

The bacteriological laboratory is equipped to conduct routine bacterial isolation and identification by conventional and molecular approaches. The bacterial agents associated with enteritis, mastitis, septicaemia and other affections were isolated and characterized were *E. coli, Streptococcus spp, Staphylococcus* spp, *Staphylococcus haemolyticus, Corynebacterium pseudotuberculosis, Pseudomonas*, *Coryneform*, *Brevundimonas diminuta, Acinetobacter, Klebsiella*, *Enterobacter*, *Proteus, Shigella, Moraxella* and *Bacillus* spp.

Antibiotic sensitivity test is routinely employed for bacterial isolates for scheduling the antibiotic use in institute flocks and prevention of indiscriminate use of antibiotics. During last six decades, resistance to common antibiotics have appeared in pathogenic organisms infecting sheep population. Trend observed has been of antibiotic resistance in *E. coli*, *Pasteurella* and *Corynebacterium* spp. to common antibiotics like penicillin, streptomycin and tetracycline. However, they are variably sensitive to ciprofloxacin and chloramphenicol. Organism causing mastitits were found resistant to amphotericin B, methicilin, streptomycin, penicilin-G and polymixin B. *Acinetobacter* spp. was found sensitive to amikacin, ciprofloxacin, ofloxacin, polymyxin B and sulbactam. The bacterial isolates causing enteritis were found resistant to ampicillin, amoxicillin, amikacin, amoxycillin-clavulanate, cefixime, ceftazidime, ciprofloxacin, chlortetracycline, cephoxitin, enrofloxacin, gentamicin, imipenem, meropenem, norfloxacin, ofloxacin and tetracycline. Beta-lactam resistant bacterial isolates showed varying number (1-4) and size (2 to >20 kb) of plasmids. The *bla*TEM gene that enables the bacteria resistant to beta-lactam antibiotics was detected among 80% of beta-lactam resistant isolates.

***Pneumonia and pneumoenteritis complex*:** Acute pulmonary disease has been a serious problem in sheep flocks since inception of the Institute. Usually, mortality due to respiratory syndrome starts in March and reaches at peak in May. Losses were at the maximum in suckling (0-3 months) mostly with non-suppurative lesions. However, incidence of pulmonary suppuration and formation of abscesses increases with the age. In general, the agents implicated in etiology of respiratory syndrome include a wide spectrum of viruses such as PI 3, Adeno and Reo viruses, bacterial species such as *Hemophilus, Bordetella, Pasteurella, Corynebacterium, Mycoplasma* and *Chlamydia* along with a chain of predisposing factors mainly the environmental and managemental fluctuations. Presence of only few of these agents could be ascertained in the Institute flocks. In last decade, from lung and nasal swab, both Gram positive and negative bacterial isolated were obtained. *E. coli* and *Staphylococcus* sp. were major Gram negative and positive bacteria, respectively. The other bacteria identified were *Proteus* and *Streptococcus* sp. Studies on serum antitrypsin activity in pneumonic sheep revealed that double fold increase in the level of total trypsin inhibitor with clinical signs are better parameter for detecting the acute pneumonia in sheep. Screening of sera samples against Ovine adenoviruses (OAV) antigen revealed 8.62% prevalence rate with higher prevalence in exotic animals followed by higher crosses and half bred. Incidence of reactors to OAV antigen was highest in the suckling followed by weaners and hoggets. The initiation by the viral agent is further complicated by secondary infections like *Pasteurella*, *Pseudomonas* and *Corynebacterium*. Up to 2009, involvement of PI virus could not be ascertained at Avikanagar but

its role in sheep and goat pneumonia has already been proved in the country. However, in last decade, presence of retrovirus of ovine pulmonary adenomatosis in institute flocks was detected using by U3 gene PCR. Pasteurellosis is a well-known cause of pneumonia and septicaemia in sheep with high morbidity and mortality. *P. multocida* serotype B and *P. haemolytica* serotype A were isolated from pneumonic cases in farm and field respectively. Initially i-ELISA was standardized by using the capsular antigen for use in sero-surveillance in the flocks. In the year, 2012-13, at farm majority of deaths (>50%) in suckling and weaner lambs / kids were due to involvement of *Mannheimia haemolytica*. To specifically detect and characterize the *M. haemolytica* isolates from sheep, nucleic acid-based detection methods (PCR) were developed targeting manganese-dependent superoxide dismutase (*sodA*), O-sialoglycoprotein endopeptidase (*gcp*) and leukotoxin A (*ltkA*) gene. The PCR products were of 144, 267 and around 500 bp for *sodA*, *gcp* and *lktA* gene respectively. Further, SYBR green RT-PCR was also developed using PHSSA primers targeting serotype specific antigen (*ssa*) gene of *M. haemolytica*. *Mycoplasma* spp. has also been isolated from sheep having respiratory distress and typed as *M. agalactiae*. Both conventional and SYBR green RT-PCR assays targeting manganese-dependent superoxide dismutase (*sodA*) gene (144 bp) were developed for detection of *Bibersteinia trehalosi* in pneumonic cases of sheep.

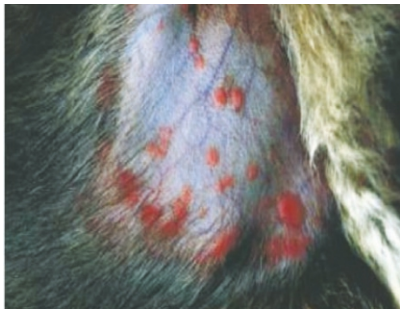
***Peste des Petits Ruminants (PPR)*:** PPR outbreaks were recorded in goat flocks of CSWRI, Avikanagar and in sheep flock of Bikaner. At Avikanagar, outbreak affected only weaners with group specific morbidity, mortality and case fatality to the tune of 40.84, 9.85 and 24.13%, respectively. Confirmatory diagnosis was made by immuno-capture ELISA using specific monoclonal antibody. Immunoperoxidase test and fluorescent antibody test were standardized for detection of PPR antigen in various tissue samples collected from necropsied animals. At Sheep Breeding Farm, Fatehpur, the sero-prevalence was 19.20% in exotic and crossbred sheep. However, in field flocks the sero-prevalence was relatively higher and ranging from 62.13% in sheep to 63.48% in goat flocks. A systematic study during July 2004 to March 2006 with 2024 sheep and 1389 goats at risk in 61 flocks of 24 villages of Rajasthan revealed that proportion of animals exhibiting typical and atypical signs of PPR was 73.77 and 27.23%, respectively. The clinical occurrence of PPR was predominantly (74%) limited to winter season. The prevalence was maximum (50.82%) in flocks possessing only goats followed by 37.70% in flocks having mixed population of sheep and goat while minimum of 11.48% in flocks possessing only sheep. Thus, there was higher susceptibility of goats for PPR than sheep. Initially the TCRPV in use has now been replaced by specific PPR vaccine. The division also assessed economic losses inflicted by PPR associated morbidity in flocks. The probability of outbreak of PPR in small ruminants of Rajasthan was estimated to be 50% and susceptible population of small ruminants was considered to be 45% in view of presence of PPR virus specific antibodies in 55% small ruminant population of the state. Based on livestock census (2003), the total morbidity loss due to PPR in small ruminants of the Rajasthan amount to Rs.85.13 crore (66.86 crore in goat and 18.27% in sheep). Thus, PPR disease is responsible for a loss of 2.31% of total value of small ruminants (2.65% in goats and 1.58% in sheep).

***Bluetongue (BT)*:** It is endemic in Rajasthan and a few frank cases of BT occur in post-monsoon season at CSWRI, Avikanagar. Though mortality is low, but morbidity in the flocks have been significant including lamb losses, wool losses, congenital deformities and weak weaners and hoggets in affected flocks which causes concern. The occurrence of cranio facial defects (agnatha, brachygna, cleft palate, bifid tongue, parrot mouth, absence of muffles, suicephalus), abnormalities of abaxial skeleton (kyphosis, torticollis arthrogryposis, tail defects etc.) shortness of legs, apodia and dwarftism were observed as congenital abnormalities. The disease superimposes itself onto the breeding season causing temporary sterility in rams. The BT virus serotype 1 has also been isolated from this farm with the help of HAU, Hisar. From

1978 onwards, study on epidemiology of BT was undertaken and sero-surveillance of BT was conducted covering State Sheep farms and village flocks all over Rajasthan. During 1985-88, in sheep and goats, 7.01% of the animals were found positive for BTV antibodies on AGPT. Higher prevalence (33%) of the disease was detected in exotic sheep (Rambouillet and Merino) followed by higher crosses (9%), whereas in native breed there was lack of antibody response. Further, 3 serological tests viz. AGPT, indirect ELISA and competitive ELISA were compared for detection of BTV antibodies in sheep during 1994-96. By AGPT, 23% animals were found positive whereas ELISA could detect 63.6% positive cases. There was higher rate of sero-prevalence in exotic breeds (80.4%) than crossbreds (63.6%) and the indigenous breeds (53.6%). BTV antibodies were equally prevalent in male and female and more in hoggets than adults. c-ELISA and i-ELISA were found more or less equally sensitive. Dot ELISA was also standardized by using dipsticks for BTV antibodies and its results corroborated fully with i-ELISA results. It was found to be easy and rapid and could easily be appreciated by naked eye. Therefore, i-ELISA and dot ELISA can be used suitably in detecting prevalence of BTV antibodies.

Since 2003, under AINP on BTD at CSWRI, Avikanagar, the sero-prevalence of BTD was ascertained in farm and field flocks of Rajasthan state. Since inception of this project, though no clinical cases of BTD were observed but, testing of serum samples using c-ELISA or i-ELISA revealed an average sero-prevalence for BTD to the tune of 39.24% in sheep and 58.55% in goats of Rajasthan. The incidence was higher (56.06%) in sheep flocks of semi-arid compared to 35.57% in arid Rajasthan. However, in goats no regional variation was observed in sero-prevalence of BTD. The management system was also found to affect the sero-prevalence of BTD with higher level in migratory flocks (63.29% in sheep, 84.84% in goats) compared to stationary flocks (35.03% in sheep, 72.88% in goats).

***Sheep and Goat Pox*:** Outbreaks of sheep and goat pox were encountered in both unvaccinated and vaccinated flocks belonging to both institute and villages since very beginning. Various vaccines from B.P. units, Jaipur, Hisar, Lucknow, Ranipet and IVRI, Izatnagar were used in institute's flock to prevent the disease. Out of them, Ranipet vaccine was found better as compared to other contemporary vaccines as the losses in terms of disease incidence and deaths were reasonably lower. In India sheep and goat pox are believed to be caused by two different viruses. Hence, to our experience Ranipet SP vaccine appears to be dependable and thus recommended for control of the disease through annual vaccination by following required cold chain precautions.



***Johne's Disease (JD)*:** It is a chronic disease with no simple and reliable diagnostic tests. Clinical cases can only be detected at the advanced stage; hence it is difficult to control as the carriers cannot be eliminated from the flocks. Since 1974, control of JD has been a major concern to animal health scientists. At CSWRI, Avikanagar, the overall prevalence rate in sheep over 9 years (1978-85) was 0.7% on the basis of faecal sample examination and 10.6% on the basis of necropsy. On comparative efficacy of allergic tests, it was found that single intra dermal Johnin test was not very reliable for testing the JD. Vaccination strategy was used to control JD in sheep. Lamb-hood vaccination (Iceland JD vaccine) for a period of 7 years followed by faecal examination and elimination of positive cases from the flock, resulted in reduction of the incidence of JD from 1.26% in 1985 to 0.41% in 1987. Although faecal smear examination cannot be taken as a confirmatory and sensitive (hardly 25%) method for diagnosis of JD in sheep, it still can serve as a useful tool in JD diagnosis. As the highest clinical incidence of JD occurs around lambing and in between August and October, thus the faecal examination for detection of acid fast bacilli (AFB) may be of better use, if done during this period.

For effective reduction in incidence of JD through early and precise detection, protocol for PCR was standardized through targeting IS900, ISMav2 and 251 genes.During the 2002-12, examination of samples from clinically suspected and necropsy cases, showed positivity for acid-fast bacilli in faecal and ICV/MLN smear as 21.76 and 63.87%, respectively. However, the average annual positivity for JD on AGID was 5.61%. On ELISA, the sero-positivity ranged from 11.42 to 21.00% with 70 to 100% cut-off values. On AGID, breed-wise analysis revealed maximum incidence in Chokla sheep (6.14%) followed by Avikalin (1.09%) and Bharat Merino (0.96%). In last decade the overall positivity for JD ranged from 33.1 to 38.0% in sheep and from 11.1 to 15.6% in goats on ZN staining, i-ELISA and IS900 gene PCR on faecal, serum and ICV/MLN samples. Further, the positivity was increased to 50.0% on examination of ICV/MLN smear on post-mortem however, on random screening using i-ELISA, the positivity was 5.45 and 18.45% in sheep and goat, respectively. The haematological profile showed decrease in TEC, Hb and PCV with lymphocytopaenia and anaemia in clinical cases of JD. The serum phosphorus, magnesium and calcium level were comparable to control sheep; however, the total protein and albumin were significantly decreased.

***Abortion and Still births*:** The causes of abortion/still births like brucellosis, chlamydia, BT, selenium deficiency etc., have been identified to some extent. Serum samples suspected for brucella are being tested regularly by RBPT. One field trial was conducted to determine the prevalence of brucellosis by using milk ring test in milk samples of sheep and goats. Incidence in sheep was low (1.72%) as compared to goat (7.25%). During November 2003, an abortion storm was observed in Sirohi goat flock at CSWRI, Avikanagar. The slight rise in body temperature with sudden abortion was the only clinical symptoms observed. There was severe congestion and haemorrhage in intestine along with whitish pinpoint foci on liver of foetus. Only *E. coli* was isolated on bacterial culture. With strict vigilance and monitoring for brucellosis during quarantine of newly purchased animals at CSWRI, Avikanagar, there was complete absence of the disease in both sheep and goat population at farm up to 2012. During 2002-12, among field flocks the annual average sero-prevalence for brucellosis ranged from 2.66% in goats to 7.91% in sheep. In last decade, the presence of *Brucella* antibodies on RBPT was detected in 11.6 to 12.1% of samples from sheep in field flocks. In sheep it was 6.21% (19/306) in Patanwadi, 52.31% (68/130) in field flocks around Avikanagar, 5.30% (7/132) in CSWRI sheep. In the month of April, 2017 at Sirohi goat unit 5 cases of abortions were reported in advance pregnant goats and out of 536 samples tested using i-ELISA kit (NIVEDI, Bangalore) only one female goat was found positive for Brucellosis.

***Enterotoxaemia*:** Only sporadic cases of enterotoxaemia were recorded in the institute flocks. In the year 2012-13, outbreak of enterotoxaemia was diagnosed in field goats at Kalyanpura village on post-mortem and histopathological lesions in lungs, liver, kidneys and spleen with acute enteritis.

***Suppurative lymphadenitis / Caseous lymphadenitis (CL)*:** During 2002-03, the clinico-epidemiological profile in Sirohi goat flock at CSWRI, Avikanagar exhibited maximum incidence (66.7%) in adult followed by hogget (30.0%) and weaner (3.3%). Male had higher (72.2%) incidence compared to female (27.8%). The seasonal incidence was 22.2% in monsoon, 36.7% in winter and 41.1% in summer. Though, the single / multiple abscesses occurred at parotid, pre-scapular and pre-femoral regions but most preferred sites included were pre-scapular (36.7%), pre-femoral (33.3%) and parotid gland (15.6%) area. The size of abscess varied from areca nut to cricket ball and growth was non-inflammatory. Pus samples from clinically suspected cases were directly inoculated on 5% defibrinated sheep blood agar plates. Pure colonies were prepared from the colonies after studying macroscopic characteristic of bacterial colonies, bacterial morphology and staining features by Gram's test. Colonies were inoculated on Cystine tellurite blood agar and incubated at 37º C for 72 hr for its characteristic growth. The resultant colonies were subjected to biochemical tests like nitrate reduction, catalase, urease. Those found positive for catalase and urease,

and negative for nitrate were selected for further characterization. On blood agar, a total of 17 pure *C. pseudotuberculosis* isolates were obtained. A known virulence factor, phospholipase D production was determined by detection of synergistic lysis of erythrocytes in the presence of extracellular *Rhodococcus equi* factor and hemolytic antagonism with a β toxin producing *Staphylococcus aureus.* In another study involving 575 goats of Sirohi breed of CSWRI farm, overall prevalence rate of CL based on clinical, bacterial culture and PCR assay were found to be 4.7, 2.4 and 2.4%, respectively.

Molecular characterization of *C. pseudotuberculosis* isolated from sheep and goats were carried out. Bacterial genomic DNA extraction was made from a few colonies from the characterized /pure cultures of 48-72 hr growth on blood agar. Primers targeting the putative oligopeptide /dipeptide ABC transporter, NADP oxidoreductase genes and Proline iminopeptidase (PIP) of *C. pseudotuberculosis* were used for PCR amplification. PCR products for sequencing were amplified with the use of Pfu DNA polymerase. Sequencing reports of three genes each from sheep and goat isolates were submitted to NCBI GenBank. All the 3 genes showed high degree of homology with the published sequences. A PCR assay targeting three genes was developed to detect *C. pseudotuberculosis* directly from the pus samples. The assay is rapid, specific and serves as an alternative to cumbersome and time-consuming bacterial culture and further biochemical characterization. Further, A total of 25 *C. pseudotuberculosis* isolates from peripheral lymph node abscesses in sheep and goats were used to develop and validated the SYBR green real time PCR assay. A few colonies from the phenotypically characterized pure cultures of *C. pseudotuberculosis* isolated from caseous lymphadenitis suspected cases were subjected to bacterial genomic DNA was extraction. The primers targeting putative oligopeptide/dipeptide ABC transporter genes of *C. pseudotuberculosis* (285 bp) were used for SYBR green real time PCR. The specificity of the assay was also examined with regard to the nucleic acids extracted from *Rhodococcus equi, E. coli, Staphylococcus aureus, M. haemolytica, P. Multocida and B. trehalosi*. Another PCR was developed targeting phospholipase D (*pld*) gene (203 bp) of *C. pseudotuberculosis*. Sheep specific 12S rRNA gene PCR over blood and lung tissue samples was standardized to use as an internal amplification control in clinical diagnosis. Gene sequences of Pfu amplified and gel purified PCR products of 16S RNA, *nuc, coa* and *spa* genes of *S. aureus* sub spp. *anaerobius* were compared with the online databases and were found to matching to them.

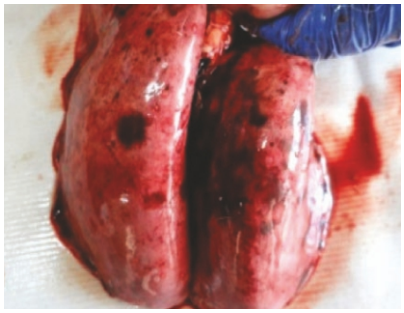
***Yersiniosis*:** In goat flocks of CSWRI, Avikanagar, an outbreak of yersiniosis was recorded in the year 2005-06 with overall morbidity of 20%. The age-wise incidence was maximum (66.7%) in adult males followed by 16% in females and 10.00% in hoggets. Isolation and characterization study confirmed *Yersinia pseudotuberculosis* and organism was found sensitive to chloramphenicol, enrofloxacin, levofloxacin, doxycycline and gentamycin.

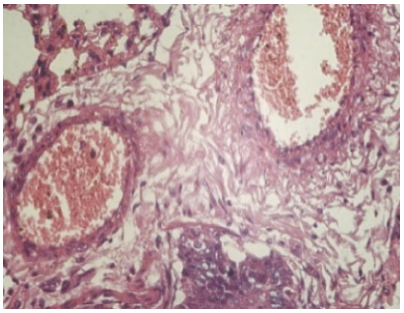
***Foot rot*:** In the year 2010-11, outbreaks of foot rot in farm sheep and goats were investigated. The disease was observed in most virulent form in goats. The disease in sheep was, however, mild. After a thorough investigation, more than 20 samples from the foot rot affected animals were collected. After staining and direct microscopic examination, the causative Gram-negative bacteria indistinguishable from *Dichelobacter nodosus* and *Fusobacterium* spp. were detected, which requires confirmation. Almost all animals were successfully treated within 2-3 weeks of the outbreaks. There was no mortality; however, economic losses especially in goats were tremendous. Specific primers for molecular detection of *Dichelobacter nodosus* and *Fusobacterium necrophorum* were designed.

Foot and mouth disease (FMD): In December 2015, an outbreak of FMD was observed in goat unit at CSWRI, Avikanagar. The overall morbidity was 20.10% and ranged from 0.41% in kids to 41.94% in hoggets. Sex-wise morbidity rate was 11.03% in female and 38.01% in male. The overall mortality due to FMD was 0.50% and ranged from 0.20% in adults to 1.62% in hoggets. Sex-wise mortality rate was 0.37% in female and 0.74% in male. The lesions observed were salivation, ulcerative / erosive lesions in oral cavity (particularly on tongue and dental pad), fever, anorexia, respiratory distress, dullness, painful walking. The samples were sent to IVRI, Izatnagar for confirmation of disease and out of four samples, two were found positive for FMDV type O. The epidemic was managed by strict screening of flock for oral lesions, isolation of affected animals and their treatment with antibiotic, anti-inflammatory and supportive therapy. The overall case fatality rate was 1.94% (2/103) and ranged from 1.15% (1/87) in adult male to 6.25% (1/16) in hogget male.

Contagious ecthyma (Orf) and mastitis in goats: Investigated and managed the outbreak of contagious ecthyma / orf in Sirohi goat flock during 2018-19 and 2019-20. The complication of orf lesions on udder and development of mastitis was documented.

Coli-septicaemia outbreak in lambs: The sudden deaths were occurred in healthy lambs (15-20 days old) without showing any clinical symptoms in February, 2019. Affected lambs showed a mild rise in rectal temperature (103°F-104°F), marked respiratory distress characterized by abdominal effort, recumbency and death. Over 46% of the lambs were found dead in the morning. On PM examination, there were severe congestion and enlargement of liver (90.62%), highly congested renal parenchyma to the extent of haemorrhage (84.38%) and severe pulmonary oedema and multifocal petechiae to ecchymotic lesions on the lung surface (89.58%). Very importantly, 57.29% of the lambs had soil mixed ingesta giving a dirty appearance to the abomasal contents. Among the dead lambs, 25% had hyperaemia and necrotic spots on abomasal mucosa. Microscopically, lungs blood vessels were severely engorged with RBCs. Inter-alveolar and inter-lobular septa were thickened with fibrinous exudate. Alveoli were filled with serosanguinous exudates, RBCs and inflammatory cells. Haemorrhage was observed at places in the lung's parenchyma. The walls of the blood vessels were thickened with proliferation of fibrous connective tissue. The pleura was found thickened with fibrous connective tissue in some cases. Liver was affected with uniform degeneration of hepatocytes, cytoplasmic vacuolation of the hepatocytes and necrosis. The necrosis of the hepatocytes was prominently seen around the hepatic veins and other blood vessels. The wall of hepatic blood vessels was thickened with fibrinous connective tissue proliferation. Kidneys showed tubular degeneration and coagulation necrosis of the tubules. The blood vessels of renal parenchyma were affected with fibrosis of the wall and engorged with RBCs. Heart showed cardiac muscle degeneration and mild haemorrhage in some cases. Spleen revealed mild congestion and areas of lymphoid depletion. Out of 55 bacterial isolates obtained from heart blood, lung, and liver samples of lambs died, 45 were identified as *Escherichia coli*, indicating it as cases of septicemic colibacillosis in lambs. The sero-types identified were Upon O9 (1), O2 (6), O7 (2), O11 (9), O22 (1), O26 (3), O20 (1), O118 (1), O119 (2), O120 (3), O121 (1), O134 (2) and UT (3). The conventionally identified *E. coli* strains were detected positive for major virulence factor genes like shiga toxin (890 bp) and intimin (381 bp) gene by PCR.

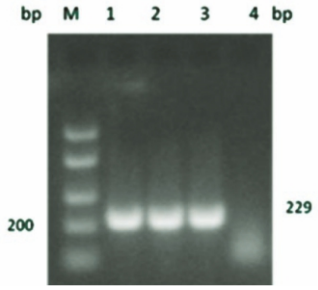




Hepatitis in lambs: Since August 2017 onward, syndrome of hepatitis was observed in weaner and hogget with clinical sign of jaundice, lethargy, standing in isolation from flock, red coloured urine, rise in rectal temperature and recumbency. Wasting of musculature was observed on palpation of the ailing animal's body contours. On PM, gross lesions were severe jaundice, moderate to severe enlargement of liver, pale / orange coloured liver surface, congestion in kidneys and lungs, froth in trachea, cortico-medullary distinction loss in kidneys, putrid rumen and intestinal contents, sand in the ingesta, black discoloration of serosal surface of small intestine and petechiae in epicardium.

Enzootic nasal adenocarcinoma: Recently from September 2019 onwards, several cases in field flocks with history of unilateral exophthalmos, lacrimation, circling and blindness were encountered. Clinical examination showed unilateral protrusion of eyeball, coarse respiratory noise, peripheral blindness, flaring of nostrils, open-mouth breathing, circling and rapid muscle wasting. Empirical therapeutic attempt was not fruitful. It was suspected to be cases of enzootic nasal adenocarcinoma affecting almost 10% of the population. Preliminary molecular study based

on *gag* gene (229 bp) PCR and restriction enzyme digestion *identified it as enzootic nasal tumour virus (ENTV-1) affecting sheep.* The tumour revealed the characteristic proliferative changes in the alveoli with papillomatous proliferation forming well marked papillae with distinct connective tissue cores giving adenomatous appearance. These papillomatous ingrowths partially or completely obstructed the alveolar lumen with projections into the alveoli. There was infiltration of numerous macrophages in the lumen and in the vicinity of proliferated alveoli was seen. Similar infiltration of mononuclear cells was also evident in peri bronchial, peribronchiolar and perivascular areas. The nasal tumour sections revealed proliferating epithelial cells organised in a glandular architecture with infiltration of inflammatory cells. The tumour cells revealed less mitotic features throughout the section. On nasal cytology, nasal smear revealed high turnover of cells with nuclear condensation, multiple nucleoli and mitotic figures characteristics symmetrical to cancer cells. Thus, it can be inferred that bleeding neoplasm may be secreting the cancers cells in nasal secretions which may act as a non-invasive diagnostic tool for diagnosis of ENA affected animals similar to the FNAC but this technique may be tested on a greater number of animals for a conclusion.



Acute myocardial infarction: No gross abnormalities were observed on external examination of an adult ram died with history of sudden fall on ground, struggling, paddling and bleating for 3-4 min. Among visceral organs, a fan shaped degenerative lesion was seen on the apex of heart with a bluish coloration of blood clot above the level of degenerative area of ventricles was observed. The papillary muscle was intact with no vegetative growth in the valves of heart. Histopathological examination revealed a mural thrombus in left coronary vein attached to the endothelium with a stalk, area of coagulative necrosis adjacent to vein and polymorphonuclear cells infiltration. Cardiac muscles revealed loss of the myofibril structures with wavy cardiac cells and necrotic cells. The pathological investigation revealed that affected sheep died due to acute myocardial infarction.

Parasitology

In the field of Parasitology, during initial phase mainly need-based research work was carried out. However, with the emergence of problem of anthelmintic resistance in sheep nematodes, the systematic work on epidemiology at farm level was initiated in 1994 and later on the entire Rajasthan state was covered under All India Network Programme on Gastrointestinal Parasitism.

Epidemiological studies: The results of initial studies at farm exhibited that intensity of strongyle infection in adult sheep started rising from April and reached a peak in August and then declined to a very low level until March. In young sheep, intensity of infection remained nil up to June and began to rise from mid-July to reach a maximum in early September. The availability of infective larvae on herbage was mainly restricted for the period from July to October. The predominant nematode parasite of economic significance at farm is *Haemonchus contortus* followed by *Oesophagostomum columbianum, Trichostrongylus axei* and *T. colubriformis*. The worm burden in sheep exhibited the positivity of abomasi for *H. contortus* and *T. axei* infection to the tune of 91.7%. Of these 83.2% cases were infected with only *H. contortus* while 16.7% were infected with mixed infection of both. The average worm count varied from nil (February) to 7694.4 (August). The young animals up to one year of age harboured more worms compared to adults. The observations on development and survival of larvae on pasture revealed that infective larvae survived for maximum period (up to 9 weeks) during September followed by August and November (8 weeks). The study indicated that in semi-arid condition contaminated pasture should be kept free from grazing at least up to 9 weeks to make it

parasitologically safe pasture for grazing. On the basis of above findings deworming frequency at CSWRI, Avikanagar was reduced from 4 times a year to once a year (tactical). This not only economized the worm control programme but also decrease the selection pressure on parasites population needed to develop anthelmintic resistance thus extended the life of existing anthelmintics.

Since 2000, with the launch of All India Network Programme on Gastrointestinal Parasites, extensive study on epidemiological aspect was undertaken in both arid and semi-arid agroclimatic conditions of Rajasthan involving flocks managed at farm or field level. The salient findings of long-term on GI parasitism in sheep flocks are as below:

Bio-climatographs: Based on long term climatic conditions, the bioclimatographs for different zones of Rajasthan revealed existence of suitable conditions for translation of exogenous stages of *Haemonchus contortus* from June to mid-September in semi-arid and from late June to early September in arid Rajasthan. Like-wise, suitable conditions for translation of exogenous stages of *Trichostrongylus* spp. were from October to mid-February in semi-arid and from late October to mid-March in arid Rajasthan. On annual basis, a minor variation in length of suitable period occurred depending on climatic conditions.

Epidemiology of G.I. Parasites: *Under traditional sheep rearing, t*he overall incidence of *strongyle* worms was almost similar in all the zones and management systems and ranged from 51.5% to 60.6%. Both season and month had significant influence on the incidence of strongyle worms in sheep flocks. Seasonal incidence was higher during Jun-Nov. The overall annual incidence of *Trichuris* spp. varied from 0.7 to 1.9%, *S. papillosus* 6.4% to 8.9% (farm) and 1.3% to 6.4% (field) and *Moneizia* spp. 0.2% (arid) 4.7% (semi-arid). Annual incidence of *Eimeria* infection was comparatively higher in field flocks of both the agroclimatic region and ranged from 28.3% to 53.0% and was maximum Sep-Nov. Annual incidence of amphistomes in field flocks was significantly higher in semi-arid than as arid region. Seasonally, incidence was higher during Jun to Aug, possibly associated with ingestion of metacercaria during summer. Annual incidence of *S. indicum* was 0.37% to 0.50%. *M*ean annual intensity of *strongyle* infection in semi-arid region was significantly higher in farm flocks than field flocks. However, this intensity was similar in farm and field flocks under arid conditions. The period from December to May is of low risk for transmission of *strongyle* infection in flocks due to occurrence of hypobiosis. Further, in spite of major lambing season there was absence of periparturient rise in flocks. From May onward with onset of monsoon and development of hypobiotic worms, sudden rise in FECs peaks June/July or August/September (depending on anthelmintic intervention).

Generic composition of G.I. nematode larvae on coproculture: In semi-arid region, the annual prevalence of *H. contortus* larvae on coproculture was significantly higher (82.6 to 95.8%) in field flocks as compared to farm flocks (65.9 to 70.8%) with higher proportion during monsoon and post monsoon seasons in farm flocks. The annual proportion of *Trichostrongylus* spp. was 25.9 and 1.7% in farm and field flocks, respectively. The annual proportion of *O. columbianum* larvae was 8.2 and 2.5% in farm and field flocks, respectively. The overall annual proportion of *Trichostrongylus* spp. was 20.0 and 14.5% in farm and field flocks, respectively with maximum proportion during winter season. The annual proportion of *O. columbianum* larvae was 9.2 and 2.9% in farm and field flocks, respectively. The pattern suggested suitability of warm moist season with adequate rainfall for survival of *H. contortus* larvae. The low annual prevalence of *H. contortus* larvae in farm flocks could be attributed to the more use of narrow spectrum anthelmintics (e.g., closantel) compared to more use of broad spectrum anthelmintics (e.g., benzimidazoles, tetramisole). Further, *H. contortus* is highly prolific compared to *O. columbianum* contributing significantly to generic population of nematode on pasture.

Generic composition of Eimeria oocysts in sheep: In both the agroclimatic region and flock management systems, *E. parva* was predominant with annual prevalence of 28-35% foll*owed by E. faueri (18-22%), E. pallida (15-19%), E. ovinoidalis (11-17%), E. granulosa (5-9%), E. arloingi / ahasata* (3-8%) *and E. intricata (3-6%). The seasonal and monthly prevalence also revealed predominance of E. parva in majority of months in both the regions.*

Herbage infectivity profile in Rajasthan: On grazing land, the annual herbage infectivity ranged from 36.6 L_3/kg DM of herbage in arid farm to 522.8 L_3/kg DM of herbage in semi-arid farm. The monthly pattern exhibited that average

herbage larval burden varied from nil (Apr-Jun) to 1449.3 L_3/kg DM of herbage (Jul) in semi-arid farm, from nil (Jan-May) to 1477.0 L_3/kg DM of herbage (Jul) in semi-arid field, from nil to 282 L_3/kg DM of herbage (Nov) in arid farm and from nil to 1378.3 L_3/kg DM of herbage (Mar) in arid field. In general, the herbage larval burden started rising with pre-monsoon shower and reached to peak in August-September.

Modified worm management programme for sheep flocks of Rajasthan: In Rajasthan the agroclimatic conditions does not favour the development of strongyle larvae during December-June and their availability as infection and absence of typical peri-parturient rise in ewes. As such, anthelmintic drench as practiced by farmers in February-March could be withdrawn without affecting productivity. Hypobiosis in *H. contortus* is common in Rajasthan during winter and spring and worm development resumed in June possibly due to nutritional and walking stress along with pre-monsoon showers raises FECs. Further, decline in FEC in following months occurs due self-cure phenomenon. Thus, it is unnecessary to drench the flock on first rise in FECs at the end of summer season. Adoption of this practice was useful in increasing the size of *refugia* and maintenance of anthelmintic efficacy for longer period. In field flocks, occurrence of bottle jaw without anaemia in 20-30% of sheep, during Nov to Feb is a constant feature. To mitigate the problem, anthelmintic intervention is common practice. However, sheep flocks remained under low plane of nutrition during summer and with the onset of monsoon, though there is enough grazing material on surface but higher water content in fodder maintains low plane of nutrition as such. Subsequently, majority of sheep became pregnant and in late gestation/early lactation failed to meet required amount of protein, resulting in hypoproteinemia and occurrence of bottle jaw. Role of nutritional stress during this period is supported by low FECs (<200 epg) and almost nil pasture infectivity, thereby nutritional amelioration than drenching. During July-September, around 20-30% and 50% of sheep in field and farm, respectively had FECs to the tune of >1000 epg. Assumption that each host have same worm load should not be a criterion for en-mass anthelmintic intervention. In field, farmer implements anthelmintic intervention in all the animals (including 30% lambs <3 month of age), thus unnecessary using 30% of anthelmintic. Spring-born lambs had the opportunity to pick up infection during late June-July; as such these lambs with marketable age (3-6 months old) could be raised without anthelmintics till July. Initially, modified worm management programme (MWMP) comprised of single en-mass strategic anthelmintic drench per year in sheep flock during early monsoon as compared to 2-3 drench per year in conventional worm management programme (CWMP). However, later on by considering the importance and role of *refugia* in management of anthelmintic resistance in *H. contortus* and quality and quantity of fodder affecting pharmacokinetics of anthelmintics, the MWMP was fine-tuned by shifting the timing of strategic anthelmintic drench from early monsoon to mid to late monsoon.

In addition, to harvest the benefits of over-dispersion in faecal egg counts in sheep flocks, a mechanism for targeted strategic treatment (TST) was also developed and implemented in sheep flocks maintained at farms in arid region. The MWMP was implemented in both farm and field flocks of the agro-climatic regions (arid and semi-arid) of Rajasthan. Since April 2004 to March 2020, a total of 156409 faecal samples were screened and evaluated for GI parasites to assess the impact of MWMP and TST. While implementing, MWMP at farmer level, one should have patience as impact are appreciable only after long-term implementation. Seasonal magnitude exhibited maximum incidence during Jun-Aug in all the flocks managed under MWMP and TST followed by Sep-Nov. Overall, seasonal profile showed that favourable conditions for higher pasture infectivity and simultaneous magnitude of incidence in sheep flocks were mainly restricted during monsoon and post-monsoon period. In order to maintain the quantum of *refugia* and simultaneous to maintain anthelmintic efficacy and manage the anthelmintic resistance, it is need of hour to institute strategic anthelmintic drench during mid to late monsoon. The anthelmintic drench at the end of summer as practiced in CWMP has not yielding any additional advantage. Higher incidence during August-September was due to increased pasture infectivity as a result of parasite pro climatic conditions of temperature and moisture on surface vegetation. The anthelmintic intervention in September was found effective in reducing the incidence in following months with unfavorable climate. The comparative profile for different management strategies showed higher efficiency of MWMP as compared to CWMP. The major observations and indications in epidemiology of GI parasites in sheep flocks of Rajasthan are as under:

Comparative economics of sheep flocks under different worm management programme: Sheep flocks drenched as per MWMP, had incurred Rs.27,250/- total expenditure/100 sheep/year, while in CWMP flocks, it was Rs.34,440/-. In MWMP flocks, the overall component-wise expenditure/sheep/yr was Rs.130.8 on feed and fodder, Rs.50.2 on health management and Rs.91.5 on miscellaneous items like shearing, purchase of animal and labour etc. The corresponding figures for CWMP flocks were 105.7, Rs.59.0 and Rs.179.7, respectively. The overall component-wise income/sheep/yr was Rs.872.5 (55.7%) from sale of live animals, Rs.35.4 (2.3%) from sale of wool, Rs.91.8 (5.9%) from manure and Rs.567.0 (36.2%) from addition of lambs to flocks in MWMP flocks. The corresponding figures for CWMP were Rs.1191.8 (65.0%), Rs.37.1 (2.0%), Rs.81.7 (4.5%) and Rs.522.8 (28.5%). The annual proportion of income through addition of lambs ranged from 17.9 to 46.1% in MWMP and from 3.40 to 58.6% in CWMP flocks. The overall net income per 100 sheep per year was Rs.1,29,420/- in flocks drenched as per MWMP and Rs.1,48,900/- as per CWMP.

***Peri-parturient rise (PPR) in faecal egg count*:** In a study conducted at CSWRI, Avikanagar during spring lambing season it was observed that there was no significant difference in FECs between lactating and dry ewes up to 12 weeks post lambing as well as FECs remained almost similar in sheep maintained under different stages of reproduction. The studies on lambing pattern in field flocks of Rajasthan revealed that majority of ewes in flocks are in lambing / lactation during October to February and agroclimatic conditions of the state does not favour the development and dissemination of worms from December to June resulting in non-availability of source of infection for lactating ewes. On the basis of these studies, it was concluded that in Rajasthan there was absence of classical PPR in FEC in sheep.

Studies on hypobiosis: The epidemiological profile of strongyle worms in sheep flocks of Rajasthan exhibited that there is possibility of occurrence of hypobiosis. From June 2012 to March 2021, out of 397 abomasi, a total of 34.8% of abomasi were found to possess L_4. The monthly profile exhibited a sharp decline in abomasi harbouring only adult worms from September to January. The digestion of the abomasal mucosa revealed presence of hypobiotic *H. contortus* larvae in significant proportion during October to March. The monthly mean number of adult *H. contortus* in sheep exhibited its magnitude as >500 per abomasum during the period from July to September. The numbers of L_4 in abomasal mucosa were low (<15) during April to September and started rising from October onward with maximum (446.0 L_4/abomasi) in January. The analysis of ratio of adult to L_4 in abomasi showed higher (>50%) proportion of L_4 during October-March (except 41.02% in Nov) as compared to <50% proportion of adult worms. The PM and faecal examination showed that infection in host persisted round the year. Persistence of a parasitic nematode infection may be due to the successful survival of the pre-parasitic stages on the pasture and/or of the adults or hypobiotic larvae in the host. Over the period (2012-21) at Avikanagar, the average monthly THI varied significantly from 15.61 (Jan) to 33.12 (May), revealing that for sheep flocks at farm the periods of non-stress and extreme stress were from November to February and March to October, respectively. The monthly average FECs varied significantly from 191.54 (Jan) to 3051.09 epg (Sep). Under modified worm management programme, the monthly average FECs varied significantly from 210.68 (Jan) to 3148.13 epg (Sep). Average abomasal adult worm counts varied from 24.87/sheep (Mar) to 1238.53/sheep (Sep). The average L_4 counts in abomasal mucosa ranged from 0.16 / abomasi (Jul) to 541.94 / abomasi (Jan). The mean adult worm count and FECs in sheep varied significantly among the THI groups with higher intensity in high THI group. However, a reverse pattern was found for L_4 count in abomasi. Both FECs and abomasal worm count showed a positive relation with THI while a reverse pattern was exhibited for L_4 counts. A significantly negative correlation between FECs and L_4 counts during January to June further supports the occurrence of hypobiosis in *H. contortus.* It would appear that factors responsible (probably cool and dry conditions) for induction of hypobiosis were probably dominant during October to March and it can be derived that dryness is more conducive to development of infective larvae. Resumption of development occurs in response to yet unidentified stimulus in June but is thought to be related with nutritional and walking stress along with suitable climatic conditions with pre-monsoon showers. Hence, the decrease of hypobiosis and increased number of adult worms in abomasi during June to September may be due to the onset of the rainy season which is suitable for *H. contortus* to propagate and for the arrested larvae to develop into adult worms.

Anthelmintic resistance:

The original optimism of successful control of GI parasites with novel broad spectrum anthelmintics received a setback with emergence of resistant strains of parasites. It frustrates worm control measures and limits the available anthelmintic types to combat the primary problem of worms. Failure of benzimidazole anthelmintic at CSWRI, Avikanagar was first suspected during 1993. The detailed investigations were carried out to detect anthelmintic resistance in nematode parasites during 1994 using both *in vivo and in vitro* tests.

***Benzimidazole (BZ) resistance*:** On *in vivo* faecal egg count reduction test (FECRT), the efficacy for fenbendazole and tetramisole was more than 95% while for albendazole it was 80% at CSWRI, Avikanagar. Pre- and post- treatment faecal culture revealed that *H. contortus* had developed resistance to BZ. Further the isolated strain of *H. contortus* revealed LC_{50} value of 0.239±0.13 µg TBZ /ml on EHA. Larval development assay (LDA) using commercially available kit was performed to confirm the results, which supported the results obtained by FECRT and EHA. More over the LDA data also revealed the emergence of BZ-resistant *Trichostrongylus* spp., which could not be detected on FECRT because of low proportion of their larvae on coproculture. The results also indicated that there was no multiple resistance against BZ/LEV in *H. contortus* at this farm as the combination of BZ/LEV gave 100% efficacy on LDA. In field flocks around Avikanagar, emergence of BZ resistant *H. contortus* was recorded with efficacy of 64-88% against fenbendazole in FECRT. On EHA the LC_{50} of TBZ against *H. contortus* ranged from 0.157±0.016 to 0.493±0.053 µgTBZ/ml. Due to failure of anthelmintic treatment at Large Scale On Sheep Breeding Farm, Fatehpur (Sikar) in arid region of Rajasthan, FBZ was found to have nil efficacy against *H. contortus.* The EHA showed LC_{50} value of 0.625±0.098 µg TBZ/ml.

***Rafoxanide (RFX) resistance*:** In flocks naturally infected with *H. contortus* at CSWRI, Avikanagar, the reduction in FEC with RFX was 31% with lower 95% confidence limit suggested emergence of resistance to RFX in *H. contortus.* At LBSSF, Fatehpur, the efficacy of RFX against *H. contortus* was 96% with lower 95% confidence limit less than 90 suggested suspected resistance to RFX.

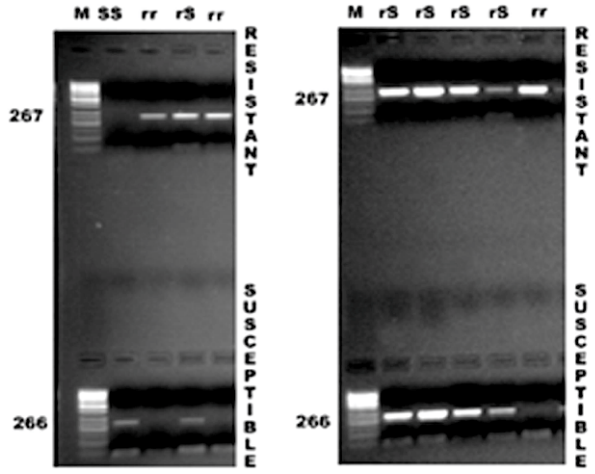
***Tetramisole (TEM) / Levamisole (LEV) resistant*:** The resistance to LEV in *H. contortus* was detected only at LBSSF, Fatehpur, where its efficacy was 25%. At CSWRI, Avikanagar, the % efficacy of LEV against *H. contortus* was 96% with lower confidence limit less than 90 which indicated suspected resistance against the LEV. The results were also confirmed by LDA, which showed 97% efficacy. However, in animals of ARC, Bikaner the LEV was found 100% effective against *H. contortus.*

***Prevention of borrowing of anthelmintic resistant parasites*:** Regular monitoring for status of anthelmintic resistance in animals introduced in CSWRI, Avikanagar from outside is being performed in quarantine. Indian Karakul transported from Arid Region Campus, Bikaner to CSWRI, revealed that FBZ was 100% effective in reducing the egg count on FECRT. LC_{50} value on EHA was 0.074±0.015 µg TBZ/ml. It was concluded that the Bikaner strain of parasite was susceptible to BZ. Presence of BZ and TEM susceptible strains of strongyle worms was encountered in Garole sheep from West Bengal. Patanwadi sheep from Gujarat found to possess TEM resistant and BZ susceptible strains while Kendrapada sheep from Orissa exhibited presence of BZ resistant strains of strongyle worms. Suitable measures were undertaken to prevent the entry of resistant worm at CSWRI, Avikanagar.

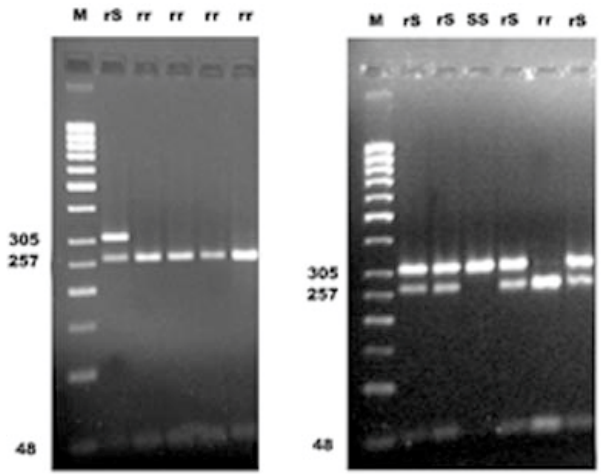
Profile of H. contortus genotypes and role of refugia: With respect to BZ resistance in H. contortus, the type of genotypes and their prevalence / frequency in population (in relation to refugia) were determined by using both allele specific (AS-PCR) and restricted fragment length polymorphism (RFLP) - PCR assays. On AS-PCR, the susceptible and resistant primers amplified a product of 266 and 267 bp, respectively. On RFLP-PCR, the “rr” individuals (homozygous resistant; Tyr/Tyr) showed 257 and 48 bp bands. The “rS” individuals (heterozygous; Tyr/Phe) exhibited 305, 257 and 48 bp bands while “SS” individuals (homozygous susceptible; Phe/Phe) exhibited an uncut 305 bp band.

On PCR assay, the seasonal variation in different genotypes of *H. contortus* (w.r.t. BZ-resistance) and possible role of *refugia* in development of AR showed that in adult male *H. contortus* (from CSWRI, Avikanagar), the overall annual frequency of rr, rS and SS types was 72.5, 25.5 and 2.0%, respectively with maximum number of BZ-

susceptible worms during monsoon and winter compared to summer in sheep. The study on variations in genotypic frequency for infective larvae (L_3) of H. contortus from different sources exhibited that in semi-arid farm, the overall annual frequency of rr, rS and SS genotypes were 86.38, 13.19 and 0.43%, respectively which contributes to gene pool of supra-population on pasture. The seasonal pattern revealed relatively higher prevalence of BZ-susceptible genotypes in supra-population during monsoon season. On monthly analysis, prior to strategic anthelmintic intervention, the proportion of rr genotype in gene pool of larvae was >90% in host (up to September). Following deworming in mid-September, the proportion of rr, rS and SS genotypes was 40.0, 55.0 and 5.0%, respectively. In succeeding months when environment is not favourable for dissemination of pre-parasitic stages of parasite with minimal chances of reinfection, the ratio of different genotypes in supra-population returned to previous level with >95% of rr genotypes. At arid farm, the overall annual frequency of rr type of H. contortus larvae recovered from sheep and found to contribute to gene pool of supra-population on pasture was 59.41% and varied from 49.50% (winter) to 73.56% (summer). On monthly basis, the frequency of rr genotype ranged from 40.0 (Aug) to 100.0 (Jul). The relatively higher proportion of rr genotype in supra-population during the period from March to July indicates existence of unsuitable climate for larval dissemination as well as meager chances of reinfection from pasture. In comparison to semi-arid farm there was higher prevalence of BZ-susceptible H. contortus larvae in supra-population.



AS-PCR profile of beta-tubulin isotype 1 gene of *Haemonchus contortus* infective larvae (rr: Homozygous resistant; rS: Heterozygous; SS: Homozygous susceptible; M: 50 bp ladder)



RFLP-PCR profile of beta-tubulin isotype 1 gene of *Haemonchus contortus* infective larvae (rr: Homozygous resistant; rS: Heterozygous; SS: Homozygous susceptible; M: 50 bp ladder)

In field flocks of semi-arid Rajasthan the proportions of rr genotype of *H. contortus* larvae contributing to the gene pool of supra-population on pasture were 97.58, 88.57 and 96.43% during summer, monsoon and winter season, respectively. In pre-drench gene pool, the frequency of rr genotype was 92.5% which decreased to 75.0% in October indicating that smaller proportion of susceptible genotypes able to disseminate in later half of monsoon and dilute the gene population on *refugia*. Thus, deworming in later half of monsoon is helpful in increasing the efficacy of anthelmintics by increasing the size of refugia. Rising trend in prevalence of rr genotype from November onwards might reflect the role of migration, unplanned grazing and anthelmintic use in field flocks in maintaining the high level of BZ-resistance. *In Arid field, the proportion of rr genotype of H. contortus* larvae found to contribute to gene pool of supra-population on pasture was 85.62, 86.54 and 92.13% during summer, monsoon and winter season, respectively. Similar to semi-arid region, in pre-drench gene pool the frequency of rr genotype was around 90.0% which reduced to 40.0% in October but reached to pre-drench level thereafter. The correlated response between genotypic frequency of homozygous BZ-resistant larvae and BZ-efficacy exhibited that a marginal rise in the proportion of BZ-susceptible alleles during September to November resulted in increase in efficacy of BZ anthelmintics as well as reduces the proportion of flocks harbouring BZ-resistant *H. contortus*.

The molecular analysis suggested that community dilution strategy for reversion of susceptibility to BZ in *H. contortus* could be feasible in farm condition. Under prevailing managemental and grazing practices in field flocks the variation in genotypic frequency could not be recorded. The period from September to November in semi-arid and from June to February in arid Rajasthan was found appropriate in increasing the frequency of BZ-susceptible alleles in the refugia. The study on correlated response between genotypic frequency of homozygous BZ-resistant worms and BZ-efficacy exhibited that a marginal rise in the proportion of BZ-susceptible alleles during September November resulted in increase in efficacy of BZ anthelmintics and reduction in the proportion of flocks harbouring BZ-resistant *H.* contortus.

Extent of anthelmintic resistance in Rajasthan (2001-2006): The prevalence of anthelmintic resistance in nematode parasites of sheep was studied on 141 sheep flocks by employing *in-vivo* FECRT and *in-vitro* EHA. On FECRT, it was observed that predominant parasite (*H. contortus*) had developed wide spread resistance to BZ. The overall BZ-resistance in *H. contortus* was observed in 85.7% of flocks in Rajasthan (ranging from 74.2% in arid to 90.0% in semi-arid). Out of 115 flocks tested on FECRT, TEM-resistant strain of *H. contortus* was observed in 56.5% (ranging from 17.4% in arid to 85.2% in semi-arid) of the flocks in Rajasthan. Out of 56 flocks in which the Closantel was tested, none of the flocks showed CLS-resistance *H. contortus*. On *in-vitro* EHA, BZ-resistance was detected in 73.0% of the flocks tested. The BZ-resistance in GIN ranged from 37.9% (arid) to 90.5% (semi-arid) of the flocks. The findings suggested that in sheep flocks, predominant parasite *H. contortus* had developed high level of resistance against BZ anthelmintics. Replacement of this class of anthelmintic with other narrow spectrum anthelmintic like closantel was advocated with rotational use of tetramisole / levamisole. The change in use of anthelmintic type in sheep flocks has yielded effective control of GINs.

Prevalence of anthelmintic resistance in H. contortus from sheep (2007-08): A total of 18 flocks from field and 4 flocks from farms in three different regions of Rajasthan were screened for status of BZ and TEM resistance. On FECRT, 100.0 and 88.9% of flocks found to harbor BZ resistant *H. contortus* with mean % efficacy for FBZ ranging from 68.56±5.28 (field) to 71.50±16.03 (farm). The prevalence of TEM resistance was 25.0 and 38.9% in farm and field flocks, respectively with mean % efficacy varying from 92.44±2.15 (field) to 97.00±2.12 (farm). On *in-vitro* EHA for BZ the ED_{50} values for TBZ against *strongyle* worms in farm flocks ranged from 0.060±0.034 µg TBZ/ml (northern Rajasthan) to 0.421±0.017 µg TBZ/ml (north-eastern Rajasthan) revealing 50.0% prevalence of BZ resistant *strongyle* worms. In field flocks, the ED_{50} values ranged from 0.030±0.022 µg TBZ/ml (north-eastern Rajasthan) to 0.347±0.005 µg TBZ/ml (northern Rajasthan) revealing 94.44% prevalence of BZ resistant *strongyle* worms.

A total of 691 infective larvae of *H. contortus* isolated from pooled faecal samples (flock-wise) on pre-treatment occasion (while conducting FECRT) were subjected to detection of mutation at 200 codon in beta-tubulin isotypeI gene using AS-PCR technique. It was observed that the frequency of BZ-rr (homozygous BZ resistant) larvae in population ranged from 17.39 to 100.00% while % allelic frequency for BZ resistance varied from 52.17 to 100.00%. The correlation between % FECR or ED_{50} value for BZ and frequency of Bz-rr genotype / BZ-r allele in *H. contortus* larvae from sheep exhibited that efficacy of BZ anthelmintic starts declining (<95%) on appearance of 25-30% BZ-rr genotypes in population. Like-wise ED_{50} started rising (>0.100 µg TBZ/ml) on appearance of > 30% BZ-resistant alleles in population.

In 2013 and 2014, trials were conducted for anthelmintic resistance in nematode parasites in Patanwadi sheep purchased from Gujarat and stationed in quarantine shed at CSWRI, Avikanagar. The results of FECRT exhibited resistance to tetramisole with 52 and 71% efficacy in first and second trial, respectively. However, GINs were found susceptible to benzimidazole (95% FECR), closantel (99-100% FECR) and ivermectin (98% FECR). On *in-vitro* EHA, the mean ED_{50} for Thiabendazole was 0.017 and 0.006µg/ml in first and second trial, respectively suggestive of susceptibility to benzimidazoles. During 2017-20, on FECRT in newly purchased Malpura sheep, BZ resistance was observed in *H. contortus* with FECR of 90%, however FECR with levamisole and closantel was 99 and 100%, respectively. In newly purchased Patanwadi sheep BZ resistance was detected on EHA with ED_{50} value of 0.178 µg TBZ/ml.

Worm control approaches and their impact on status of anthelmintic resistance at an organized sheep farm in

arid region: The aim of study was to ascertain efficiency of different worm management strategies in reversion to susceptibility to anthelmintics in sheep maintained at Sheep Breeding Farm, Fatehpur (Rajasthan). During April May, 1998, higher mortality in sheep flocks at farm was occurred due to varied reasons. However, majority of sheep showed heavy worm burden on necropsy. The sheep were treated several times with different classes of anthelmintics, but problem of haemonchosis remained uncontrolled. Study on anthelmintic resistance in *H. contortus* exhibited 0% and 25% efficacy for fenbendazole (FBZ) and levamisole (LEV), respectively on FECRT. Both the drugs (BZ and LEV) were withdrawn and closantel (CLS) was introduced in worm control programme at farm in 1998. However, existence of resistance to BZ and LEV (with relatively increased efficacy) was observed even after their withdrawal for almost a decade, suggesting limited role of withdrawal strategies in reversion to anthelmintic susceptibility in worms. In the year 2010, new animals belonging to native breeds like Marwari, Nali and Chokla were purchased and stationed at farm.

The strategies implemented and evaluated were consisted of withdrawal / restricted use anthelmintic types (up to 2010); community dilution (since 2010) through either introduction of Chokla sheep possessing anthelmintic resistance / susceptible worms coupled with annual rotational use of anthelmintic types (BZ, TEM and CLS) or introduction of Nali sheep possessing susceptible *H. contortus* with use of BZ and CLS anthelmintics in rotation; and introduction of Marwari sheep possessing susceptible *H. contortus,* with application of TST (based on eye colour chart) using CLS. The susceptibility of *H. contortus* in newly purchased Marwari and Nali sheep was confirmed by *in-vivo* FECRT (with efficacy of 96 and 98% FBZ and TEM, respectively) and *in-vitro* EHA (ED_{50} value of 0.057 ìg TBZ/ml). The effect of withdrawal of type of anthelmintics exhibited that efficacy of BZ against *H. contortus* of sheep increased from nil (1998) to drug for 10 years. The result of FECRT obtained after implementation of different community dilution strategies showed a marginal increase in BZ efficacy (up to 43%) after introduction of new animals possessing both the types of (anthelmintic resistant / susceptible) worms and rotational use of BZ, TEM and CLS for 5 years. A moderate rise in BZ efficacy (up to 56%) was observed after 5 years of community dilution through introduction of Nali sheep possessing susceptible *H. contortus* and use of BZ and CLS anthelmintics in rotation. A significant increase in BZ efficacy (up to 88%) was noticed after 5 years of community dilution through introduction of Marwari sheep possessing susceptible *H. contortus* and application of TST using CLS only since last 5 year. The efficacy of TEM increased from 25% (1998) to 92% (2007) after 8 years of withdrawal of TEM from worm management programme which further increases to 99% (2015) after introduction of TEM susceptible *H. contortus* through introduction of newer sheep coupled with rotation of anthelmintic classes. The efficacy of CLS against *H. contortus* was maintained at 100% from 1998 to 2015 through adoption of practice of rotational anthelmintic use in worm management programme. The results of study indicated that just withdrawal of ineffective anthelmintics from worm management programme is not sufficient enough to cause evident reversion to susceptibility. However, community dilution coupled with targeted selective treatment with newer class of anthelmintic will help in reversion to susceptibility in GINs with faster rate in sheep flocks at farm.

Impact of withdrawal of anthelmintic type and community dilution/refugia strategy on reversion to susceptibility in H. contortus: In sheep flocks of ICAR-CSWRI, Avikanagar reduced efficacy (80% on FECRT, ED_{50} of 0.239 µg TBZ/ml on EHA) with emergence of parasites (predominantly *H. contortus*) resistant to BZ was observed in 1995. Following discontinuation of BZ for deworming at farm since 1996, the efficacy varied between 0-44% in the year 2000 (5 yr post withdrawal) with predominance of BZ-resistant alleles (>90%) between the year 2005 to 2010. The efficacy was still observed low (26% on FECRT, ED_{50} of 0.196 µg TBZ/ml on EHA) even after 15 yr post withdrawal (in 2010). Later on, the concept of community dilution was implemented by allowing contamination of farm pasture with animals (purchased and tested for anthelmintic resistance in quarantine) harbouring BZ susceptible *H. contortus*. In addition, concept of *refugia* was also taken in consideration by shifting strategic drench during early monsoon to mid-late monsoon. From these efforts, during 2018-20 (22 yr post withdrawal) a significant improvement (86-93%) in efficacy of BZ was noticed against *H. contortus*. Simultaneously, the ED_{50} values ranged from 0.011 to 0.119 with an average of 0.075±0.008 µg TBZ/ml on *in-vitro* EHA with prevalence of BZ susceptible alleles up to 48% on PCR assay. The study indicates the possibility of reversion to BZ susceptibility in *H. contortus* population in farm area with community dilution and refugia based worm management strategies.

***Variation in LC_{50} value during patency of infection*:** During the patency of *H. contortus* infection in sheep the LC_{50} values of TBZ on EHA showed parabolic pattern in both resistant and susceptible strains. The maximum LC_{50} value was observed between 40-50 days post-infection. However, LC_{50} value for susceptible strain never reached to the level of 0.1 µg TBZ/ml that is the value used to discriminate susceptible and resistant strain. Like-wise the LC_{50} values always remained > 0.1 µg TBZ/ml for resistant strain. It was concluded that day to day variation in LC_{50} values during patency of infection on EHA does not alter the diagnostic interpretation and EHA can be used a suitable diagnostic test.

Studies on pharmacokinetics of benzimidazole in sheep

The studies were undertaken in collaboration with NDDB, Anand (Gujarat) with the objective to manipulate the pharmacokinetics of benzimidazole in an attempt to extend the life of existing BZ anthelmintics and to evaluate the preventive medication by targeting more susceptible larval population of parasite nematodes through long-term low-level medication incorporated in feed pellets.

***Effect of route of administration of ABZ in sheep*:** It was concluded that oral administration of anthelmintic in ruminants stimulated the closure of oesophageal groove leading to diversion of drug to the abomasum resulting in faster absorption and elimination. Thus, the increased bioavailability of BZ anthelmintics given through intraruminal route could be exploited for optimizing the use of anthelmintic for sustainable parasite control.

***Effect of diet type on the pharmacokinetics of ABZ in sheep*:** The effects of changing the proportion of two locally available green and dry fodders in the diet of sheep on the disposition of ABZ metabolites in plasma revealed significantly higher plasma concentration of ABZ-SO_2 following 2 hr of ABZ administration in mixed and dry fodder group compared to green fodder fed group. The ABZ-SO concentration remained significantly higher in dry group at 10-12 hr of administration (1.914±0.166 to 1.977±0.104 µg/ml) compared to other groups. There was a substantial reduction in the bioavailability of both the metabolites in sheep offered fresh green fodder compared to those maintained on dry mature hay. Animals offered dry fodder had the higher mean C_{max}, T_{max}, AUC and MRT value compared to other groups suggesting higher uptake, greater availability of the drug for absorption and slower elimination. It was concluded that the decreased transit time of digesta on the green fodder reduced systemic availability by reducing the time available for gastrointestinal absorption of the drug.

***Effect of pre-treatment fasting on anthelmintic availability in sheep*:** The study suggested that restricting the intake of feed is an alternative means of enhancing the systemic availability by increasing its dissolution and absorption and delaying the elimination of anthelmintics. Thus, allowing more time to contact between drug and parasites. Restriction of feed intake may be practiced to enhance the anthelmintic efficacy against parasites.

***Efficacy of long-term low-level intraruminal ABZ in sheep experimentally infected with BZ-resistant H. contortus*:** The result revealed that on long-term low-level dosing with ABZ, the ABZ metabolites reached plateau level after 4 day and remained almost unchanged up to day 10-11 indicating stage of equilibrium between the absorption and disposition of drug by day 4. In comparison to single intraruminal administration (@ 5.0 mg/Kg), long-term low-level administration (@ 0.5 mg/Kg/day for 10 days) resulted in lower mean C_{max} and longer $t_{1/2}$ value. The higher AUC suggested more period of parasite-drug contact at required level in long-term low-level approach. The FEC and abomasal worm count revealed that though, a plateau concentration of ABZ metabolites reached, but it was unable to kill the incoming larvae, however, reduced the fecundity of parasite. The study suggested that long-term low-level medication of albendazole against BZ resistant worm failed to reduce establishment of incoming larvae but showed effect against egg laying capacity of adult worms, resulting in low egg output. Thus, it may be concluded that medication in divided doses against resistant worm might be helpful in reducing the pasture contamination.

Efficacy of long-term low-level anthelmintic medication through feed pellets: Long-term low-level delivery of ABZ through feed pellets could successfully control the nematode parasites in hoggets. The faecal egg count (FEC) in group receiving medicated feed pellets (MFP) remained at low-level up to 3 weeks post treatment. Similarly single oral treatment with Nilverm (TEM) also reduced FEC up to 3 weeks PT but thereafter, there was significant rise in FEC in comparison to MFP group. On the other hand, single oral treatment with closantel (CLS) due to its protein binding

capacity controlled the intensity of infection up to 8 weeks PT, where the FEC remained <100 epg. Following long-term low-level administration of ALB in feed pellets the plasma disposition profile of the metabolites explained three distinct phases, a first order absorption and adaptation for 5 days, plateau from day 5 to 30 and first order elimination from day 31 to 33. The AUC value of ABZ-SO of more than 1000 µg hr/ml and long elimination half-life could readily kill the incoming infective larvae and prevent their establishment in the abomasum. It was concluded that CLS and medicated feed pellets could be used for sustainable parasite control in sheep at epidemiologically strategic points, so that incoming larva from pasture is killed before establishment.

Targeted selective treatment for sheep flocks

Because of rapid emergence, spread and borrowing of anthelmintic resistance in *H. contortus* and limited option for selecting a suitable anthelmintic class an attempt was made to develop the suitable strategy for application of TST approach in sheep flocks. The observation on frequency distribution for intensity of strongyle infection in sheep with in flock in a locality during the similar period showed existence of over-dispersion phenomenon in faecal egg counts in flocks managed in all sorts of rearing and grazing system and environmental conditions. Based on extensive and detailed epidemiological findings, variation in susceptibility of animals to GI nematodes and status of anthelmintic resistance, worm management programme was modified (from 2-3 drench per annum to single drench during mid to late monsoon) and tested on real-time basis. Following successful implementation of single drench / annum schedule, it was planned to further reduce the use of anthelmintics in flocks by developing a mechanism for targeted selective treatment (TST) through harvesting the benefits of over-dispersion phenomenon in FECs. Due to predominance, pathogenicity and economic importance, the target parasite for TST was *H. contortus*. The main clinical manifestation of this blood sucking parasite is development of anemia in affected sheep which could be adjudged by looking in to colour of ocular mucous membrane.

Formulation of mechanism for targeted selective treatment in flock against H. contortus: At the start for development of conjunctiva color chart, a flock of 34 young sheep (6-9 month old) was monitored at monthly interval for conjunctiva color, micro-hematocrit (PCV), hemoglobin (Hb) and intensity of strongyle infection from Aug, 2007 to March, 2008. On each occasion photographs of individual's conjunctiva were also taken. Pooled faecal sample for each month were cultured to know the proportion of prevalent strongyle species.

***Magnitude of FEC, PCV and Hb in visually anemic and normal sheep*:** During wormy season (Aug-Nov), the mean FEC was significantly higher (around 3 times) in visually anemic group as compared to visually normal group. However, in non-wormy season (Dec-Mar) the intensity of strongyle infection was at acceptable level (<500 epg) in both the groups. The larval composition revealed predominance of *H. contortus* during wormy season. The FEC pattern and clinical anemia exhibited necessity of anthelmintic intervention in anemic group only during wormy season. The mean PCV values ranged from 18.50±0.50 (Mar) to 27.20±1.24% (Aug) in visually anemic group and from 24.67±0.65 (Mar) to 31.84±0.71% (Oct) in visually normal group indicating significantly lower values in anemic group during both wormy and non-wormy season. Similar pattern was observed for hemoglobin.

Correlation between visual anaemia categories and PCV/Hb/FEC in sheep: The identification of sheep as anaemic through visual assessment of conjunctiva color was significantly correlated with the PCV value in all the months. The correlation between conjunctiva color and Hb concentration was correlated low as compared to PCV in both the wormy and non-wormy season. The relation between FEC and conjunctiva color was strongly positive in wormy season only. Based on correlated response, PCV and color of conjunctiva color were considered as best determinants to develop mechanism for TST approach in flock.

***Comparison of extent of anaemia based on visual inspection of conjunctiva color and actual PCV*:** Two categories of animals were made based on PCV values as normal (PCV >22%) and anaemic (PCV< 22%). The observed proportion of anaemic animals in flock based on conjunctiva color and actual proportion of anaemic animals based on PCV values showed that in all the months' estimates of clinical anaemia were higher on visual assessment as compared to actual PCV values. Overall out of total observations, 28.4% of the estimates fall outside the

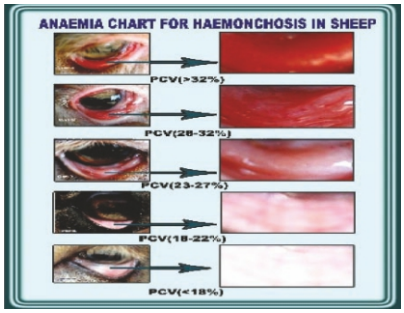
corresponding categories. However, 21.4% of the mistakes were not serious as the PCV values of the animals concerned were not low enough (>22%) to merit drenching and in these animals anaemia was less severe compared to 7.00% in which the anaemia was more severe and rated as normal based on color of ocular mucous membrane.

Further, for more precise identification anaemic animals on visual inspection and to obtain uniformity among assessment by different observers, a color chart was prepared from the available photographs by categorizing conjunctiva color sheep in to 5 groups based on PCV value. The frequency distribution of animals for each month was made as per PCV value and for each category mean FECs for *H. contortus* were calculated. The level of PCV was significantly correlated with FEC for *H. contortus* during wormy season. On the basis of categories of conjunctiva color, it was observed that during wormy season (Aug-Oct) an average of 7.4% of animals fall into category 4 (PCV <22%) with average FECs ranging from 2720 to 4703 epg.

Implementation and evaluation of TST in sheep flocks

From the year 2008-09, the developed conjunctiva color chart was applied for effectiveness in adult sheep under different physiological state. Every year all the animals in flock were screened at monthly interval for conjunctiva color from the month of July to March. Simultaneously, blood sample and faecal samples were also collected from anaemic animals (category 4 and 5) and evaluated for PCV, Hb, TEC, erythrocytic indices and intensity of strongyle infection at monthly interval. Pooled faecal sample for each month were cultured to know the proportion of prevalent strongyle species. In addition to SBF Fatehpur (Sikar), the approach was also tested at Arid Region Campus, Bikaner from the month of July, 2011.

***Status of anaemia in flock*:** Sheep flocks reared at SBF, Fatehpur (2008-16) and ARC, Bikaner (2011-13) were screened for conjunctiva color using anaemia color chart already prepared. The animals were categorized in different 5 groups of the conjunctiva color as 1- (non-anaemic), 2- (non-anaemic), 3- pink (mild anaemic), 4- pink-white (anaemic) and 5- white (severely anaemic). During the period a total of 32807 observations were recorded. The overall annual proportion of visually anaemic sheep in flocks was 2.34% and ranged from 1.11 (2012-13) to 5.89% (2008-09). The overall monthly of visually anaemic sheep ranged from 0.96 (Jan) to 3.78% (Sep) suggesting relatively higher proportion during months (monsoon season) favourable for translation of exogenous stages of *H. contortus* on pasture. Relatively increase in proportion of visually anaemic was started after mid monsoon and reached to peak up to end of monsoon. In subsequent season due to unfavorable climatic conditions for translation of exogenous stages of strongyle worms, the intensity of infection remained quite low and unable to produce anaemia. Further, it was also interesting to observe that lambing and lactation stress fail to increase the FEC as well as proportion of anaemic animals in flock due to unsuitable climatic conditions. The animals found anaemic were given extra nutritional care till they recover from anaemia as adjudged by conjunctiva color.



***Status of visual anaemia in relation to age and reproductive stage of sheep*:** Over the period from 2011-2016, on the basis of conjunctiva color, the proportion of anaemic animals (category 4+5) ranged from 0.82 (Nov) to 2.70% (Sep) in dry female and male, from nil (Jan) to 7.86% (Jul) in pregnant / lactating and from nil (Dec) to 5.35% (Aug) in hoggets. The relative higher proportion of visually anaemic sheep in pregnant/lactating group suggested the role stress on pathogenicity of *H. contortus.*

***Worm and haematological profile in visually anaemic sheep*:** Overall the mean FECs in visually anaemic (category 4+5) sheep ranged from 453.6±120.2 (Feb) to 5629.6±695.5 epg (Aug). The effect of higher intensity of infection during August to October was observed to be reflected on proportion of visually anaemic animals in flock. The haematological profile of visually anaemic sheep exhibited that mean Hb, PCV, TEC, MCH, MCHC and MCV ranged from 5.94±0.13 (Aug) to 7.06±0.15 g% (Jul), 16.70±0.44 (Aug) to 20.29±0.58% (Jul), 2.77±0.19 (Mar) to 4.35±0.67 million/mm^3 (Feb), 25.35±3.02 (Dec) to 29.62±1.72 µ µg (Aug), 32.74±1.18 (Mar) to 40.28±1.53% (Jan) and from 69.24±3.88 (Sep) to 77.11±4.17 $µ^3$ (Mar), respectively. Compared to normal values in sheep, lower Hb, PCV and TEC

and higher MCH and MCV values were observed in visually anaemic animals infected with *H. contortus*. On coproculture the predominant parasite was *H. contortus* in all the months and its mean proportion in population ranged from 55.6±9.9 (Mar) to 97.0±1.9% (Sep).

Sensitivity and specificity analysis for TST: A linear trend was observed in proportion of true positives and level of FECs in all the seasons at both the PCV cut-off values. On classification of visually anaemic animals as per magnitude of intensity of strongyle infection, it was observed that percentage of correct treatment was maximum (71.3 to 83.4%) in individuals with intensity of infection ≥3001 epg and it remained >65% in all the seasons. The kappa index indicated poor (criteria as FEC ≤1000 epg) to moderate (criteria as FEC ≥3001 epg) association between FECs and PCV in visually anaemic sheep. The proportions of false negatives were <10% with both PCV cut-off in sheep possessing FEC ≥3001 epg. A higher percentage of false negative and especially false positive scores with a considerably lower kappa value indicated that the TST scores were less accurate in animal with FECs ≤1000 epg compared to FECs ≥3001 epg. Therefore, the lower accuracy for FECs ≤1000 epg group did not lead to a higher risk of nematode related losses, but meant that more treatments than considered necessary were given. The overall sensitivity of TST system ranged from 22.9% (FEC ≤1000 epg and PCV ≤18) to 90.1% (FEC ≥3001 epg and PCV ≤22).

Observations on peri-parturient rise in FEC in sheep under TST approach: Lactating ewes were monitored from December 2008 to March 2009. The magnitude of FEC revealed that there was absence of peri-parturient rise in FEC in sheep flocks of arid region. The mean FEC in anaemic group ranged from 660.0±448.2 (dry stage) to 125.0±75.0 epg (3-7 week of lactation) compared to 334.6±99.4 epg (dry stage) and 218.8 ± 53.4 epg (3-7 week of lactation) in visually normal ewes. The PCV and Hb values in anaemic group were within limit. The study suggested that there is no need of anthelmintic treatment in lactating ewes even if they appear anaemic.

Efficacy and impact of TST on drench frequency: Over the years of application of TST approach in sheep flocks exhibited that 72.33% decisions were correct (infected and drenched) for detection of anaemia as well as infection. Incorrect decisions like uninfected but drenched (sheep side) and infected but not drenched (worm side) were made on 21.00% and 6.67% occasions, respectively. With the 8 years of TST application it was observed that proportion of animals drenched with anthelmintic/year ranged from 8.65% in 2012-13 to 29.31% in 2008-09 with an average of 16.94±2.62%. Further, on evaluation of comparative performance of flocks under en-mass and TST approaches of anthelmintic intervention showed that significant reduction in anthelmintic use and cost incurred on it in flock with better performance of flock.

Evaluation of flukicide intervention in sheep flocks of semi-arid Rajasthan

Based on epidemiological observations, it was realized that in semi-arid region of Rajasthan among flukes only the amphistomosis had endemicity and require a suitable intervention. Keeping in mind the incidence pattern of amphistomes and their life cycle, flukicide intervention (Oxyclozanide) during the period from end of March to mid-April was applied and tested for its effectiveness in curtailing the incidence rate. The monthly incidence rate for *Amphistomum* ova in faecal sample from un-drenched animals varied from nil (December) to 32.42% (August) with an overall annual incidence rate of 7.89%. On the other hand, in samples from drenched flocks the monthly incidence ranged from nil (November to February) to 8.84% (July) with overall annual incidence to the tune of 2.21%. The strategic inclusion of flukicide (to overcome the immature amphistomosis) during March-April exhibited significant reduction (~70%) in incidence of amphistomes.

Mathematical modelling for forecasting of *H. contortus* in sheep in Rajasthan

It was attempted to obtain more precise prediction of pattern of GIN (particularly *H. contortus*) in sheep. An outline of mathematical model based on development, mortality and establishment rate, climatic data, translation of larvae on pasture, fecundity of parasite, stocking density and migratory behaviour of larvae was used to predict the level of pasture contamination and subsequent possible intensity of infection in sheep. Monthly total rainfall, average maximum and minimum temperature and relative humidity were used to determine the period in which worm eggs from faeces reach the infective larval stage and migrate on to the herbage. The steps involved were (i) interaction between FEC and climate,

development rate from eggs to L_3, (iii) larval survival rate, (iv) larval migration (vertical) rate on grass blade, stocking density on community grazing land, (vi) seasonal herbage availability, (vii) dry matter consumption rate, faecal output rate, (ix) establishment rate of adult worms in sheep and (x) fecundity rate of adult worm.

All the steps enlisted above were arranged sequentially and organized in "visual basic" programme to develop forecasting system for GIN in sheep of Rajasthan (FROGIN). It is a computer based mathematical modelling of *H. contortus* population tailored for different zones of Rajasthan. It give result as predicted FEC on start of month, intensity of FEC for next 60 days and pasture larval burden for that month. Studies on testing and validation of FROGIN in farm and field flocks of both agroclimatic conditions of Rajasthan exhibited that while considering a variation of 500 epg in FEC as non-significant, the FROGIN based forecast about intensity of infection was >80% in agreement in all the location and management system except in arid farm where agreement % was 66.7. The low agreement in arid farm could be due to creation of artificial environment suitable for worm propagation by practicing the irrigation means to cultivate the fodder. Variation in predicted and observed FEC to the tune of > 500 was noticed mainly during monsoon season and this could be due to variation in quantity of herbage and dilution of infection on pasture.

Alternative control methods for gastrointestinal nematodes

Effect of urea application on pre-parasitic stages of *Haemonchus contortus:* On egg hatch assays, mean hatching of eggs varied significantly from 4.59±2.34 (@ 5.0 g N_2%) to 92.20±1.92% (control) in trial 1 and from 1.44±0.63 (@ 4.0 g N_2%) to 90.26±1.44% (control) in trial 2. The mean ED_{50} value of urea against eggs of *H. contortus* was 1.1477±0.0097 g N_2% indicating potent ovicidal action of nitrogenous fertilizer. The mean larval mortality ranged significantly from 1.12±0.18 (control) to 100.00 % (@ 20.0 g N_2%) in trail 1 and from 5.76±2.19 (control) to 100.00% (@ 20.0 g N_2%) in trial 2. The mean ED_{50} value of urea against infective larvae of *H. contortus* was 5.9012±0.4870 g N_2% indicating larvicidal activity of nitrogenous fertilizer. *On larval development assay, a* significant variation in larval recovery was observed with different concentrations of urea. The mean L_3 recovery in urea incorporated cultures varied from 62.02±6.65 (@ 0.019 gN_2%) to nil (@ >5.0 gN_2%). The relationship between exogenous N_2 concentration and larval recovery suggested that increase in N_2 content of faeces caused significant embryonic mortality of *H. contortus* eggs leading to decreased L_3 recovery. The observations on effect of urea application on translation of infective larvae revealed that the larval translation and pasture larval burden reduced significantly to almost nil when pastures were sprayed with urea @ 2.5 gN_2% or more. Even at the lowest urea concentration (1.25 gN_2%), the pasture larval burden was only 19.7% compared to untreated pasture (100%). In untreated pasture the larval recovery started from day 10 post-contamination and continued up to day 28 post-contamination. The period of larval availability on pasture decreased with increasing concentration of N_2 application as well as there was delayed translation of larvae on grass blades. In semi-arid region of Rajasthan, the recommended level of N_2 for agricultural operations is 40 kg N_2 per hectare. The results of study reveal that if N_2 is sprayed on pasture at recommended level, it may cause considerable reduction in larval translation that may simultaneously decrease the pasture infectivity, as well as lead to low intensity of strongyle infection in animals grazing such pasture.

Bioactive forages and role of condensed tannins (CTs): Beneficial effect on the ability of ruminants to withstand internal parasitic infection has been found with tannin-containing plants. The study conducted at CSWRI, Avikanagar revealed significant reduction in larval development rate in faeces from CT fed animals. CTs could bind to the protein available in the nutrient media for larvae leading to larval starvation and death as well as developing larvae can ingest CT, which bind to the intestinal mucosa and cause autolysis. CTs may also inactivate hatching enzymes in worm eggs (causing reduction in egg hatching) and can paralyze the body musculature (pharyngeal muscles) of larvae (leading to reduced viability of larvae). Hence, sufficient evidences are available that suggests that CTs can disrupt the life cycle of nematodes and help in worm management. On *in vivo* study, around 40-60% reduction in FEC with marginal rise in haemoglobin and packed cell volume were observed in sheep (infected with GIN) fed CTs (@ 5 % of DM) either as leaves of Khejri (*Prosopis. cineraria*) or as extract (acetone: water) of leaves compared to those offered diet having no CT.

Pasture resting: The study conducted in semi-arid Rajasthan (using tracer lambs) revealed that sheep grazed during

monsoon on spring contaminated-summer ungrazed pasture had very low FEC and worm count compared to those placed on continuously grazed contaminated pasture. The pasture larval burden was higher in general pasture than summer ungrazed pasture. Thus, resting the contaminated pasture during summer found to effectively control the pasture larval burden.

Biological control

***Screening of faecal samples and isolation of nematophagous fungi*:** A total of 1774 faecal samples from farm flocks (Avikanagar- 1154 and Fatehpur/Bikaner- 620) and 1316 faecal samples from field flocks (semi-arid-773 and arid-543) were screened for the presence of nematophagous fungi. In farm flocks of semi-arid region, the species of nematophagous fungi isolated were *Arthrobotrys oligospora (in 4.51% samples), Duddingtonia flagrans* (in 0.09% *samples*), *Verticillium spp. (in 0.69% samples) and unidentified (in 4.94% samples). Similarly, in farm flocks of arid region,* the species of nematophagous fungi isolated were *A. oligospora (in 10.97% samples), Verticillium spp. (in 2.58% samples) and unidentified (in 1.45% samples).* There was more frequent occurrence of the nematophagous fungi from arid than from semi-arid zone. *D. flagrans* was not recovered from arid region. It was observed that majority of *A. oligospora were recovered during February and March in both the agro-climatic region, while unidentified isolates prevails throughout the year with maximum during January to March.* From arid zone about 40 and 28% isolates were obtained during winter and summer months, respectively. However, from semi-arid zone majority (87.5%) were isolated in summer (April to June) months. Similarly in samples from field flocks, *A. oligospora* was isolated predominantly. Only *A. oligospora* could be isolated from faeces of arid region, whereas from semi-arid region two isolates of *Verticillium* spp. were also recorded in addition to *A. oligospora*. Similar to farm flocks, higher prevalence was recorded for *A. oligospora* (5.89%) in samples from arid region as compared to semi-arid region (2.85%) with maximum positivity during January to March.

Mycological studies on A. oligospora: On 2% CMA growth was excellent with numerous conidia formation. Conidiophores were straight with multiple conidiogenous heads. These conidiogenous heads had many denticles bearing conidia. There were usually up to 10 conidia per conidiogenous head. Conidia had dimensions of 11-14 x 15-25 µm and were broad and ovoidal in shape with 1-2 septa. Chlamydospores were noted in very old cultures (1 to 2 months old) as round to ovoid, intercalary and in chains.

Predatory activity of fungi on agar: An excellent net-formation and trapping of larvae on CMA was observed with *D. flagrans*. However, *A. oligospora* did not display the net-forming ability on CMA and when grown on 2% water agar medium it grew well and displayed the net-forming ability. *D. flagrans* has been found very efficient in trapping the larvae as compared to *A. oligospora*. The former trapped about 98% larvae by 24 to 48 h post inoculation (PI), whereas the later trapped only about 67% on 144 h PI. Both the fungi trapped the larvae in sticky nets produced along the vegetative hyphal system. Although isolates of *A. oligospora* grew well on 2% CMA, but very poor loop formation and trapping of larvae was noted when baited with infective larvae. Therefore, isolates were allowed to grow on 2% agar. On this medium, although, the growth was poor but there was excellent net formation when baited with larvae. Therefore, for studies on predatory ability isolates were grown on 2% agar. Larval trapping by all the isolates of *A. oligospora* increased steadily and on day 10 almost all larvae were found trapped. Isolates from semi-arid farm and arid farm trapped the larvae more effectively than semi-arid field isolates in the initial part of the experiment (up to 6th day). However, in the later part there was no difference in trapping of larvae by all the isolates.

Predatory activity of A. oligospora in faecal culture assay: All the isolates reduced the number of infective larvae at a considerable rate in comparison with the controls. Although arid farm isolate had higher predatory activity (97.7% reduction) at conidia concentration of 20/ g faeces while all the isolates were equally capable of reducing the larval development at 2000 conidia/g faeces concentration. In another trial, one isolate of *A. oligospora* obtained from farm and field flocks of each agroclimatic and the only isolate of *D. flagrans* obtained from semi-arid farm were selected for evaluating their ability to kill nematode larvae on *in vitro* faecal culture assay. All the isolates tested reduced the number of infective larvae at a considerable rate in comparison with the controls. Although field isolate of *A. oligospora*

from arid region showed higher predatory activity (98.6% reduction) at conidia concentration of 20/ g faeces while all the isolates were equally capable of reducing the larval development at 2000 conidia/g faeces concentration. Further, addition of chlamydospores of *D. flagrans* in faeces infected with *H. contortus* eggs revealed 3.9, 56.3 and 92.0% reduction in larval number at the concentrations of 20, 200 and 2000 chlamydospores/g faeces, respectively. At 2,000 chlamydospores/g faeces concentration faeces were completely over grown by mycelium carrying conidiophore with conidia. Similarly, with the addition of conidia of *A. oligospora,* the reduction was 43.0, 73.7, 78.8 and 84.2% at the concentrations of 10, 100, 1000 and 2000 conidia/g faeces, respectively. On microscopic examination faecal cultures were full of conidiophores with conidia at the conidial concentrations of 1000 and 2000.

Gut survival of fungi in sheep: Single oral dose of 1.5 million chlamydospores of *D. flagrans* led to both re-isolation of fungi from faecal cultures and significant reduction in the number of infective larvae recovered from faecal cultures 24 h post dosing suggesting existence of gut survival ability of the fungus. However, no gut survival of *A. oligospora* could be noted following the oral administration of $1x10^7$ conidia to sheep. In another trial, the arid field isolate survived well with very poor development of larvae (8.2±2.9 and 4±1.0%) from both the animals on day 2 post feeding. Profuse growth of fungus was detected in all the cultures. The other two isolates had a very poor survival as evident by very scanty presence of fungus in faeces and no significant effect on larval development.

In another study, *A. oligospora* isolate from arid field flocks survived well after the passage through the GI tract of sheep resulting into profound fungal growth on both faecal cultures set up from each animal and significant reduction in larval numbers on day 2 post-dosing. However, isolate from semi-arid region caused slight reduction in larval numbers on day 2 post-dosing with very poor growth of fungus. The isolate from arid farm flocks resulted into slight reduction in larval numbers on day 2 post-dosing with scanty fungal growth. The isolate from semi-arid region caused very slight reduction in larval numbers on day 1 post-dosing with poor growth of fungus. There was profound growth as well as significant reduction in larval numbers in both faecal cultures set up from each animal fed with chlamydospores of *D. flagrans* farm isolate from semi-arid region. *A. oligospora* was isolated from faecal cultures on 2 days after feeding (except for isolate from semi-arid farm), whereas *D. flagrans* was isolated from faecal cultures on 1 day after feeding. On oral dosing of two isolates of *A. oligospora* (@ 1.5 million conidia / animal, orally) to infected sheep, it was found that isolate from arid region survived well after the passage through the GI tract of sheep resulting into profound fungal growth on both faecal cultures set up from each animal and significant reduction in larval numbers on day 2 post-dosing. However, isolate from semi-arid region caused slight reduction in larval numbers on day 2 post-dosing with very poor growth of fungus in one out of 2 cultures set up from one animal only.

***Incorporation of D. flagrans chlamydospores into complete feed blocks*:** The initial experiments on feeding barley grains on which fungus was allowed to grow revealed the re-isolation of fungus as well as reductions in larval recovery from faecal cultures. This has prompted us to incorporate barley grains containing *D. flagrans* into straw based complete feed blocks to determine whether this device could be possible in our situation. The fungus containing grains (1.25 kg) were thoroughly mixed with the grain portion of the block formulation. After thorough mixing with other ingredients, complete feed blocks (1.5 kg in weight) were prepared. In trial with fresh fungal blocks, a significant reduction in larval numbers recovered from faecal cultures concurrent with growth of *D. flagrans* in the majority of agar plates was observed. The percentage of larvae produced from available eggs before fungal block feeding (68.98±3.52, mean for days 0 to 2) was significantly higher than during fungal block offer (3.52±0.79, mean for days 3 to 7). However, the difference in percent development of larvae before and after block offer was non-significant. The percent development of infective larvae remained low for 2 days after the fungal blocks were withdrawn and then returned to almost pre-fungal block levels. In second trial where sheep were offered fungal blocks stored for 5 weeks showed that *D. flagrans* chlamydospores incorporated into CFB survived well and resulted into similar pattern of larval reduction as with fresh blocks.

***Effect of D. flagrans on H. contortus of sheep on pasture*:** A striking effect of the fungus on the larval development was observed in faecal culture. The number of infective larvae recovered from the fungus treated group was consistently lower than from the control group. The presence of fungus was also seen in faecal cultures from fungal

fed group. On the pasture plots recovery of larvae started from the 2nd week of the experiment and from then larval counts increased markedly on the plot grazed by the control group. On the other hand, low levels were maintained on the plot grazed by the fungus treated group.

Nutritional management

The pathogenesis of *H. contortus* infection was studied in growing Malpura male lambs under stall feeding. A trickle infection with 200 larvae of *H. contortus* was given three times a week for 8 week period in infected group. On the basis of PCV, Hb, serum protein, albumin and body weight values, it was found that the pathophysiological effects caused by *H. contortus* infection were mild. Furthermore, no clinical signs such as mucous paleness and sub-mandibular oedema were observed. Therefore, it is likely that either the larvae caused relatively mild infection and/or high protein diet (17% CP) withheld the effects of infection. Role of protein supplementation to lambs with clinical *H. contortus* infection primarily on the resilience and secondly on their ability to resist the establishment of the infection was studied under stall feeding protocol. The infection protocol followed caused pathophysiological effects in Chokla lambs as revealed by haematological and biochemical parameters and body weight values. The disease was more severe in lambs receiving low protein (LP) diet. Weight gain was reduced in infected lambs relative to their controls. Faecal egg counts, worm burden, per cent establishment of larvae and fecundity of females were not significantly different between groups of infected lambs, suggesting no effect of diet on parasite establishment. Both high protein (HP) and moderate protein (MP) diets resulted in higher increase in body weight as compared to LP diet. Dry matter intake was lower in low protein fed groups without any significant effect of *Haemonchus* infection. Correspondingly, intake of other nutrients (OM, CP, NDF, ADF, cellulose, hemicellulose) was lower in the LP fed groups. No significant difference in digestibility of all nutrients was observed between control and infected lambs fed with HP and MP diets, however, the digestibility of DM, OM, NDF, ADF, cellulose and CP was significantly low in infected lambs fed with LP diet as compared to control lambs. Nitrogen balance parameters showed lower value in LP and the combined effect with infection was more pronounced (2.30±0.64 in LP infected vs 4.40±0.41 in LP control). The performance of animals on LP diet was significantly lower as evidenced from lower average daily gain, which was depressed further when combined with *Haemonchus* infection (13.4 g in LP infected vs 39.9 g in LP control). The normal animals in all the three dietary groups gained higher live weight compared to their *H. contortus* infected counterparts. In conclusion there was significant adverse effect of infection in Chokla lambs on low protein diet and the supplemental effect of protein supported better performance through higher feed and nutrient intake, increased digestibility, N balance and growth, but with a lower magnitude compared to control counterparts. A series of experiments were conducted to elucidate the role of nutritional manipulation on resistance / resilience to *H. contortus* in lambs.

***Anthelmintic effect of Khejri leaves*:** Khejri leaves fed lambs (Gr 1) remained clinically healthy up to 8 week, however, one lamb developed bottle jaw condition after withdrawal of khejri feeding. On the other hand, in control group (Gr-2), six out of 8 lambs were found anaemic up to 8 week and bottle jaw was exhibited by three lambs. Feeding of khejri leaves did not reduce the FEC significantly, however numerically it was lower in Gr-1 than Gr-2. This was equivalent to an average reduction of around 12% between day 24-30 and 9-10% between days 42- 54. The percentage of larvae developed in faeces from Gr-1 lambs was lower on all the occasions. There was no significant effect of khejri feeding on worm count, % establishment, fecundity and female/male ratio. Gr-1 lambs had non-significantly higher average daily gain (57.10±6.88 g) than Gr-2 (28.10±13.80 g) during 8 week khejri leave feeding. Although PCV and Hb values were lower starting from week 4 in Gr-2 than Gr-1, the difference was significant only on week 8. Weekly voluntary feed intake per animal lamb was low in Gr-2 as compared to Gr-1.

***Synergistic effect of tannin and protein supplementation*:** Malpura lambs were fed concentrate and roughage in the ratio of 60:40. Two levels of protein (HP- 17% CP and NP- 11.5% CP) were taken. Both during the khejri feeding period as well as after khejri withdrawal, lambs of both the groups remained clinically healthy. Eggs appeared in faeces on 23 and 18 days post first infection in HPTI and NPTI lambs, respectively. Supplementing the diet with protein and khejri leaves did not reduce the FEC; however, HPTI group excreted fewer eggs than NPTI group. After khejri withdrawal FEC rose in HPTI group and reached to maximum of 21767 epg on day 109. However, there was no

increase in FEC in NPTI group after khejri withdrawal. There was no significant effect on worm count, % establishment, fecundity and female/male ratio, however higher values were recorded in NPTI lambs. Nutrition had significant effect on average daily gain as NPT group lambs had higher average daily gain (107.10±5.10 g) than HPT lambs (64.00±12.10 g) group after 8-week khejri leave feeding. Nutrition had significant effect on PCV and Hb on week 4. Infection had significant effect on PCV and Hb on week 4 and 10 and week 8 and 14. Significant effect of nutrition was observed on pre-slaughter weight, empty live weight, hot carcass weight and loin eye area with significantly higher values in NPT lambs than HPT lambs. Infection had no significant effect on these parameters.

Study on the protein sparing effect of khejri leaves on resistance and resilience of GMM lambs exhibited that feeding of normal protein concentrate and dried khejri leaves was as effective as high protein concentrate feeding alone indicating protein sparing effect of khejri leaves. The combination of normal protein concentrate (11.6% CP) and 50% khejri leaves gave better results as far as resistance and resilience of lambs against *H. contortus* infection. Similarly, the feeding of combination of normal protein concentrate and 50% Pala leaves resulted in improved resistance and resilience of lambs against *H. contortus* infection. *Feeding normal protein with sole Pala leaves and combination of Pala and Khejri (Prosopis cineraria) leaves (50: 50) resulted in almost similar improvement in resistance and resilience of Malpura lambs against H. contortus infection.* Feeding of complete feed blocks containing dried Neem leaves had no effect on resistance and resilience of lambs against *H. contortus.*

Phyto-anthelmintics: Under NATP a large number of crude extracts from different plants were evaluated for antiparasitic activities and it has been found that *Malia azedarach* (Bakain), *Butea frondosa* (Palas), *Artemesia martima* (Kirmala), *Mallotus philippinensis* (Kamala), *Azadirachta indica* (Neem), *Embelia ribes* (Baberang), *Tagetes patula* (Gaatakadi), *Andrographis peniculata* (Kalmegh), *Vernonia anthelmintica* (Kaljiri), *Vitex negundo* (Bana), *Xanthium stramurium* (Chotta Gokhru) etc possess low to high level of antiparasitic activity against different stages of GI nematodes. Recently aqueous, methanol, ethanol, acetone and hydro-alcohol extracts from diiferent parts of plants were subjected to *in vitro* efficacy against *H. contortus* egg hatch (EHA) and larval mortality assay (LMA).

The mean IC_{50} values of 1.38, 2.44 and 5.09 mg/ml for inhibition of egg hatching and mean LC_{50} values of 0.55, 0.64 and 0.82 mg/ml for larval mortality were obtained for aqueous, ethanolic and methanolic extracts of *P. granatum* fruit peel off, respectively. Being the lowest IC_{50} and LC_{50}values, it was inferred that aqueous extract of *P. granatum* fruit peel off presented the highest ovicidal and larvicidal activities. The mean IC_{50} values of 0.44, 0.40 and 0.85 mg/ml for inhibition of egg hatching and mean LC_{50} values of 1.78, 0.83 and 0.85 mg/ml for larval mortality were obtained for aqueous, methanolic and ethanolic extracts of *Aloe vera*, respectively. Being the lowest IC_{50} and LC_{50} values, the highest ovicidal and larvicidal activities was expressed by methanolic extract followed by ovicidal activity by aqueous extract and larvicidal activity by ethanolic extract. The mean IC_{50} value of 0.24 mg/ml for inhibition of egg hatching was observed with aqueous extract of *V. negundo* leaves. The mean LC_{50} values of 0.35, 1.52 and 1.72 mg/ml for larval mortality were obtained for aqueous, methanolic and ethanolic extracts of *V. negundo* leaves, respectively. Being the lowest IC_{50} and LC_{50} values, it can be inferred that aqueous extract of *V. negundo* leaves had potent ovicidal and larvicidal activities against *H. contortus*. The mean LC_{50} values of 0.49, 0.16 and 0.31 mg/ml for larval mortality were obtained for aqueous, methanolic and ethanolic extracts of *T. terrestris*, respectively. Being the lowest IC_{50} and LC_{50} values, the highest ovicidal and larvicidal activities was expressed by methanolic extract.

Phytochemical analysis of extracts showed presence of tannins, flavonoids and phenolic compounds in al the extracts. Absence of steroids and presence of terpenes was detected in extract of *A. squamosa. The number and major phyto-compounds recorded on* GC-MS analysis of the extracts of different plants are as below:

Synthesis of silver nanoparticles and in vitro evaluation: On LDA, AgNPs were found very effective at lower concentrations (1.25 mg/ml) as compared to crude methanolic extract of *V. negundo* leaves (2.50 mg/ml). On EHA, inhibitory effect on egg hatching induced by *P. granatum* fruit peel off aqueous extract mediated AgNPs almost similar to crude extract. On LMA, mortality of *H. contortus* larvae induced by *P. granatum* fruit peel off aqueous extract mediated AgNPs was at par with the mortality induced by the crude extract. However, AgNPs showed higher efficacy even at lower concentrations (0.625 to 0.1562 mg/ml) as compared to crude extract. Like-wise *Aloe vera* leaves

Activities of different plant extracts on *H. contortus*

Plant	Extract	Embryonicidal	Ovicidal	Larvicidal
A. concinna pods	Aqueous, Methanol	Poor to mild	Excellent	Excellent
	Ethanol, Acetone, Hydro alcohol	Moderate		
B. aegyptiaca leaves	Aqueous, Ethanol, Hydro alcohol	Poor	Excellent	Excellent
	Methanol, Acetone	Moderate		
B. aegyptiaca immature fruits	Aqueous, Acetone	Poor to mild	Excellent	Excellent
	Methanol, Ethanol, Hydro alcohol	Excellent		
B. aegyptiaca mature fruits	Aqueous, Methanol	Poor	Excellent	Excellent
	Acetone, Ethanol, Hydro alcohol	Excellent		
P. granatum fruit peel off	Aqueous, Ethanol, Methanol	Poor	Excellent	Excellent
V. negundo leaves	Aqueous, Methanol, Ethanol	Poor	Excellent	Excellent
A. squamosa leaves	Methanol	Poor	Excellent	Poor
Aloe vera	Aqueous, Ethanol, Methanol	Poor	Excellent	Moderate
T. terrestris	Aqueous	Mild	-	-
	Aqueous, Methanol	-	Moderate	-
	Aqueous, Ethanol, Methanol	-	-	Excellent

aqueous extract mediated AgNPs were found more effective in inducing larval mortality as compared to crude extract. On EHA, > 95% inhibition of egg embryonation was observed with AgNPs of ethanolic extract from *B. aegyptica* immature fruit at minimum concentration of 2.50 mg/ml as compared to 10.00 mg/ml of normal ethanolic extract. On LMA, AgNPs of ethanolic extract from *B. aegyptica* immature fruit showed similar magnitude of larvicidal activity as observed with normal ethanolic extract, however, the excellent larvicidal activity (>99%) was observed even at lowest concentration (0.01 mg/ml) of silver-mediated nanoparticles of *B. aegyptica* immature fruit hydroalcoholic extract as compared to 0.15 mg/ml of normal hydroalcoholic extract.

Plant	Extract	No. of phyto-compounds	Predominant phyto-compound (%)	%
V. negundo leaves	Methanol	30	2-Dodecen-1-yl(-)succinin anhydride Benzoic acid, 4-hydroxy-	>20 >20
P. granatum fruit peel off	Methanol	24	1,3-Propanediol, 2-(hydroxymethyl)-2-nitro- 5-Hydroxymethylfurfural	52.3 12.66
Aloe vera leaves	Methanol	26	n-Hexadecanoic acid 1,3-Propanediol, 2-(hydroxymethyl)-2-nitro-	>10 >10
T. terrestris leaves	Methanol	16	4-O-Methylmannose	69.6
A. concinna pod	Methanol	9	1,2,3-Cyclopentanetriol	78.42
B. aegyptiaca immature fruits	Ethanol	7	4-O-Methylmannose	83.14
B. aegyptiaca mature fruits	Hydroalcohol	5	4-O-Methylmannose	93.10

In vivo trial with crude ethanolic extract of *B. aegyptiaca* immature fruit exhibited a non-significant variation in FECs in extract treated sheep, however on majority of days numerically mean intensity of infection remained low in

extract treated group as compared to control group. A non-significant variation was observed for weekly haemoglobin, packed cell volume and body weights in all the groups.

Studies on genetic variation in sheep for GI nematode infection

The study was initiated in 1996-97 taking 4 breeds (Awassi x Malpura, Malpura, Avikalin and B. Merino). The initial result revealed that in Malpura breed out of 74 progenies of 13 sires tested, 8 were under low FEC group. In Avikalin out of 11 sires, 8 sires were under moderate level of infection whereas in Bharat Merino, majority of sires was in high FEC group.

***Comparison of response to repeated challenge of H. contortus in sheep*:** It was found that FEC, Hb, PCV, MCHC and body weight were reasonably repeatable with significant repeatability around or above 0.5. The correlation among various parameters showed that log transformed worm count had significantly positive correlation (r= 0.836) with transformed FEC and significantly negative correlation with Hb (r= - 0.678), PCV (r= -0.667) and TEC (r= -.587). Similarly transformed FEC had negative correlation with Hb, PCV, TEC and body weight. Multiple regression analysis revealed that both the transformed FEC and PCV together accounted for 73% of the total variation in the transformed worm burden. Hb accounted for an additional 4% of the variation while transformed FEC, Hb, PCV, TEC and body weight factor together accounted for 86% of the observed variation in transformed worm burden. It was concluded that FEC and PCV was reasonably reliable phenotypic marker for assessing resistance to GIN in sheep.

Heritability estimates of FEC in sheep: In the initial phase, based on pre-treatment FEC of 300 progenies from 25 sires (pooled over 3 years) of Avikalin breed, the heritability estimate (h^2) of FEC was calculated to be 0.35 ± 0.18, which was suggestive of existence of within breed variation and feasibility of selection for worm resistance. Further 2004 onward, the study was undertaken at large scale. The FEC data for all the progenies born during 2004 to 2010 were pooled for estimation of heritability. The overall h^2 estimates for log transformed FEC in naïve animals were 0.104 and 0.141 for Malpura and Avikalin, respectively. In exposed animals the h^2 estimates for log transformed FEC were 0.081and 0.043 for Malpura and Avikalin, respectively. Creation of divergent lines either resistant (R-line) or susceptible (S-line) was possible through regular screening for FEC at naïve and exposed stage of infection and selection of progenies. In another analysis on genetic parameter estimates for FECs and their relationship with growth in Avikalin and Malpura sheep (2004-16) revealed moderate heritability (h^2) for pre-drench log transformed faecal egg count (LFEC) in Avikalin (0.21±0.06) and Malpura (0.18±0.04) sheep. The post-drench $h^2$for LFEC was low in Avikalin (0.04±0.03) and Malpura (0.11±0.03) sheep. Thus, effective selection program can be carried out for further improving the resistance against *H. contortus* in both the breeds using pre-drench LFEC estimates. The genetic correlation between the pre-drench LFEC and growth traits was not in the desired direction. Existence of substantial genotype × environment (G ×E) interaction was seen in Malpura sheep, where major shift in ranks of sheep based on pre-drench LFEC as that of post-drench LFEC was observed owing to genetic correlation of 0.65±0.15. The G ×E was absent in Avikalin sheep. Unreliable genetic correlation between growth and LFEC does not warrant a multi trait selection index development and its utilization in breeding program. The independent selection for LFEC followed by corrected 6WT can precisely help in achieving the goal of improving growth in nematode resistant sheep.

On comparison of host response to single and trickle infections of *H. contortus* in Malpura lambs selected for either resistance or susceptibility to *H. contortus, o*ver the period of 10 weeks, a gain of 0.3 kg was recorded in lambs of R-line compared to a loss of 4.1 kg in S-line on single challenge. However, on trickle infection both the groups exhibited gain (5.7 kg in R-line and 5.2 kg in S-line) in body weight. On majority of occasions intensity of infection was lower in R-line compared to S-line. Non-significant variation was observed in Hb and PCV among both the lines on single challenge. However, significant variations among divergent lines (lower Hb value in S-line compared to R-line) were observed on trickle challenge. In both the forms of challenge, plasma pepsinogen level revealed non-significant variation. On slaughter, the mean number of adult *H. contortus* in abomasum varied non-significantly between 498.7±40.1 (R-line) and 576.7±270.1 (S-line). The worm length remained more or less similar in both the lines. Correlation between log FEC and body weight was significant only in S-line. Log FEC showed significant negative

correlation with Hb and PCV in both the lines on single challenge. The correlation between log FEC and plasma pepsinogen level was significantly negative in both the lines on trickle challenge. It was concluded that the animals selected for resistance can tolerate parasite challenge effectively with reduced intensity of infection, higher body weight gain and reduced pathogenic effect.

***Intensity of GIN in selected lines*:** In comparison to S-line, the animals of R-line possess lower (11.3% in Oct to >50.0% in Jul, Aug and Feb) intensity of strongyle infection on overall basis with minor year to year variation. In spite of no anthelmintic intervention in the R line the FEC never reached the threshold level (> 2000 epg) during the year (except during June in Avikalin) suggesting that these animals could be maintained without anthelmintic drench. On the contrary in animals of S line peak of infection (passing the threshold limit) was noticed during the period from June-July and required anthelmintic intervention. It was evident that animals of R-line could be maintained without any anthelmintic drench and this mean of alternate worm control would result in lowering the anthelmintic frequency as well as helpful in marinating the anthelmintic susceptible population in *refugia* at sufficient level.

***Performance of selected lines*:** Initially, non- significant variations were observed in monthly body weights, annual GFY and reproductive performance of adult sheep belonging to R and S-line in both the breeds. During 2012-17, in comparison to initial body weight, the gains in body weight at the end of year were 7.05% in S-line and 7.59% in R-line of Malpura breed. Like-wise the annual gains in body weights were 6.67% in S-line and 7.08% in R-line of Avikalin breed. Thus, adult body weight profile showed no adverse on rate of weight gain in R-line in spite no anthelmintic intervention over the years. The mean annual GFY ranged from 0.976±0.020 kg (R-line) to 1.041±0.027 kg (S-line) in Malpura and from 1.335±0.032 kg (R-line) to 1.471±0.035 kg (S-line) in Avikalin. The overall tupping and lambing rate (on tupped basis) were slightly higher in S-line of both the breeds.

The analysis on disposal profile of sheep from divergent lines (2004-18) exhibited that overall disposal by all the means was lower in R-line of both the breeds (18.38% in Malpura, 20.39% in Avikalin) as compared to S-line (21.18% in Malpura, 24.08% in Avikalin). Among different means of disposal, maximum disposal (10.05 to 12.84%) was due to culling of animals in both the lines. The overall disposal through mortality was lower in R-line (3.94% in Malpura, 4.13% in Avikalin) as compared to S line (4.62% in Malpura, 7.81% in Avikalin). The difference in R and S line of Avikalin for mortality were significant. The disposal through mortality was lower in both the sexes in R-line as compared to S-line. It was interesting to observe that overall average age of disposal by all the means was higher in R-line (46.0±1.9 months in Malpura, 43.7±2.1 months in Avikalin) as compared to S-line (42.2±1.8 months in Malpura, 39.0±2.1 months in Avikalin), suggesting higher susceptibility and lower retention period for animals in S-line. The age- and sex-wise analysis for contribution to disposal exhibited that in totality higher proportions of animals were disposed up to 4 years of age in S-line (67.4% in Malpura, 78.2% in Avikalin) as compared to animals in R-line (58.4% in Malpura, 64.5% in Avikalin). In both the lines, the contribution of deaths in overall disposal was maximum in >24 month old animals. Like-wise, contribution of culling due to varied reasons was maximum in 24-48 month old animals. The analysis suggested lower disposal rate and prolonged retention of animals of R-line in flock even without any anthelmintic intervention.

Monitoring the level of infection in naïve and exposed animals under natural conditions: Sire-wise mean FECs in lambs born during 2011-16 revealed that naive lambs get infection from contaminated pasture in July. In the month of September the sire-wise mean FECs in naïve animals ranged from nil to 8575.0±3261.5 epg in Malpura and from 66.7±66.7 to 13640.0±4298.2 epg in Avikalin breed. The sire-wise mean FEC in exposed hoggets (November) ranged from 40.0±24.5 to 2260.0±954.3 epg in Malpura and from 16.7±16.7 to 3420.0±1918.7 in Avikalin. Over the period of five years, among selected sires of Malpura breed, the overall mean FECs for R and S lines were 1065.5±127.9 and 3219.7±423.7 epg on pre-drench stage and 273.8±31.7 and 789.6±96.6 epg on post-drench stage, respectively. For selected progenies, the mean FECs were 611.0±89.3 and 3227.0±539.4 epg on pre-drench stage and 170.2±21.3 and 1024.2±164.5 epg on post-drench stage for R and S lines, respectively revealing around 5-times higher FEC in S line compared to R line. In Avikalin breed the overall mean FECs for R and S lines were 2622.6±418.0 and 3727.6±446.3 epg on pre-drench stage and 444.4±105.7 and 553.9±109.2 epg on post-drench stage, respectively.

For selected progenies, the mean FECs remained around 3-times higher in S line compared to R line and were 1009.8±164.9 and 3728.2±604.2 epg on naïve stage and 246.0±39.4 and 911.8±194.7 epg on exposed stage for R and S lines, respectively.

***Observations for animals born from selected animals*:** In both the breeds it has been observed that progenies having inheritance of R-line possess comparatively lower FEC than those having inheritance of S-line. The ADG (0-12 month) and annual GFY remained slightly higher in progenies born from S-sire compared to those from R-sire. Likewise during 2012-17, in Malpura breed the magnitudes of ADG at 0-3 month, 3-6 month and 6-12 month were 150.22, 100.89 and 34.22 g, respectively in R-line and 158.89, 102.78 and 35.56 g, respectively in S-line. In Avikalin breed the magnitudes of ADG at 0-3 month, 3-6 month and 6-12 month were 146.33, 103.22 and 33.00 g, respectively in R-line and 150.67, 112.33 and 35.89 g respectively in S-line. The annual GFY in selected progenies ranged non-significantly from 0.932±0.043 kg (S-line) to 1.177±0.032 kg (R-line) in Malpura breed and from 1.591±0.069 kg (R-line) to 1.688±0.0573 kg (S-line) in Avikalin breed. In another study on variation in intensity of strongyle infection and growth performance in lambs (2004-14) of divergent lines (R, S and general) during their first grazing season and its contribution in pasture contamination, it was observed that the monthly mean FECs remained significantly higher in S-line (29.5±7.0 epg in July to 3939.7±227.1 epg in September) compared to other lines in Malpura breed. In Malpura breed, the analysis on variation in pasture contamination rate by a lamb exhibited that in comparison to S-lamb, R-lamb had lower contamination rate with a magnitude of >30% in all the months except in August (3.9%). Lamb of general line also had lower contamination rate (0.9% in November to 38.7% in October) compared to S-line. In Avikalin breed, R-lamb had lower contamination rate (from 17.4% in July to 43.3% in August) compared to S-lamb. Lamb of general line also had lower contamination rate (5.7% in November to 64.5% in July) compared to S-line. *T*here was non-significant variation in mean body weight at 6, 9 and 12 month of age of lambs in all the three lines of Malpura breed. However, in Avikalin breed significantly lower body weights were recorded in lambs of general line at all the stages compared to R- and S-lines. The magnitude of ADG at different stages of growth exhibited significant variation among different line only between 6-9 months of age in Malpura breed (31.1±1.2 g/day in general line to 38.5±2.3 g/day in resistant line). On the other hand in Avikalin breed, ADG remained significantly higher at 6-9 months of age in R-line (35.6±1.7 g/day) compared general line (27.1±1.9 g/ day). A non-significant variation in mean first six-monthly GFW was observed among all the divergent lines in both the breeds.

Generation level and intensity of infection in divergent lines: *It was observed that in both the breeds under natural challenge monthly intensity of strongyle infection remained at consistent level across the different generation levels on majority of occasions. Further for all the generation levels, the monthly FECs remained around 1.5 to 2-times lower in R-line compared to S-line supports heritable nature of FECs.*

Assessment of economic losses due to gastrointestinal parasitism: The estimations were made for production losses as well as for financial impact evaluation of different treatment schemes in sheep flocks by the method of partial farm budgeting. The estimated losses in sheep flocks of Rajasthan were Rs. 973.715 million / annum in adult sheep and Rs. 217.993 million / annum in yearling sheep. The cost-benefit analysis for strategic control of GIN (single drench schedule) resulted in prevention of losses to the tune of 45.53% in female and 59.00% in male sheep. The short term studies with limited numbers of animals did not give consistent results on economic losses. The economic evaluation of various schemes revealed better economic impact of TST followed by targeted approach compared to conventional drench schedule.

Observations on the effect of FecB gene inheritance on FEC in sheep: Comparatively lower incidence was observed in Garole (~ 98% *FecB* inheritance) followed by Garole x Malpura (~ 55% *FecB* inheritance) and maximum in Malpura (nil *FecB* inheritance) breed. The monthly incidence of strongyle worms ranging from 33.3% (February) to 86.0% (September) in Garole, from 40.0% (January) to 94.8% (June) in Garole x Malpura and from 59.8% (January) to 94.8% (September) in Malpura sheep. The mean monthly FECs for strongyle infection varied significantly from 70.0±17.9 (May) to 1293.0±330.4 eggs per gram (epg) (July) in Garole, from 86.7±17.6 (February) to 1203.2±174.5 epg (August) in Garole x Malpura and from 178.6±18.3 to 1868.7±211.3 epg (August) in Malpura sheep. Interaction

between *FecB* status and intensity of strongyle infection exhibited that mean FECs remained relatively at the lowest in *FecB* homozygous carrier sheep followed by *FecB* heterozygous and maximum in *FecB* homozygous non-carrier sheep. In *FecB* carrier sheep there was single peak of lower magnitude during August compared to two peaks of higher magnitude during August and October in *FecB* non-carrier sheep. The study concluded that Garole inheritance provides resistance to GI nematodes infection to some extent however, presence of *FecB* gene in Garole was not associated with intensity of infection.

Miscellaneous studies on parasites

***Incidence of Sarcocystis tenella infection in sheep*:** A total of 349 muscle samples of tongue, heart, oesophagus and diaphragm from sheep necropsied at CSWRI, Avikanagar were examined for *Sarcocystis* infection. The overall prevalence rate was 37.3%. The season, organ and age of animal had significant effect on prevalence rate. The infection was highest (46.2%) in monsoon. Heart muscles had highest prevalence (56.2%). There was positive correlation between the age of animal and prevalence rate of infection. The sex and breed had non-significant effect. The species prevalent was *S. tenella* with mean cyst size of 270.1±12.4 x 66.3±3.1 µm.

***Efficacy trials*:** Closantel was found to have 100% efficacy against both BZ-resistant and susceptible strains of *H. contortus.* However, it was observed that following treatment with closantel*, H. contortus* which constituted 38% of the larvae in pre-treatment faecal cultures reduced to nil. While, *Oesophagostomum* larval concentration increased from 62% (pre-treatment) to 96% (post-treatment). The finding has significant bearing on future epidemiology of GIN as closantel use may alter the parasite composition leading to predominance of non-haematophagus parasites in population. Closantel was also found effective against *Sarcoptes scabiei* causing 95.3 to 99.1% reduction in mite population / cm^2 of skin scrapping.

Ivermectin was found to be 100 % effective against GIN of sheep. The FEC in treated animals come down to nil on day 4 post-treatment and persisted up to day 30 post treatment. On day 21 post-treatment, slaughter of treated animals revealed absence of worms while 7750 *H. contortus* were recovered from untreated animals. Further, 1% solution of Ivomec was tested for its efficacy against natural sarcoptes mange in sheep. Among sheep 74.5% cases were recovered after first injection while 25.5% required second dose after 21 days. In rabbits infected with *Psoroptes* mites, injection of Ivomec (@0.02 ml/kg) resulted in absence of mites in scrapping by 21 days of first injection. No reoccurrence was seen up to 6 months after treatment. Moxidectin (@200µg/kg BW s/c on 0 and 10 days) was evaluated against *Sarcoptes scabiei* at SBF, Fatehpur and on day 30^{th} post treatment 93.3% animals showed complete recovery of lesions with absence of mites in skin scrapping.

***Bionomics of Oestrus ovis larvae*:** The study revealed highest prevalence in June, the pupation period was 16-28 days and life span of adult fly was 8-16 days in female and 3-8 days in male. Rafoxanide was found to be 100% effective against nasal myiasis. By a strategic approach of using Rafoxanide on the whole flock during pre-monsoon period when the nasal flies emerges to lay the bots, the disease has been reduced considerably.

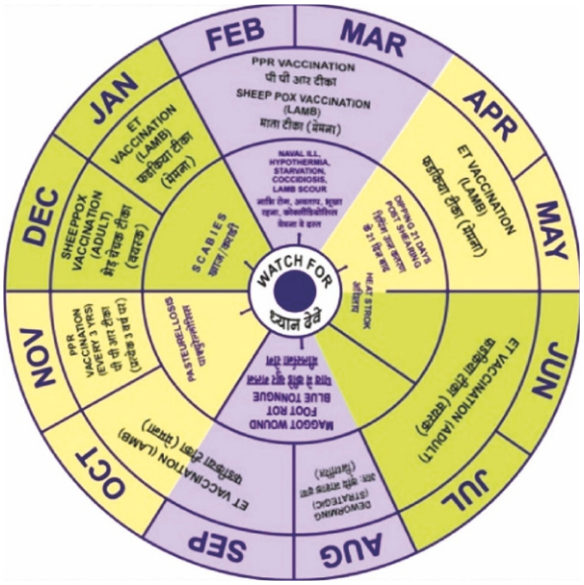
Ear mange of rabbit: Studies were conducted to observe the off host survival and infectivity of *Psoroptes cunniculi* mites in rabbits. The study revealed the survival of mites from 2 to 26 days at temperature between 2-4 and 40°C. At 8°C and above 40°C maintained for 24 hours 100% mortality was observed in mites. The time required for 50% mortality in mites (LT_{50}) ranged from 13.29 to 0.89 days for the temperature intervals between 2-4°C and 40°C. The infectivity trials revealed that mites starved up to 7 days at 2-4 °C successfully produced viable infection in rabbits but they failed to produce clinical infection in rabbits when starved for 10 days or more at this temperature. On the basis of these results it is recommended that when time permits and where disinfecting is not practical, enclosures suspected of mite contamination be vacated for at least 10 days before occupancy by clean rabbits.

Examination of faecal samples from rabbits revealed that among positive cases, the intensity of infection ranged from 100 to 91600 oocysts/g of faeces. The generic composition of Eimeria oocysts showed predominance of *E. perforans* (32.9-67.9%) followed by *E. coecicola* (11.2-29.1%), *E. media* (2.3-10.1%), *E. exigua* (0.9-8.3%), *E. magna* (0.0-29.2%), *E. piriformis* (0.0-13.0%) and *E. irrisidua* (0.0-12.0%).

Flock health and preventive medicine

The division, keeping pace with recent trends of system approach in animal health management, has developed a planned flock health programme consisting of new concepts in preventive medicine, flock health and epidemiology. The flock health programme was modified time to time based on diseases pattern in flocks and as per need. The division has developed a computer-based disease data information system (DDIS) for organized sheep and goat farms. This system provides facility of disease data collection, storage, processing and retrieval for future analysis.

***Morbidity profile in sheep*:** In general, non-specific ailments of skin and subcutaneous tissue were the highest which included mainly wound, lameness, sprain and fracture as major constituents. These were followed by condition of general systemic state (debility, pyrexia, etc), alimentary system (enteritis etc) and respiratory system (pneumonia). The specific diseases contributed to morbidity were facial mange (*Sarcoptes scabiei*), pasteurellosis, sheep pox and blue tongue. The highest morbidity rate was in hoggets followed by suckling and lowest in weaners. The diseases of skin and musculoskeletal system were recorded maximum in all age groups followed by diseases of GSS in adult and hogget and diseases of alimentary system in weaner and suckling. Sheep pox was observed only in adult flock while BT and facial mange encountered in animals >3 month of age and pasteurellosis in animals >6 month of age. There was variation in the incidence of clinical diseases between different years. The incidence of diseases of skin and musculoskeletal system, alimentary system, GIN and BT was highest in the monsoon season while diseases of GSS and respiratory system had high incidence during summer season.



***Mortality profile in sheep*:** Considering all the types of genotypes (exotic, crossbred and native) the annual EADR per 1000 animals at risk in sheep flock varied from 0.176 (6.42%) in 1989-90 to 0.817 (29.82%) in 1997 with an average of 0.350 (12.78%). The mortality in flock was high up to 1981 but following implementation of planned flock health programme it was considerably reduced except in few years. The high EADR was attributed to outbreak of sheep pox (1992-93), pasteurellosis (1994-95) and due to sudden change in feeding schedule of flocks leading to non-specific debility (1996-97). In general, the maximum EADR was due to affections of respiratory system (pneumonia, suppurative pneumonia) followed by diseases of GSS (debility, toxaemia, septicaemia, etc) and alimentary system (enteritis). Among specific diseases neonatal inanition, pasteurellosis, pregnancy toxaemia, enterotoxaemia and sheep pox were identified as a major cause of death. Age-wise maximum EADR was observed in suckling followed by hoggets and lowest in adults. Diseases of respiratory system and GSS cause maximum death in all age group followed by diseases of alimentary and hepatic system in adult and suckling, alimentary and circulatory system in weaner and hoggets. Among specific conditions in adult sheep, GIN, pregnancy toxaemia, ET, sheep pox and JD were major cause of mortality. In hoggets, pasteurellosis and GIN, while in suckling neonatal inanition and tetanus were major specific cause of death. In last decade, the EADR per 1000 sheep days at risk was 0.288 (10.51%) during 2012-17 with minimum (0.229) in non-prolific native sheep followed by 0.261 in non-prolific crossbred sheep, 0.329 in prolific crosses and maximum (0.861) in pure prolific sheep. The magnitude of EADR clearly indicates an inverse relationship between mortality rate and prolificacy rate in a genotype. The higher EADR (0.632) in 2012-13 was attributed to both the intensive reproductive practices in flocks (round the year breeding) and occurrence of *Mannhaemia haemolytica* infection in weaners. Like-wise during 2017-20, the EADR was 0.277 (10.11%) with minimum (0.249) in prolific crosses followed by 0.277 in non-prolific native,0.278 in non-prolific crosses and maximum

(0.875) in pure prolific sheep.

***Mortality profile in goats*:** Over the years (2004-2010), the annual EADR ranged from 0.076 to 0.311 per 1000 goat days at risk. The EADR was 0.149 (5.44%) and 0.107 (3.91%) during 2012-17 and 2017-20, respectively. Problem of mineral deficiency (copper) has been encountered in goat flock since 2017. The major causes of deaths were enteritis, pneumonia, hepatitis, ruminal impaction, toxaemia/septicaemia, neonatal inanition etc. Ailments of GSS (mainly toxaemia) accounted for major deaths, followed by diseases/ conditions of alimentary system, and respiratory system. The age wise mortality pattern showed higher rate in sucklings as compared to weaner, hogget and adults. Because of the strict implementation and monitoring of the prophylactic majors as per the health calendar the mortality as well as morbidity rates were within acceptable limit. Moreover, mortality rate in goat was significantly less than sheep at CSWRI farm.

***Mortality profile in rabbit*:** Mortality data from 2003 to 2011 were analysed with respect to EADR and causes of mortality in rabbits. Over the years the EADR per 1000 rabbit days at risk (excluding kits) ranged from 1.796 (2009-10) to 4.629 (2005-06). The gastroenteritis syndrome accounted for maximum mortality followed by toxaemia, pneumonia, cystitis, urolithiasis and coccidiosis. The EADR was higher in weaner and remained lower in adult. In general, male had higher EADR compared to females. Monthly mortality pattern revealed higher mortality from May to July and from November to February.

Pathology and Clinical Medicine

Necropsy and histopathology were among the initial facilities developed in the Division. This enabled better diagnosis of various diseases and their pathology. Impact of Blue tongue virus on developing foeti was recorded and studied. The histopathological lesions of Orinjya poisoning were examined and found that lesions were similar to cyanide poisoning. Recently on histopathology Tyzzer's disease in rabbit and adenoma of uterus and pulmonary carcinomatosis in sheep was investigated. The clinical pathology and biochemical laboratory facilities have been strengthened and this has facilitated investigation in metabolic and production diseases. The "Thin Ewe Syndrome" was studied but the results were inconclusive. This laboratory studied various haemato-biochemical levels of various body constitute during pneumonia and FMD. The haematology, protein profile and liver function tests indicated that debilitated animals are anaemic with low plasma protein level, supplementation with concentrate, copper, cobalt and iron gave adequate recovery. The retrospective studies on debility revealed that it was mainly associated with suppurative pneumonia, JD, GIN, wound complication and hepatitis. In sheep, the major pathological conditions diagnosed were squamous cell carcinoma, maedi (Ovine progressive pneumonia), suppurative pneumonia, pulmonary adenomatosis, Johne's disease, enterotoxaemia, pasteurellosis, pulmonary carcinomatosis, adenoma of uterus, lymphocytic and plasmacytic enteritis, pancreatic necrosis, hydronephrosis, obstructive urolithiasis, pyometritis, focal encephalitis, meningeo encephalitis, chronic granulomatous encephalitis, amyloidosis of kidneys, hepatitis and hepatic schistosomiasis in sheep. Among weak animals one case of lymphocytic leukaemia was recorded. In goat, cyanide poisoning lesions (due to orinjya feeding) like lung oedema and emphysema were recorded. The other conditions recorded were Pasteurella pneumonia, eosinophilic enteritis, lymphocytic gastroenteritis, various forms of pneumonia, fibrinous pneumo-pericarditis, myocarditis, lymphoreticular hypoplasia of lymph nodes, PPR, fibroma of renal capsule and goat pox. In last decade, on histopathology, septicaemia, acute enteritis, chronic suppurative bronchopneumonia, acute interstitial pneumonia, hepatitis, acidosis, paratuberculosis, cystic kidney and lipoma were diagnosed. In rabbit, haemorrhagic enteritis, suppurative pneumonia and other acute pneumonias were the main conditions diagnosed histopathologically. The specific conditions diagnosed were Tyzzers disease, intestinal coccidiosis, oat cell pneumonia, cholangitis, serofibrinous bronchopneumonia, haemorrhagic myocarditis, mild fibrosis of kidney, chronic nephritis, haemorrhagic and ulcerative gastritis and mucoid enteritis.

***Investigation on debility*:** The investigation indicated that 1/10th of total morbidity and 1/3rd of the total mortality was associated with debility. In morbidities, adults particularly females were more affected, followed by lambs with maximum in July. In adult females, stress factors like pregnancy, lambing, lactation, etc contributed for more debility.

Haemato-biochemically, debile animals revealed low haemoglobin and haematocrit values and lower levels of copper, zinc, manganese and low protein in serum. A retrospective analysis of debility (1985-96) revealed that the total debile deaths ranged from 8.93% (1989) to 31.57% (1991) and major conditions associated with debility were suppurative pneumonia, JD, GIN, sheep pox, wound complication and hepatitis.

***Pyelonephritis*:** It was recorded in crossbred weaner male sheep, where both the kidneys were highly enlarged with patchy congestion, ruptured surface and haemorrhage. The renal pelvis and calyces were highly dilated with fluid containing pus and *Corynebacterium pseudotuberculosis, C. renale and Proteus* spp. were isolated. *C. pseudotuberculosis* was further confirmed by PCR with amplification of *Proline imino-peptidase* (PIP), NADP oxidoreductase and Putative oligopeptide /dipeptide ABC transporter genes. Histopathologically, lesions were most severe in the medullary regions and renal pelvis was infiltrated with mononuclear inflammatory cells. This is first report of isolation of *C. pseudotuberculosis, C. renale and Proteus* spp. from cases of pyelonephritis in sheep.

Aflatoxicosis in rabbit: An outbreak of aflatoxicosis suspectedly due to consumption of infected concentrate or dam's milk was recorded in rabbits during 1989-90. Based on histopathology, other outbreaks were diagnosed during 2010-11.

Mineral deficiency in kids: Investigation was carried out for kid mortality in Sirohi flock of Avikanagar during 2016 and 2017. A total of 21 kids were reported with neurological signs like stiffness of back, extension of hind limbs at carpal joint, ataxic gait, anorexia, weakness and paresis starting at hind limb initially that progressed to forelimb and neck and lastly succumb to death. Heart revealed characteristic lesions of white areas on epicardium with thickening of myocardium. *Histopathologically,* degeneration and necrosis of subepicardial and myocardial muscles with fibroblastic proliferation in degenerated and necrotic areas was observed in heart. *In brain and spinal cord, n*euronal degeneration with foci of microglial cells in cerebrum were observed. Cerebellum had degeneration, necrosis and vacuolation in Purkinje cells. The most consistent focal lesions of chromatolysis were observed in anterior area of white matter of the spinal cord. Skeletal muscles showed degeneration and necrosis of the muscle fibers with thickening of blood vessel. Estimation showed lower concentration of Cu in serum and liver. Initially four cases were treated, unsuccessfully, with copper sulphate (@ 6mg/kg body weight diluted in 5ml of distilled water) orally for three days. Subsequently, kids were treated with copper glycinate (© Curan 9, Carevet Pharma) @60mg total doses S/C and 50% kids recovered from clinical illness.

***Rickets in lambs*:** Out of 113 lambs (3-6 months of age), 18 male lambs (15.9%) were reported with the deformities in limbs (inward or outward curvature of limb bones, stiff gait, decreased stride length) and pain. On the basis of hemato-biochemical analysis and clinical manifestation, the ailment was diagnosed as rickets. Lambs recovered well with supplementation of vitamins and minerals with phosphorus @ 5 g/head daily for about 45 days.

Urolithiasis: From August 2002 to July 2008, a total of 109 animals of different breeds died due to urinary tract diseases, involving mainly obstructive urolithiasis, cystitis, urinary bladder rupture and nephritis. The maximum occurrence (52.29%) was in weaner lambs followed by suckling (27.52%), adult (11.01%) and hoggets (9.17%). Sex-wise, highest incidence was in male (92.7%) and increased incidence had pattern from March to July (50.46%). It was attributed to inadequate potable water and imbalance in Ca:P due to less grass cover. A moderate increase in Hb, PCV, and TEC values were observed in confirmed cases of urolithiasis. Neutrophilia (56.64%) and lymphocytopenia were observed in animals that succumbed to death. Levels of creatinine and serum urea nitrogen were found to be significantly elevated in confirmed cases of urolithiasis (7.05±1.42 and 146.34±24.87mg/dl, respectively). The mineral profile of concentrate showed imbalance of calcium:phosphorus ratio and this ratio in blood varied from 1.34:1 (confirmed) to 1.83:1.0 (suspected). Magnesium content was significantly higher in suspected and confirmed cases; while alkaline phosphatase elevation in confirmed cases. Crystallization of urine can be prevented by dietary modification to induce urine acidification. Critical preventive measures such as providing a Ca: P ratio of 2:1 in the complete ration,

increasing the salt level to 4% of the diet in order to stimulate water consumption and to increase urine volume and the maintenance of adequate and abundant water supplies should be highly considered in feedlot management.

***Studies on neonatal mortality in sheep*:** The overall annual neonatal mortality was 4.92% in semi-arid region. Overall annual neonatal mortality in native, crossbred, pure prolific and prolific crosses was 3.38, 4.60, 20.61 and 7.76%, respectively. Among native sheep breeds, the agro-climatic conditions influenced neonatal mortality with significantly high (5.12%) in semi-arid compared to 1.86% in arid region. Among major breeds, it ranged from 0.67% in Marwari (arid region) to 23.08% in Avikalin (semi-arid region). Neonatal mortality was almost 3-times higher during hebdomadal phase (3.60%) compared to post-hebdomadal phase (1.32%). On retrospective study (1991 to 2014), it was observed that neonatal mortality contributed 59.3% to total pre-weaning mortality. An inverse relationship was found between age of lamb and % contribution to pre-weaning mortality. However, pattern was completely reverse in both the agroclimatic regions with maximum contribution by 0-1 day old lambs (22.6%) in semi-arid region compared to by 4-7 days old lambs (15.4%) in arid region. A significant increase in neonatal mortality (around 2-fold increase in crossbred sheep to 4-fold in mutton type native sheep) was observed on withdrawal of concentrate supplementation to ewes. On the other hand, *ad libitum* concentrate supplementation found to cause significant reduction in neonatal mortality mainly in pure prolific sheep (Garole/Kendrapada) while no evident effect in other breeds. The round the year lambing had no evident effect on neonatal mortality in pure prolific sheep. Irrespective of type of sheep, neonatal mortality was maximum due to General Systemic State affections (31.20%) followed by inanition (24.88%), respiratory system (17.72%) and alimentary system (9.86%) in semi-arid region. In arid region, neonatal mortality was maximum due to affections of respiratory system (32.57%) followed by GSS-mainly heat stroke (26.61%), alimentary system (16.97%) and tetanus (8.26%). Death due to neonatal inanition (24.88% contribution) at CSWRI and tetanus (8.26%) at ARC were major specific entities. Important factors affecting neonatal mortality deduced from this study were as follows:

- Birth weight of lamb had an inverse relationship with neonatal mortality.
- Sex of lamb had non-significant effect on overall neonatal mortality.
- Age of ewe (dam) affects neonatal mortality significantly. Neonatal mortality was significantly higher in lambs born from younger ewes (up to 2yr old) compared to those from ewes between 2-6yr of age.
- Dam's weight at lambing. Significantly high mortality occurs in lambs born from ewes with <20.0kg body weight followed ewes with body weight of 20.1-25.0kg and least in lambs born from ewes with 30.1-35.0 kg body weight.
- Parity of dam. Lambs from dams in 1st parity had more deaths and had around 1.5 to 2-times higher risk compared to those in higher parity.
- Season of lambing. Lambs born during April to July had higher risk (Odd Ratio = 2.37) of death compared to those born during August to November.
- Wind Chill Index (WCI) have positive relation with neonatal mortality.

***Other investigations on neonatal mortality in sheep*:**

- From lambs, the bacteria isolated and identified were *Acinetobacter indicus, A. calcoaceticu, Acinetobacter baumannii, Achromobacter xylosoxidans, Alcaligenes faecalis, Bacillus pumilus, Brevibacterium, Brevundimonas nejansanesis, Cronobacter, Eschericia coli, E. Fergusonii, Enterobacter aerogenes, Enterococcus, Klebsiella, Kocuria, Morganella morganii, Pantoea, Pasteurella multocida, Proteus mirabilis, Pseudomonas aeruginosa, P. stutzeri, P. fulva, Salmonella, Shigella, Staphylococcus aureus, S. epidermidis, S. hominis, S. pasteuri, Streptococcus pasteurianus and S. lutetiensi*s.
- Prevalence profile of *E. coli* serotypes with predominance of O11, O2, O26 and O120 along with 7 other serotypes (not encountered earlier) is changing over the time.
- *On antibiogram, E. coli* isolates from lambs were found resistant to *Amoxicillin, Ampicillin, Bacitracin, Chlortetracycline, Cloxacillin, Ciprofloxacin, Enrofloxacin, Ofloxacin and sensitive to* Amikacin (68%), Cefixime (60%), Ceftazidime (64%),

Imipenem (33%), Chloramphenicol (100%), Kanamycin (24%), Co-Trimoxazole (65%), Amoxyclav (25%), Gentamicin (91%) and Nitrofurantoin (91%). A total of 16 (36%) isolates were resistant to Ceftazidime.

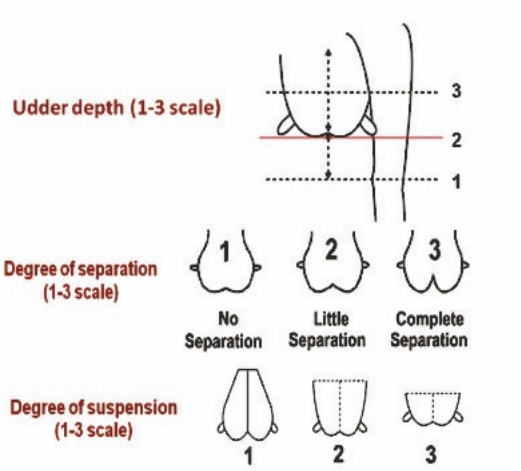
- *Staphylococcus spp. isolates* showed more than 50% resistance to methicillin (83.33%), penicillin-G (79.16%), ceftazidime (75.00%), cefixime (70.83%), cloxacillin (66.66%), enrofloxacin (62.50%), cefepime (54.16%) and streptomycin (50.00%). However, were highly sensitive (70-95%) to amoxycillin, amoxiclav, chloramphenicol, doxycycline, gentamicin, norfloxacin and moderately sensitive (50-65%) to ampicillin, bacitracin, kanamycin, ofloxacin and tetracycline.
- On AGE, no sample was found positive for the characteristic 11 bands of 11 segments of dsRNA of rota virus as visualized under gel documentation system.
- DNA samples from aborted/still born fetuses were found negative for *Brucella, Chlamydia* and *Toxoplasma* infection on PCR.
- Faecal samples from lambs affected with diarrhea were found negative for cryptosporodial infection with routine examination. However, about 33% were found for cryptosporodial infection on PCR assay.
- Incidence of *Eimeria* oocysts was 62.63-78.87% and ranged from 6.38% (0-7days old) to 80.69% (>28days old). Further, incidence was significantly higher in lambs born during Jan-Mar compared to those born in Aug-Sep.
- Milk replacer feeding in Malpura and Avikalin breed indicated a progressive increase in quantity with advancement of age and ADG remained higher resulted in faster growth after 15days in supplemented lambs. After supplementation of milk replacer for 26 days, net return was increased by Rs.23.34 per ewe over un-supplemented lambs. In prolific Avishaan sheep, the net return was increased by Rs72.63 per ewe.
- I• n Avishaan flock, during Aug-Sep, 2017 and Jan-Feb, 2018; 7-11 days old lambs exhibited clinical manifestation such as stiffness in gait, swelling of epiphyses, recumbence after 2-3 day with extension of back and limbs, abdominal respiration and death after 2-3 days. The therapeutic management of syndrome was made with Vit E and Se @0.5 ml s/c per head, once; along with mineral mixture supplementation @2-3g/head/day for 15 days. Among biochemical parameters only serum creatinine level was high on 0^{th} day in affected lambs, which return to normal after treatment. Serum copper concentration of affected group was found to be significantly low on 0^{th} and 7^{th} day but it increased on 15^{th} day. In affected lambs, manganese concentration remained significantly higher. Following institution of prophylactic supplementation of mineral mixture in healthy lambs, further occurrence of disease was not observed.

***Udder scoring and its interaction with body condition score in ewes*:** Modification of udder scoring for Indian breeds with the objective to select sheep having optimum udder score for better neonatal survival had been made. The parameters included were udder tissue content, udder depth, degree of separation, degree of suspension, teat position, teat deformity and teat size. The udder scoring was done in Avishaan and Patanwadi ewes in early lactation (within 7days of lambing). It was found that BCS of Patanwadi ewe was significantly higher as compared to Avishaan ewe. Avishaan and Patanwadi ewes differed significantly from each other in composite udder score (CUS), udder tissue content, udder depth, degree of separation, degree of suspension and teat size. The udder tissue content and teat size were significantly higher in Patanwadi ewe as compared to Avishaan ewes. However, udder depth and degree of suspension were more in Avishaan ewes. Irrespective of breeds, a significant and positive correlation existed between CUS and BCS and only udder tissue content and teat size are influenced significantly by BCS. CUS was positively correlated with udder tissue content, degree of separation, teat position and teat size. Lambs from ewes with low BCS and high CUS had maximum disposal rate (30%) than lambs from ewes with high BCS and high CUS. Further, mortality up to 15days of age is influenced by these scores and Lambs born from ewes with low score require milk replacer for better survival.

Veterinary Type Culture

In last decade, the Division has submitted more than 240 various bacterial pathogens isolated and identified from diarrhea, septicemia, pneumonia and mastitis to NCVTC, Hisar. Apart from this clone, three full length genes of

M. avium subsp. *paratuberculosis* viz. MAP02, IS1311 and IS900 genes in pTZ vector were also submitted to VTCC. The Division has received more than 80 accession numbers for bacterial pathogens consisting of *Staphylococcus* spp., *Corynebacterium* spp., *Enterococcus* spp., pathogenic *Escherichia coli*, *Bacillus* spp. *Acinetobacter* spp., *Streptococcus* spp., *Comamonas* spp., *Klebsiella* spp., *Pseudomonas* spp., *Enterobatcer* spp., *Clostridium* spp., *Achromobacter Alcaligenes* spp., *Proteus* spp. *Salmonella* spp. *Pantoea* spp., *Kocuria* spp. *Brevibacterium* spp., *Mannheimia haemolytica, Pasteurella multocida,* etc. The resistance profile of various pathogens was evaluated by antimicrobial susceptibility test and it was found that the bacterial isolates showed more than 50% resistance to major antibiotic groups. The *16s rRNA* and thermonuclease (*nuc*) gene PCR asssays specific to *S. aureus* were standardized and used to confirm the *Staphylococcus aureus* subsp. *anaerobius*.



Transfer of technology

The division has bridged the gap in application of health care technology between organized flocks and unorganized flocks in the fields. This association has resulted in lowering of mortality in field flock to less than 5%. Epidemiologic pattern of sheep and goat pox, PPR, brucellosis and parasitic gastroenteritis in the field have been studied to suggest suitable control measures through a flock health calendar. The division offers regular diagnostic facilities to farmers and this has been found to be an effective contact point between farmers and scientists in the transfer of appropriate and need based health technologies.

Animal Biotechnology

Animal Biotechnology Section was established in the Institute on May 22, 2002 with the aim to initiate and conduct the cutting-edge research in the field of sheep genomics, parasite resistance, prolificacy aspects in sheep, lustrous wool trait in Magra sheep, etc. The objectives of biotechnological research in the Institute are to characterize the native sheep breeds at molecular level with respect to the prolificacy and other reproduction traits and to identify the genes / markers linked to the economically important traits like parasitic resistance, meat production and meat quality, lustrous wool trait and other wool production parameters, milk production and diagnosis of the sheep diseases. Keeping in view of the above thrust areas, projects namely Genome analysis of sheep breeds by molecular methods, Genetic improvement of resistance to *Haemonchus contortus* in sheep, Identification of candidate gene responsible for lustre parameter in Magra Sheep and Production and multiplication of prolific sheep through embryonic stem cell and somatic cell nuclear transfer techniques were undertaken. The brief achievements made in these projects are described below:

DNA repository bank of various sheep breeds: The DNA repository bank was created for Ganjam, Kendrapara, Deccani, Nellore, Nali, Magra, Chokla, Garole, Patanwadi, Marwari, Madgyal, Kheri, Malpura, Muzaffarnagri, Jaisalmeri, Sonadi, Garole x Malpura, GMM, MGM, GMM x Patanwadi, Patanwadi x GMM, Bharat Merino, Edka, Avishaan and Avikalin breeds/strains. Approximately 4000 DNA samples has been preserved in deep freezer (-80^{0}C).

Booroola fecundity (FecB) and bone morphogenetic protein 15 (BMP-15) genes in Indian sheep breeds: It has been reported that high prolificacy in Indian Garole and Australian Booroola Merino sheep is due to a mutation (Q249R) in the bone morphogenetic protein receptor-1B (BMPR-1B), located in the region containing the *FecB* locus. Mutation in the BMPR-1B (*FecB* gene) increases the ovulation rate and litter size in sheep. *FecB* mutation in Garole, Kendrapada and Garole crosses (GM, GMM and MGM strains) was identified. A total of 191 individuals of Garole sheep were screened for the *FecB* mutation and 95.3% were found to carry *FecB* gene (119 - BB, 63 - B+, 9 - ++). In GM animals, out of 811 samples 72.7% were found to possess *FecB* gene (147-BB, 443- B+, 221- ++). Approximately 57.3% lambs (408/712) of backcross (440 GMM and 272 MGM) inheriting the *FecB* gene. Out of 138 individuals of Kendrapara sheep, 88.4% were segregating the *FecB* gene (73-BB, 49- B+, 16- ++). Out of 83 animals of Ganjam, 5 were found heterozygous for the *FecB* gene. The BMP-15 is expressed specifically in oocytes and maps to the sheep X-chromosome. The mutation in the BMP-15 gene (i.e. $FecX^G$, Galway mutation, Q239Ter) was associated with increased ovulation rate and sterility in Cambridge and Belclare sheep. Native sheep breeds were found non-carriers (FecX+/FecX+) for the BMP-15 gene mutation.

***Introduction of FecB gene into Patanwadi sheep for production of three breed cross*:** A total of 42 GMM × Patanwadi progeny were screened for *FecB* gene and 29 and 13 were found B+ and ++, respectively. In Patanwadi x GMM progeny, out of 34, 19 were B+ and 15 were non-carrier (++) for the *FecB* gene. Later on, *FecB* genotyping from progenies born out of prolific sheep project had been carried out at Animal Genetics and Breeding division.

Polymorphism in the meat production and meat quality associated genes in sheep breeds

***Polymorphism in the calpastatin gene in sheep breeds*:** Calpastatin is the specific inhibitor of the calcium-dependent proteases mu calpain (CAPN1) and m-calpan (CAPN2) and plays a regulatory role in muscle growth and tenderization of meat following slaughter. The calpastatin gene was genotyped in Deccani, Nellore, Sonadi, Malpura, Nali, Ganjam, Chokla and Garole sheep by RFLP-PCR technique. A total of 330 sheep samples were analysed for identification of the polymorphism in the calpastatin gene. The overall frequency of the M and N alleles in the population was estimated as; 0.771 and 0.229, respectively. The Nellore breed of sheep had the highest frequency of the M allele (0.899) using both the enzymes. It is indicated that Nellore sheep has the highest polymorphism in the calpastatin gene, which may be correlated as more tenderness in the meat than the other breeds of sheep.

Polymorphism in the growth hormone (GH) gene in sheep breeds: Sheep rearing in the country is mainly practiced for mutton production rather than wool production in recent years. Thus, selection of sheep for improved

growth is advantageous. Growth hormone (GH) is a polypeptide hormone which is the major regulator of growth of animals, encoded by GH gene. Growth hormone is an anabolic hormone synthesized and secreted by the somatotroph cells of the anterior lobe of the pituitary in a circadian and pulsatile manner, the pattern of which plays significant role in postnatal longitudinal growth and development, tissue growth, lactation and reproduction. Effects of GH on growth are observed in several tissues, including bone, muscle and adipose tissue. Considering the growing importance of Indian native sheep in mutton production, the investigation was undertaken to characterize the genetic polymorphism of GH gene in native sheep breeds by using the PCR-RFLP. The primer pairs used to detect the polymorphism in the GH gene in sheep breeds were GH1F and GH1R (A781G locus) and GH2F and GH2R (A1575G locus). A total of 645 animals of nine different sheep breeds belonging to different agro ecological regions were genotyped at two different loci *viz*. A781G and A1575G of GH gene using PCR-RFLP techniques. The PCR amplicons were digested with *HaeIII* restriction endonuclease and obtained DNA fragments of 366 and 56 bp for AA genotype, 422, 366 and 56 bp for AB genotype at A781G locus and 88 and 28 bp for CC genotype at A1575G locus.

Genotype and allele frequencies of GH gene across nine sheep breeds

Breed (n)	Genotype				Allele			
	Locus A781G		Locus A1575G					
	AA	AB	CC	CD	A	B	C	D
Nellore (40)	0.400	0.600	1	0	0.700	0.300	1	0
Patanwadi (40)	0.275	0.725	1	0	0.637	0.362	1	0
Sonadi (43)	0.023	0.976	1	0	0.511	0.488	1	0
Garrole (37)	0.162	0.837	1	0	0.581	0.418	1	0
BM (38)	0.078	0.921	1	0	0.539	0.460	1	0
Avikalin (154)	0.201	0.798	1	0	0.600	0.399	1	0
Chokla (42)	0.214	0.786	1	0	0.607	0.393	1	0
Magra (39)	0.051	0.949	1	0	0.526	0.474	1	0
Malpura (212)	0.061	0.093	0.97	0.03	0.530	0.469	0.98	0.02

The study had shown that a significantly high level of heterozygosity exists in native breeds and so, a substantial level of genetic variation exists at one of the investigated loci in these breeds. Furthermore, study was done to find out association of haplotypes with body weight at different ages in Avikalin and Malpura sheep. There was difference in body weights for different haplotype group. However, the effect of the genotype was not significant on body weight at different ages in both the breeds.

Polymorphism in exon 17 of diacylglycerol acyltransferase-1 (DGAT-1) gene in sheep breeds: Single nucleotide polymorphism (SNP) in diacylglycerol acyltransferase-1 (DGAT-1) gene has been associated with intramuscular fat (IMF)-mediated tenderness in sheep, heavier carcass weight and dressing yield. Deccani, Ganjam, Jaisalmeri, Magra, Mandya, Muzaffarnagri, Nali and Nellore breeds of sheep were studied for the polymorphism in the DGAT-1 gene. To amplify DGAT-1 with product size of 309 bp, forward 5'-GCATGTTCCGCCCTCTGG-3' and reverse 5-'GGAGTCCAACACCCCTGA -3' primers were used. PCR reaction was used to optimize the reactions (95^{0}C for 5 min, 35 cycles of 95^{0}C for 30 s, annealing at 60^{0}C for 30 s, 72^{0}C for 30 s, and a final extension at 72 ^{0}C for 10 min). The PCR products of 309 bp were digested with *Alu I* restriction endoneclease. The *Alu I* digested PCR fragments of 309 bp for genotype CC; fragments of 309 bp, 272 bp and 37 bp for genotype CT and fragments of 272 bp and 37 bp for genotype TT were reported. The allele C predominated in all the breeds. Since all three genotypes have been present in native sheep population. DGAT-1 gene may be used as a marker for within breed selection for mutton type sheep provided association is established between genotype and mutton quality traits.

Genotype and allele frequencies of DGAT-1 gene across sheep breeds

Breed (n)	Locus T487C Genotypes			Allele	
	CC	CT	TT	C	T
Deccani (38)	0.84	0.16	0.00	0.92	0.08
Ganjam (47)	0.99	0.02	0.00	0.99	0.01
Jaisalmeri (42)	0.57	0.36	0.07	0.75	0.25
Magra (38)	0.78	0.19	0.03	0.88	0.12
Mandya (36)	0.91	0.08	0.00	0.96	0.04
Muzaffarnagri (50)	0.76	0.20	0.04	0.86	0.14
Nali (51)	0.78	0.20	0.02	0.88	0.12
Nellore (42)	0.74	0.21	0.05	0.85	0.15

***Polymorphism in the callipyge gene in sheep breeds*:** In the world, the best documented mutation for muscle development in sheep is callipyge (CLPG), which causes a postnatal muscle hypertrophy that is restricted at the pelvic limb and loin with little or no effect on anterior skeletal muscles. Callipyge phenotype in sheep is also known as 'beautiful buttocks'. This phenotype develops only in paternal heterozygous animals (CLPG) mutant allele inherited from father and wild type allele inherited from mother. The maternal heterozygous and homozygous genotype pattern does not express the callipyge phenotype in animals. This type of non-Mendalian inheritance pattern is known as 'Polar Overdominance'.

The callipyge gene was mapped on ovine chromosome number 18 in the telomeric region within a cluster of imprinted genes. Avikalin, Bharat Merino, Chokla, Deccani, Dumba, Garole, Jaisalmeri, Kendrapada, Magra, Malpura, Mandya, Marwari, Nellore, Nali and Patanwadi were studied for the polymorphism in the CLPG gene. To amplify CLPG with product size of 426 bp, CLPG-Forward 5'-TGAAAACGTGAACCCAGAAGC-3' and CLPG-Reverse 5-' GTCCTAAATAGGTCCTCTCG -3' primers were used. Touch-down PCR method was used to optimize the reactions (94^{0}C for 5 min, 35 cycles of 95^{0}C for 30 s, touchdown annealing from 65^{0}C to 52^{0}C for 30 s (1^{0}C per cycle), 72^{0}C for 45 s, and a final extension at 72 ^{0}C for 7 min). The PCR products of 426 bp were digested with *FaqI (BsmFI)*. The *Faq*I digested PCR fragments of 395 bp and 31 bp for mutant allele G and 278 bp, 117 bp and 31 bp for wild allele A. All the samples of sheep were found monomorphic for CLPG gene and only wild allele A was detected. Thus, the Callipyge (G allele) phenotype was not present in the fifteen studied sheep breeds. The PCR product of CLPG gene was sequenced and submitted to NCBI GenBank with accession no. JN227864 and JN227865 for Malpura and Avikalin, respectively.

Polymorphism in the wool associated genes in sheep breeds

There is a major concern to reduce the fiber diameter and to improve the quality of the wool fibres through biotechnology intervention. Most important aspect is that to identify the genes and DNA polymorphism affecting the wool production and quality. Keratin proteins are the major components of hair and wool. The keratin proteins are divided into two large groups: the keratin Intermediated filament proteins (KIF) and Keratin associated proteins (KAP). In wool fibre, these are associated in highly organised fashion, the keratin IF proteins forming 8-10 nm diameter filaments embedded in a matrix of KAPs. Avikalin, Chokla, Deccani, Garole, Kendrapada, Magra, Malpura, Nellore, Nali, Patanwadi and Sonadi sheep were studied for KRT (or KIF1.2) and KAP genes. The DNA fragments were generated by the KRT 1.2 *MspI* RFLP polymorphisms were 159, 126 and 100 bp for MM genotype, 259 and 126 for NN genotype and 259, 159 and 100 bp for MN genotype. For KAP 1.3 *BsrI* RFLP polymorphisms these were 350 and 225 bp fragments for XX genotype, 309 and 225 bp for YY genotype and 350, 309 and 225 bp for XY genotype. The genotypic and allelic frequencies in the different sheep breeds were analyzed.

Genotypic and allelic frequencies at KRT 1.2 and KAP 1.3 locus in different sheep breeds

Breed (n)	KRT 1.2 locus						KAP 1.3 locus				
	Genotype			Allele			Genotype			Allele	
	MM	MN	NN	M	N	n	XX	XY	YY	X	Y
Avikalin (42)	0.62	0.38	0.00	0.81	0.19	42	0.35	0.49	0.16	0.59	0.41
Chokla (128)	0.42	0.52	0.06	0.68	0.32	50	0.12	0.31	0.57	0.27	0.73
Magra (43)	0.51	0.39	0.09	0.71	0.29	43	0.18	0.43	0.39	0.40	0.60
Malpura (40)	0.90	0.10	0.00	0.95	0.05	40	0.25	0.45	0.30	0.48	0.52
Sonadi (40)	0.75	0.20	0.05	0.85	0.15	40	0.22	0.30	0.48	0.37	0.63
Nali (41)	0.46	0.37	0.17	0.64	0.36	41	0.12	0.32	0.56	0.28	0.72
Nellore (41)	0.63	0.32	0.05	0.79	0.21	41	0.36	0.52	0.11	0.63	0.37
Garole (47)	0.40	0.43	0.17	0.62	0.38	47	0.33	0.37	0.30	051	0.49
Deccani (41)	0.80	0.17	0.02	0.89	0.11	41	0.44	0.49	0.07	0.68	0.32
Kendrapada (63)	0.64	0.35	0.02	0.81	0.19	63	0.20	0.34	0.45	0.37	0.63
Patanwadi (54)	0.65	0.26	0.09	0.78	0.22	54	0.20	0.33	0.47	0.36	0.64

The native sheep breeds exhibit variation at KRT 1.2 and KAP1.3 loci. The allele distributions of KRT 1.2 and KAP1.3 loci were observed to be in agreement with Hardy-Weinberg equilibrium (HWE) except in Sonadi, Patanwadi and Kendrapara for KAP1.3 locus, which significantly ($P<0.05$) deviates from HWE at one degree of freedom. In both KRT 1.2 and KAP 1.3 loci, Deccani and Patanwadi were distantly related (1.72 and 4.08). The carpet type breeds viz., Chokla, Nali and Magra fall in one cluster for KRT1.2 locus analysis.

Polymorphism in the reproduction associated genes in sheep breeds

***Polymorphism in the melatonin receptor gene (MTNR1A) gene in sheep breeds*:** Melatonin is monoamine that plays an important role in seasonal reproductive animals like sheep and goat. PCR-RFLP technique was used to determine the allelic frequency of the G612A and C606T (U14109) loci in the MTNR1A gene. An 824 bp fragment of the gene was amplified using the primers (forward 5-TGTGTTTGTGGTGAGCCTGG-3, reverse 5-TGGAGAGGGTTTGCGTTTA-3). The PCR products on digestion with *RsaI* revealed four cleaved sites at position 56, 323,346, and 757 bp and produced five bands of 411, 267, 67, 56 and 23 bp sizes. The cleavage site at position 323 was polymorphic. The polymorphism was caused by the presence of a cytosine (C) at position 606 of the sequence (U14109) and produced two bands of 267 and 23bp, which identified as “R allele”. The substitution of cytosine-thymine C606T caused the absence of this cleavage site and produces a single 290 bp band, and known as “r allele”. The PCR products were digested with *MnlI* and digestion evidenced seven cleavage sites at position 221, 254, 324, 560, 582, 610, and 693 bp. Site at position 324 was polymorphic. The polymorphism was caused by the presence of a guanine (G) at position 612 of the sequence (U14109) and produced two bands of 236 and 67bp, which allowed identifying the allele “M”. The substitution of guanine-adenine G612A caused the absence of this cleavage site and produce a single 303 bp band, which known as “N allele”. The remaining cleavage sites produced six bands of 221,131, 83, 36, 28 bp. The locus C606T having polymorphic site for *RsaI* restriction enzyme. The DNA polymorphic fragments present were 267 and 23bp for RR genotype, 290, 267 and 23bp for Rr genotype and 290 bp for rr genotype. Similarly, the locus G612A having polymorphic site for MnlI restriction enzyme. The DNA polymorphic fragments were 236 and 67bp for genotype MM, 303, 236 and 67bp for MN genotype and 303 bp for NN genotype. Allelic and genotyping frequencies of MNTR1A gene at locus C606T and G612A in different sheep breeds are presented in Table.

***Polymorphism in the aromatase gene in sheep breeds*:** The aromatase cytochrome P_{450} enzyme is responsible for oestrogen biosynthesis by conversion or aromatization of androgens into oestrogens. Oestrogens are imperative for reproductive development, fertility, bone growth and sexual behaviour. The key enzyme in oestrogen biosynthesis is cytochrome P_{450} aromatase (EC1.14.14.1), the protein product of CYP19 gene. The polymorphism in the CYP19 with different genotypes for this gene would be helpful in selection of animals with better production traits. The PCR

primers (forward 5'-CCAGCTACTTTCTGGGAATT-3' and reverse 5'-AATAAGGGTTTCCTCTCCACA-3') were used to amplify the CYP19 gene in nine sheep breeds viz. Avikalin, Chokla, Dumba, Garole, Magra, Malpura, Nali, Patanwadi and Sonadi and polymorphism in the Cyp19 gene at C242T locus was studied. The PCR product of Cyp19 gene was digested with the *Bsp1431* restriction enzyme. The PCR digested products revealed all three genotypes for the Cyp19 gene. Genotype AB represents three fragments, of 140, 82 and 58bp, respectively, whereas genotype BB represents only one fragments, of 140 bp. The genotype AA represents 82 and 58 bp fragments. The genotype AB was found dominant in the population of sheep breeds.

Genotype and allelic frequency of MTNR1A gene

Breed (n)	Locus C606T					Locus G612A				
	Genotype			Allele		Genotype			Allele	
	RR	Rr	rr	R	r	MM	MN	NN	M	N
Avikalin (46)	0.347	0.500	0.152	0.597	0.402	0.777	0.133	0.088	0.844	0.155
Garole (44)	0.727	0.204	0.068	0.829	0.170	0.545	0.386	0.068	0.738	0.261
Malpura (39)	0.435	0.512	0.051	0.692	0.307	0.692	0.179	0.128	0.782	0.217
Magra (43)	0.790	0.209	0.000	0.307	0.104	0.581	0.325	0.094	0.744	0.256

Genotype and allele frequencies of CYP-19 gene across sheep breeds

Breed (n)	Genotype			Allele	
	AA	AB	BB	A	B
Magra (41)	0.00	1.00	0.00	0.50	0.50
Garole (42)	0.12	0.79	0.09	0.51	0.49
Patanwadi (42)	0.00	1.00	0.00	0.50	0.50
Avikalin (42)	0.10	0.71	0.19	0.45	0.55
Malpura (41)	0.15	0.85	0.00	0.57	0.43
Chokla (43)	0.00	0.98	0.02	0.49	0.51
Dumba (43)	0.00	1.00	0.00	0.50	0.50
Sonadi (41)	0.00	0.95	0.05	0.48	0.52
Nali (20)	0.00	0.65	0.35	0.33	0.67

Polymorphism in the milk production and quality associated genes in sheep breeds

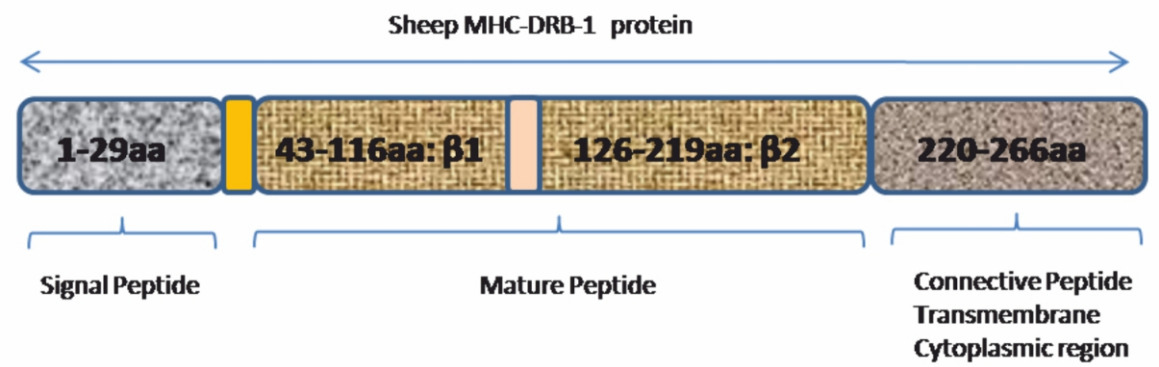
***Polymorphism in the β- lactoglobulin gene in sheep breeds*:** β-lactoglobulin (β-LG) protein encoded by (β-LG) gene is one of the major whey proteins present in ruminant's milk representing about 50% of the total protein. It is one of the several positional candidate genes which may affect milk production traits in sheep. Chokla, Deccani, Dumba, Garole, Kendrapada, Madgyal, Malpura, Nali, Patanwadi and Sonadi breeds of sheep were studied for the polymorphism in the β-LG gene. To amplify β-LG with product size of 120 bp, forward 5'-CAACTCAAGGTCCCTCTCCA-3' and reverse 5-'CTTCAGCTCCTCCACGTACA-3' primers were used. PCR condition (94^{0}C for 5 min, 35 cycles of 94^{0}C for 15 s,

Genotype and allelic frequency of β-lactoglobulin gene

Breed (n)	Genotype			Allele	
	AA	AB	BB	A	B
Chokla (43)	0.49	0.21	0.30	0.59	0.41
Deccani (41)	0.27	0.46	0.27	0.50	0.50
Dumba (43)	0.93	0.05	0.02	0.95	0.05
Garole (42)	0.40	0.43	0.17	0.62	0.38
Kendrapada (45)	0.37	0.22	0.41	0.48	0.52
Madgyal (46)	0.20	0.60	0.20	0.50	0.50
Malpura (44)	0.39	0.25	0.36	0.51	0.49
Nali (42)	0.41	0.45	0.14	0.63	0.37
Patanwadi (44)	0.29	0.24	0.47	0.41	0.59
Sonadi (42)	0.48	0.48	0.04	0.71	0.29

annealing at 60^{0}C for 30 s, 72^{0}C for 30 s, and a final extension at 72^{0}C for 10 min) was used to optimize the PCR reactions. The PCR products were digested with *Rsa I* restriction endoneclease. The Alu I digested PCR products revealed all three genotyping for the β-lactoglobulin polymorphism. The genotype AA represents three fragments of 66, 37 and 17 bp, genotype AB represents four fragments of 103, 66, 37 and 17 bp, whereas genotype BB represents only two fragments of 103 and 17 bp. Two genetic variants (A and B) and three genotypes (AB, BB and AA) were found in studied sheep breeds. Study revealed that variations exist in the Indian sheep breeds / strains at studied locus of β-LG gene and these variations may be utilized in future to study the effects of different variants on the milk production and quality traits.

Delineating genetic variations in Haemonchus contortus resistant (R) and susceptible (S) sheep developed at CSWRI: Among parasites, gastrointestinal nematodes (GIN) account for maximum morbidity and mortality and causing moderate to heavy economic losses and also increase the cost of worm control programme in sheep husbandry. Parasitic infection not only decrease the production of sheep produce (e.g. wool, meat, etc) but also increases the cost of control measures, thereby reducing the farm or flock income. Developing parasitic resistance in sheep is an alternative strategy, which not only reduce the cost of anthelmintics, but also be environment friendly as the demand of residue free animal product is increasing worldwide. There are substantial evidences for genetic variation between breed resistances to internal parasites such as *H. contortus.* The major histocompatibility complex (MHC) is one of the most gene dense regions and has been studied in different domestic animals of economic importance including sheep. Several association studies established that MHC diversity affects disease conditions. It is located on sheep chromosome 20. It is divided into three tightly linked regions termed as class I, class II and class III. MHC type II genes have been widely studied for disease resistance in different sheep breeds, particularly DRB and DRQ loci, which shown an association with disease conditions. MHC Class II genes are known to play major role in immune defence against macroparasites. The class II molecules of the MHC present fragments of predominantly exogenous antigens to CD4+ T-Lymphocytes. Polymorphism in these genes may impact on immune responses to pathogens, which may lead to a variation in disease susceptibility. Nematode resistant DRB-1 alleles have been reported in sheep. Polymorphism of MHC Ovar-DRB1 in R and S lines developed against *H. contortus* was studied to measure the association of restriction endonuclease (RE) patterns with R and S lines in Malpura and Avikalin Sheep. The Ovar-DRB1 of 296bp was amplified through nested PCR primers. In Malpura, SacI RE produced three genotypes viz; AA, AB and BB in R and S-line with frequencies of 0.36, 0.54,01 and 0.60, 0.30, 0.1 respectively. The frequency of allele 'A' (0.75) was significantly higher in S-line as compared to R-line (0.64) and the frequency of allele 'B' (0.36) was significantly higher in R-line as compared to S-line (0.25). These two alleles 'A' and 'B' may be associated with resistance/susceptibility in Malpura sheep. Furthermore, to determine DRB haplotypes, sires, dams, and selected progenies from resistant (R) and susceptible (S) sheep were genotyped. Full coding nucleotide sequences of DRB-1 and deduced amino acid sequences in were analyzed. Deduced amino acid variations in peptide binding region (β1 domain) was observed at different positions.



MHC DRB-1 gene encodes different parts of the protein region: signal, mature (β1 and β2 domains) and connecting peptide

Peptide binding region (β1 domain) involves in presentation of foreign antigens. More amino acid diversity in PBR regions may provide more interaction with enriched repertoire of foreign antigens. DRB1 transcripts in Malpura sheep selected against *Haemonchus contortus* parasite was analyzed for association between DRB alleles and worm burden measured as egg per gram (EPG). Neutral mutation hypothesis explained the nucleotide polymorphism of Ovar-DRB1 in Malpura sheep. Codon positions which undergone positive selection were mostly in peptide binding region (PBR) of β1 domain.

Intergroup comparison revealed that R line sheep have better positive selection evidence as compared to S line sheep. Since association between fecal egg count (FEC) level and Ovar-DRB-1 alleles was not established in Malpura sheep under study. It seems that multiple alleles at Ovar- DRB-1 locus have similar effect on FEC values. However, a unique amino acid substitution at position 103 of DRB1 locus has been identified in Avikalin sheep where R line sheep have Glu/Asn (E/N) and S line sheep have Ala (A). The elevated expressions of the few genes in the sheep tissues of genetically resistant and susceptible sheep have been identified. Challenge study in R and S sheep was undertaken to assess the resistance against *H. contortus* under artificial challenge condition. Animals (6 R, 6 S, males 6-11 months age) were artificially challenged with a single dose of 10000 infective larvae of *H. contortus*. Study (70 days pi) concluded that animals selected for resistance can tolerate parasite challenge effectively with reduced intensity of infection, higher body weight gain and reduced pathogenic effect. Results of challenge study demonstrated wide variations in expression of immune genes. Results had shown that the expression of IFN-γ, TLR-4, IL-12β and IL-18 was significantly ($p<0.05$) up-regulated in R-line sheep as compared to S-line sheep whereas IRF-3 and MHC-DQB was significantly ($p<0.05$) down-regulated in R-line sheep as compared to S-line sheep.

Production and multiplication of prolific sheep through embryonic stem cell and in vitro fertilization (IVF)

In vitro fertilization trials were conducted using slaughter derived sheep ovaries. Good quality oocytes were processed for in vitro maturation. IVF was conducted with Dumba and Malpura fresh semen. The cleavage rate was ranged from 30-35 %. Further, *in vitro* derived embryos (Avishaan, *FecB*$^{B+}$) were flushed for isolation and establishment of embryonic stem cells (ESCs). Additionally, granulose cells from prolific and non-prolific sheep were cultured. Real time transcript expression analysis in cultured granulose cells of both (prolific and non-prolific) groups was done. It was observed that expression of BMP-2 transcript was down-regulated in prolific sheep as compared to monotocus lamb bearing Malpura sheep. Furthermore, expression of BMP-15, TGFβR1, BMPR-1B, GDF-5 and GDF-9 was significantly ($P \leq 0.05$) up-regulated in *FecB* carrier GMM ewes as compared to *FecB* non-carrier ewes. Full coding region of BMPR1B gene from prolific and non-prolific GMM sheep was sequence characterized.

Identification of genetic and non-genetic parameters for lustrous wool trait in Magra sheep

Magra sheep in the adjoining Bikaner district of Rajasthan are yielding high quality lustrous fleece suitable for high quality carpet manufacturing. Luster is not a discrete phenomenon but a continuous gradation was observed in Magra sheep reared in similar climatic condition. A survey was undertaken in the adjoining region of Bikaner (Uttarada region) and wool, blood; wool follicles samples from Magra sheep and soil and vegetation samples from that region were collected. Results of the study conducted are summarized below in brief.

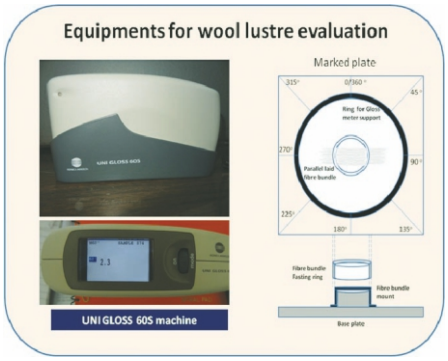
Estimating non-genetic factor (s) responsible for lustrous wool trait: Wool lustre is not only breed specific attributes but may also be affected by kind of vegetation and preference of edible species available/ consumed which varies from region to region. Detailed analysis of vegetation samples revealed significantly higher content of Cu, Fe, Mg, Mn and P in lustrous wool producing region as compared to non-lustrous wool producing region. In contrast significantly higher content of Ca and Co was observed in non-lustrous wool producing region as compared to lustrous wool producing region. Soil pH content of all the locations studied was alkaline ranging from 8.5 to 8.72.

Wool sample analysis revealed significantly higher contents of copper (1.27 vs 0.91 ppm; $P>0.008$) as well as Zinc (12.90 vs 7.33 ppm; $P \leq 0.000$) under field condition (Uttarada region) as compared to ARC Bikaner farm.

Mineral profile of soils of Uttrada region of Bikaner, Rajasthan

Area/ Location	EC Ds^{-m}	pH	Organic Carbon (%)	P_2O_5 Kg/ha	K_2O Kg/ha	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	S (ppm)
Average	**0.538**	**8.583**	**0.108**	**45.414**	**272.103**	**3.867**	**0.162**	**0.055**	**2.476**	**9.114**
Banderwali	0.520	8.604	0.114	46.400	293.800	0.820	0.162	0.048	2.178	8.756
Barju	0.760	8.720	0.120	50.200	309.600	3.356	0.514	0.120	2.860	8.362
Swainsar	0.520	8.646	0.108	47.400	290.400	2.040	0.098	0.048	3.236	9.786
Kela	0.500	8.588	0.108	35.400	198.800	12.600	0.036	0.036	2.384	8.756
Dhirera	0.475	8.498	0.113	48.500	272.500	2.500	0.000	0.025	2.975	10.358
SEM	0.005	0.005	0.002	0.284	0.001	0.378	0.007	0.002	0.029	0.055
P	0.007	0.022	0.961	0.056	0.012	0.587	0.000	0.048	0.000	0.450

Evaluation of wool lustre: Luster for a fiber/fabric system is a phenomenon to the reflectance of incident light to the surface, addressed as its shine or gloss. Wool quality is dependent upon kind of wool available in the region that affects wool pricing and its utility. Magra wool samples of ARC, Bikaner representing the animals of breeding tract of Magra sheep i.e., north western region of Bikaner having average fibre diameter of 34.07µm with medullation 50.83%. Wool samples of all three clips viz March clip (white wool); July (Asadh) clip and October Clip from same animals of Magra flock of ARC Bikaner were collected and subjectively evaluated as well as for their whiteness index. Samples of each group viz. Lustrous, medium lustre and low lustre group in subjective evaluation are considered to show the relative differences. It was observed that lustrous wools which had fibre diameter exceeding the ideal limit of 30-40µ has been rated to higher lustre grades and also observed to higher value for whiteness index (L*) with similar proportion of medullated fibres. This may infer that lustrous property of wool may be inherent genetic property of sheep breed/ strain and independent to wool fibre diameter and proportion of medullated fibres in medium coarse carpet grade wools. The average whiteness index (L*) observed was similar to the evaluation of observers for subjective assessment for lustre. While medium lustrous wool samples were observed to lower L*. Thus, the hypothesis of white ness index (L*) to be an attribute of wool lustre is not found correct. Since the luster is independent of color, it seems whiteness index is not suitable index for luster investigation. It is better used an index (luminance) that expressed the surface physical properties and surface luster. The estimation of surface shines of multiple curved surfaces of crimped wool fibers was explored in terms of gloss 60° values on gloss meter. The methodology for the wool sample preparation and its mounting on developed platform was standardized for luster measurement using gloss meter.

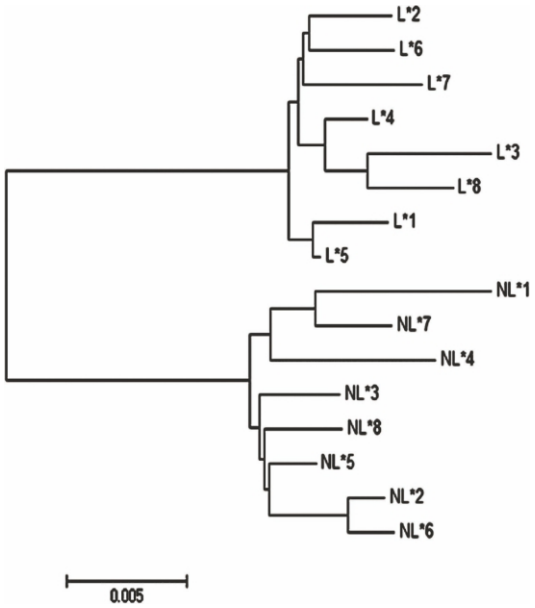


Gloss meter (UNI GLOSS 60S machine) used for objective evaluation of wool luster and schematics of developed mounting platform for wool sample analysis using Gloss meter

Wool samples of different grades/sheep breed viz. Carpet- Magra, Chokla and New Zealand, Apparel- Bharat Merino and Coarse -Malpura breed were used for optimization and development of standard The average Gloss 60° values for Malpura, Magra, Chokla, Bharat Merino and New Zealand wool was 2.30, 2.71, 2.43, 2.76, and 2.88, respectively. The differences in Gloss 60° values of different wool were found significantly ($P < 0.01$) different. The measured Gloss values had shown a good relation ($R = 0.78$) with subjectively assessed luster rank.

Analysis of putative gene (s) responsible for luster phenotype: Wool is made up of proteins and genes governing their expression in wool follicles determine the characteristics of wool fibre. Wool fibres consist of three major structural components: the cuticle, the cortex and the central medulla. Approximately 90% of the cortical cells contain longitudinally arrayed keratin intermediate filaments (IFs), consisting of keratin (K) proteins. These filaments have an

amorphous matrix surrounding them, which contains the keratin-associated proteins (KAPs), which cross-link with the IFs through extensive disulphide bonding. In wool follicles, there are type I and type II KIFs affecting structure and functions of wool follicles. These type I (acidic) and type II (neutral to basic) keratin intermediate filament proteins form intermediate filaments, which are the major structural component of wool fibrils. The major keratin type I (K31, K32, K33A, K33B, K34, K35, K36, K38, K39 and K40) and keratin type II (K81, K82, K83, K84, K85, K86 and K87) genes are expressed in wool follicles which form cuticle, cortical tissue and medulla of wool fibres. The type I trichocyte keratin genes (k31 to K40) expressed within the cortex and cuticle of wool fibre. Transcripts of K40, K82 and K84 genes were only located in fibre cuticle while K32, K35 and K85 were expressed in both the cuticles and the fibre cortex. The K31, K33A, K33B, K34, K36, K38, K39, K81, K83, K86 and K87 were expressed only in the wool cortex. KAPs are a complex class of proteins and typically possess high cysteine content. The KAPs have been classified into three broad groups according to their amino acid composition: the high sulphur (HS; _30 mol% cysteine), the ultra-high sulphur (UHS; >30 mol% cysteine) and the high glycine-tyrosine (HGT; 35–60 mol% glycine and tyrosine) groups. It is assumed that the genetic markers responsible for wool quality are mainly the keratin and its associated genes. Polymorphism at the keratin loci (Keratin intermediate filament, keratin associated proteins) is responsible for observed variation in the wool characteristics and impact on wool quality. The genetic variations in different loci of Keratin, KAPs and trichohyalin (THH) genes were studied by PCR-RFLP, quantitative PCR and nucleotide sequencing methods in lustrous Magra sheep. PCR-RFLPanalysis of the THH gene revealed that AA genotype was predominating than the AB genotype and homozygous BB genotype was not reported. Allele A was most occupied in Magra lustrous animals. Furthermore, Single Nucleotide Polymorphism (SNPs) among KRT 2.10 gene sequences of Magra sheep was analysed. Two evolutionary lineages have been observed representing lustrous and non-lustrous Magra sheep.



Evolutionary relationships of KRT 2.10 partial sequences of Magra sheep

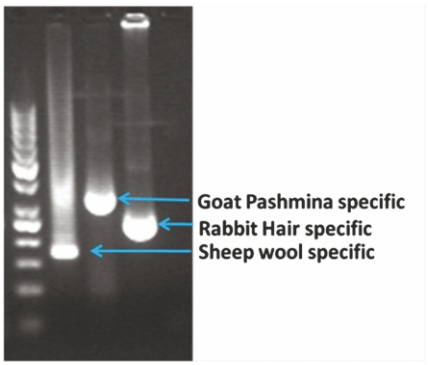
The PCR amplification and nucleotide sequencing of KAP 6, 7 and 8 genes from lustrous Magra sheep revealed 4, 31 and 7 SNPs in KAP 6, 7 and 8 genes, respectively. In KAP 6 gene frequent occurring SNPs were located in promoter (c. -329 T>C), 5'-UTR (c. -8 C>G) and 3'-UTR (c.*69 C>G). In KAP 7 gene, frequent occurring SNPs were located in open reading frame (c.173 G>A) which leads to an amino acids change (S58N) and in 3'-UTR (c.*112 C>T; c.*136 G>T; c.*142 A>G; c.*294 G>A and c.*310 A>G). Similarly, in KAP 8 gene frequent occurring SNPs were located in 5'-UTR (c. -208 C>G; c. -65 C>T) and in open reading frame (c. 100 T>A) which leads to an amino acid change (Y34N). It is evident from result that most of these SNPs were located to 5' and 3' un-translated regions (UTRs) of gene. The 5'- and 3 -UTRs play important roles in post-transcriptional regulation of gene expression may affect its expression potential and hence lustre of wool. Further, K33 transcripts from lustrous Magra sheep has been sequence characterized. Seventeen mis-sense variations were observed in Magra K33 sequences, out of which twelve variations are not reported earlier. Protein phosphorylation is an important player in mechanistic regulation of intermediate filament structure and function. Predicted sites in the Magra K33 protein sequences indicated that Ser (S), Thr (T) and Tyr (Y) amino acids have above threshold phosphorylation potential.

Most interestingly almost all mis-sense mutations observed in Magra K33 gene falls in these amino acids. However functional characterization at protein level gives true picture of possible role of these amino acid variations in regulation of K33 structure and functions in lustrous Magra sheep.

Real Time PCR (qPCR) analysis of transcript variability in wool follicles of lustrous and non-lustrous wool producing Magra sheep: Over expression of some of the keratins to transgenic sheep enhanced the overall luster of the wool produced from them. In order to find out gene expression profile of KAP and Keratin genes in lustrous Magra sheep, wool follicles were collected in RNA stabilization solution and processed for RNA extraction and cDNA synthesis. Gene specific primers were designed and synthesized for study of major keratin and keratin associated proteins expressed in wool follicles. The qPCR data were analyzed for fold expression in wool follicles. Ct values obtained in triplicates were used for analysis and GAPDH gene was used for normalization of expression of transcripts. Student t-test was used to find out significant ($P \leq 0.05$) differences between mean values of normalized Ct values of transcript levels in two groups viz. low and high lustrous Magra sheep. Observed results revealed that type 1 hair cortex keratin K33A (K1.2) was significantly ($p \leq 0.05$) up-regulated in lustrous wool however other genes were down regulated in wool follicles collected from one season. Furthermore, to know the seasonal variations in gene expression among the three season clips, wool follicles were randomly collected from Magra sheep after grading them in lustrous and non-lustrous by Gloss 60 measurement. Overall result of transcript expression had shown up-regulated expression of keratin genes in lustrous sheep as compared to none (low)-lustrous Magra sheep in all three seasons. It was speculated that luster phenotype is influenced by many genes. Most probably by some kind of trigger point in cellular pathway of wool follicle which up regulates the expression of keratin family of genes.

Development of PCR-based diagnostic tests for detection of wool and meat samples

The DNA test is the most reliable and accurate method of species identification and is using in many fields. DNA of each species is different and have many species-specific signature nucleotide sequences caused due to mutations. The principle of DNA identification in post genomic era is based on Polymerase Chain Reaction (PCR) technique. The present invention is related to the extraction of high-quality DNA from textile materials and species-specific identification of goat and sheep origin fibers by qualitative PCR based method. Later on, species-specific identification of rabbit hairs using PCR techniques have also been developed. This test will be useful to identify the Pashmina fiber from the processed wool/textile and also helpful to analyse the extent of the sheep wool adulteration in the Pashmina products. In this invention, quality DNA was extracted from textiles by modified partial digestion with proteinase K and followed by phenol chloroform extraction method. DNA was further purified with silica-based column. PCR-amplification of sheep and goat specific DNA was done using sheep and goat specific primers. Specificity of PCR was checked with DNA extracted from other textile fibers like Angora rabbit, silk etc. No amplification was found from these animal fibers, which have shown the specificity of the technique. Sensitivity of this PCR method was judged by admixing of known amount of DNA from pure animal fibers. Different combinations of DNA mixture consisting of sheep wool, rabbit fibre and Pashmina fiber were made and minimum detection limit was determined as ~10 %. This technology had yielded first patent (no 340284) from CSWRI, Avikanagar. Protocol developed was adopted by Bureau of Indian Standard (BIS) for identification and labelling of Pashmina products from textile.



PCR-based identification of Pashmina from textile materials containing sheep goat and rabbit origin fibres: Lane 1-50 bp DNA ladder; lane 2-sheep wool specific PCR band; lane 3-Goat Pashmina specific PCR band; Lane 4-Rabbit hair specific PCR band; lane 5: non-template PCR control.

PCR test has been developed for qualitative differentiation among ovine (*Ovis aries*), caprine (*Capra hircus*) and bovine (*Bos indicus*) origin of meat mixture. Novel primers for detection of bovine origin meat were designed targeting mitochondrial D-loop region. Different sizes of the species-specific PCR products were separated by agarose gel electrophoresis for all species identification. Sensitivity of the bovine specific primers was tested with two fold serial dilutions of genomic DNA. Amplification could be achieved with 20 ng of genomic DNA. Specificity of the developed test was cross tested with DNA of sheep, goat and buffalo, wher amplification was not observed. This test can be handy for accurate identification of three meat animal species which will help in preventing mislabelling and fraudulent substitution of meat and meat product for economic gain.

Livestock Products Technology

The research in the areas of meat science in the institute was initiated in the early 70's on carcass evaluation of lambs of native sheep and their crosses (Malpua, Sonadi, Dorset x Malpura, Suffolk x Malpura, Dorset x Sonadi, and Suffolk x Sonadi) under the feedlot system to evolve a mutton breed with 30kg body weight at 6 months of age. Similarly, All India Coordinated Research Project (AICRP) on Goat for Meat was started from 1976 with an object to evolve a new breed of goat suitable for Rajasthan to attain a body weight of 25kg at 6 months of age. Carcass composition of Sirohi, Beetal, Beetal x Sirohi, Jakhrana, Kutchi and Marwari goats on different nutrition and management was evaluated. Until 1985, most of the research in meat science was conducted to evaluate the carcasses of sheep and goats maintained under different management, native sheep and goats and their crosses and effect of nutrition on feedlots. In 1985, a separate Meat Science Section was started with the specific objective to take up the study on meat technology and utilization of meat and meat by-products. In addition to carcass studies of sheep and goats, carcass composition of different broiler rabbits (Soviet Chinchilla, Grey Giant), was started in 1986.

In early 70's, most the research was confined to standardisation of slaughter and estimation of meat to bone ratio, empty live weights, proximate composition, fat from various fat depos, meat tenderness, electrical stunning etc. Until 1985, to understand carcass traits of sheep, goats and rabbits, utilize meat from cull animals, in meat products, utilize day old meat of pelt lamb, utilize muscle of dead animals and blood of slaughtered animals in ruminant and rabbit rations and processing of slaughterhouse offal's like intestine and fats. In 1983, Avimaans strain of sheep for meat production was evolved from crossbreeding of Malpura and Sonadi with Dorset and Suffolk rams. Carcass traits of germplasm was studied and slaughter at 4.0-4.5 months of age weighing 25kg body weights was found ideal for meat traits.

The name of Meat Science Section was changed to Meat Science and Pelt technology in 1998-99 to take up the research on rabbit fur processing and value-added products. In 1997-98, First time sheep meat products like nuggets and patties from sheep, goats and rabbits were prepared and evaluated in the institute. Again in 2015-16, the name of Meat Science and Pelt Technology changed to Livestock Products Technology (LPT) to strengthen research on carcass evaluation of sheep, goat and rabbits and value addition of not on meat but also milk and other produce. Regular preparation and selling of ready to eat and heat and serve healthy meat products started from the year 2006-07 to consumers. First time research on sheep milk processing and products (cheese, paneer, sweets etc.) development was started in the year 2014-15. Since then, further research was strengthened to improve the quality of sheep meat and milk products especially on development of diversified and functional meat products with low in fat and salt and rich in fibre contents.

In the livestock products Technology Section apart from sheep meat, section also focused the research on rabbit carcass and value addition to rabbit meat and skin. Several feedlot experiments were carried out in rabbits to analyse their carcass traits and meat quality and different type of meat products like nuggets, soup, sausage, pickle, etc. were also prepared. Rabbit skin was converted to fur to develop various handicraft items. Detailed compositional analysis was carried out in sheep milk and various value-added sheep milk products (Kulfi, Peda, Panner, Cheese, Gulab jamun, etc.) were developed. Section is mainly carried out research on two aspects viz., carcass evaluation of different species (sheep, goat and rabbits) and development of value-added convenience milk and meat products.

Carcass traits and meat quality of sheep, goats and rabbits under different feeding regimes/treatments

A series of experiments have been conducted over the last 60 year to evaluate the carcass traits of sheep, goats and rabbits under different feeding protocols. Similarly, the new strain developed from cross breeding of native sheep with exotic one was also evaluated in term of carcass yield and quality attributes.

Suffolk and Dorset sheep breeds were imported for crossbreeding with native sheep to develop mutton sheep for enhancing mutton production in the country. Among the halfbreds, the Suffolk × Malpura yielded heaviest carcasses followed by Suffolk × Sonadi, Dorset × Malpura and Dorset × Sonadi in the descending order. Half breds were 4.49 to 32.25% superior over their respective natives. Dressing percentage based on empty live weight of Dorset × Sonadi (F2) and Karakul × Sonadi was significantly higher than that of Suffolk crosses with Sonadi and Malpura. On empty body weight basis halfbreds were superior to Malpura but not different from Sonadi lambs. Sensory attributes of meat from Malpura, Dorset × Sonadi and Dorset x Malpura revealed that overall scores were higher for meat obtained from Malpura lambs. Mutton synthetic, Malpura selected and Malpura control groups attained 25kg body weight almost on similar days. At 30kg slaughter weight, lean and bone portions decreased and fat increased compared to carcass at 25kg slaughter weights.

The growth performance of Bharat Merino lambs during 3-6months was better under intensive feeding than grazing with supplementation. Further, the finisher lambs raised on both the feeding protocol provided carcass of acceptable quality. The dressing yield and cut ability of standard cuts were comparable in Awassi × Malpura half bred and Malpura lambs. Carcass and meat quality of Garole was similar to Malpura and their crossbreds. Pre-slaughter weight was higher in Malpura hoggets as compared to Garole. However, the dressing percentage on live weight basis was higher in Malpura × Garole than Malpura and Garole. In Avikalin, Chokla synthetic, Malpura and Garole × Malpura (GM) of 3, 6, 9 and 12months of age maintained under grazing with concentrate supplementation revealed that pre-slaughter weight was similar in Avikalin, Chokla synthetic and Malpura while it was considerably lower in GM. Tenderness of meat decreased and intramuscular fat increased with increase in carcass weight of older lambs.

Carcass characteristics of new developed strain A (GMM × Patanwadi) exhibited that average pre-slaughter weight, dressing on ELW, loin eye area, caul fat and kidney fat was 43.69kg, 53.65%, 16.49cm^2, 0.28kg and 0.14kg, respectively. Average lean, fat and bone content in carcass were 56.87, 9.04 and 29.59%, respectively. Meat: bone and lean: fat ratio was 1.94 and 7.06, respectively. Water holding capacity was 25.28% while cooking losses and drip losses were 15.37 and 6.76%, respectively. Shear force value as measure of tenderness was 4.14 kg/cm^2. GMM × Patanwadi (A genotype) genotype is more suitable than Patanwadi × GMM (B genotype) for mutton production due to higher body weight and thereby more meat yield. However, the dressing yield, lean and fat contents and other quality attributes of both the genotype remained similar. Growth performance of finisher lambs was better under cafeteria system of feeding management than grazing with 1.5 or 2.5% of body weight of concentrate supplementation. Under cafeteria system of feeding management, the feed conversion efficiency improved while carcass fat content remained well within limit of 9%.

Ad-libitum concentrate feeding in cafeteria system of feeding management provided carcass of desired quality thus rendering the production system suitable for commercial application. Carcass yield and dressing percentage were higher in lambs maintained under grazing with supplementation and intensive feeding than extensive range management. The carcass separable fat content was 8% under extensive range management while it was 12% and 16% in semi-intensive and intensive system of management, respectively indicating that the carcass was of acceptable quality. About 15% fat and 2.2 mm back fat thickness are considered optimum for better keeping and eating quality. Intensively fed younger lambs deposited more fat in their carcasses at younger age. Carcass characteristics and meat quality attributes of defaunated, refaunated and control finisher Malpura lambs was similar, however comparatively higher bone and fat contents of defaunated lambs indicated their higher gain was primarily in terms of undesirable tissue like bone and fat accretion.

The dietary supplementation of sodium bicarbonate in high concentrate diets did not exert much influence on carcass and meat quality characteristics. However, the dressing yield improved and total separable carcass fat was

reduced by supplementing buffer to high concentrate fed lambs. The lambs receiving higher energy under heat exposure had higher dressing yield and muscle growth and optimum carcass fat content, and those lambs fed adequate energy provided carcasses of desired characteristics even under heat exposure. Replacing the maize with animal food grade damaged wheat at 25, 50, 75 and 100% in the ration did not affect the carcass characteristics and saleable meat yields. Pre-slaughter weights, empty live weights, hot carcass weights and dressing yield on ELW of spent ewes fed concentrate mixture @2.5% of BW containing urea and molasses were 33.84, 28.82 and 15.53 kg and 53.77% and not adversely affected by incorporating urea in concentrate mixture.

Carcass traits of Malpura weaner lambs (6-month-old) maintained on complete feed containing microbial feed additives under intensive feeding were evaluated. The carcasses of lambs supplemented with *Saccharomyces cerevisiae* and *Lactobacilli* were found better than the control. S. cerevisiae supplementation alone has no beneficial effect on meat yield and quality. The supplementation of microbial probiotics (*S. cerevisiae* and *Lactobacilli*) in the ration of lambs provided additional body weight of 3.32kg and hot carcass weights of 3.16kg. Dressing yield on ELW was improved from 56.24 to 59.30%. The finisher lambs maintained on grazing and ad libitum concentrate mixture feeding and slaughtered at 6 months of age provided hot carcass weight of 14-15kg with dressing yield of 50-51%. Average lean, fat (subcutaneous and intra muscular fat) and bone contents of different parts of the carcass (leg, loin, rack, neck and shank and shoulder and breast) were 50-54, 18-20 and 21-22%, respectively. The fat content of carcass was found to be on higher side than standard norms of 13-14%.

Malpura lambs maintained under stall feeding and supplemented with different level of fat (0, 2.5, 5.0 and 7.5%) and slaughtered at 6month of age showed that the carcasses of lambs supplemented with 5% fat were better than the control and 2.5% and 7.5% level of fat supplementation however, with non-significant differences. Hence, it was concluded that there was no difference of fat supplementation in male lambs as far as carcass characteristic is concerned. Supplementation of rumen protected fat at 4.0% level in cull ewe's diet increased pre-slaughter weights and carcass yield but did not improve meat quality. Spent sheep on an average produced carcass weight of 8.86 kg with dressing yield of 50.25%. The carcass contained 57.94% lean, 11.20% fat (subcutaneous and intra muscular fat) and 33.36% bone. Spent sheep meat contained higher proportion of bone and less of fat and lean and poorly accepted by the consumers due to toughness of muscle fibre. Carcass characteristics of spent ewes of BCS (body condition score) 3.0 to 3.5 yielded quality carcasses with desirable lean and fat contents. Further, BCS system could be used for estimating carcass traits of sheep without slaughtering of animals. Spent sheep maintained on grazing and supplemented concentrate mixture at the rate of 2.5% of BW or ad libitum were slaughtered at 45, 70 and 90 days of fattening. The study indicated that 90 days of feeding increased the carcass yield and desirable composition in term of lean, bone and fat contents over 45 or 70 days but its economic viability is to be assessed.

Urea and molasses can be used in the feeds of spent sheep without any adverse effect on meat yield and quality. The supplementation of lambs with 2 or 4 % levels of rumen protected fat did not improve the carcass quality and composition in 3month old Malpura lambs. Supplementation of 4% rumen protected fat in lamb's diet improved pre-slaughter weight, lean yield but did not improve meat quality significantly.

Carcass traits and meat quality of Malpura ewes fed overnight with ad libitum 70% roughage (*Cenchrus ciliaris*) and 30% concentrate was studied under simulated natural heat stress condition (38˚C at 10:00h; 40˚C at 11:00 h; 42˚C at 12:00h; 43˚C at 13:00h; 44˚C at 14:00h and 42˚C at 15:00h in the chamber for 30 days) revealed that thermal stress did not affect carcass characteristics and meat quality. Restricted feeding (25% less than the requirement) followed by re-alimentation didn’t have any effect on carcass yield and traits of Chokla rams. Probiotics supplementation to enhance growth during post weaning stage in Malpura lambs indicated no added advantages on carcass traits and meat quality.

Meat tenderness is important meat quality attribute. Meat from cull sheep is very tough. To improve its tenderness locally available *Cucumistrigonus Roxb* (Kachri) powder and papain was used. After several combinations, 2.5% Kachri powder found suitable for tenderization of tough meat from cull/spent sheep. The body condition and carcass characteristics of cull Malpura ewes were significantly improved by feeding complete feed block made up of non- protein nitrogen and rumen bypass protein and fat. An experiment was conducted to establish the effect of nutritional stress on carcass traits of Malpura ewes. In one treatment ewes were fed as per the NRC recommendation for maintenance while in another group ewes were fed 30% less than NRC recommendation for 30 days and study revealed that nutritional stress did not affect carcass characteristics of Malpura ewes. Malpura lambs (3-6 months) were supplemented with rumen bypass full fat soybean and 6% Rumen bypass fat, respectively and the trial showed comparable carcass traits and meat quality in both groups. In another experiment lambs of Malpura breed (3-6 months) in 3 groups were supplemented with ad libitum concentrate and pala leaves, 10% crushed linseed and group 5% Rumen bypass fat, respectively. Study indicated that linseed and RBF feeding to lambs improved live weight and tenderness and could be useful to alter the fatty acid profile of the meat to improve health benefits.

Supplemented with concentrate mixture with or without rumen protected fat (5% level) and a basal roughage diet of silage (Oat 75% + Ardu 25%) with ad libitum concentrate mixture in Garole × Malpura × Malpura (GMM) cross prolific lambs (3-6 months) showed comparable carcass traits in both groups. Study on carcass traits of Dumba × Malpura (DXM) and Malpura lambs revealed that for 12kg carcass weight D × M cross and Malpura lambs took 179 and 194days, respectively. The effects of Azolla supplementation on carcass traits and meat quality of lambs revealed that azolla could be used to replace concentrate mix up to 5% without affecting growth and meat yield and quality. Carcass traits of Kendrapada sheep at 2 and 3yr of age indicated that the meat of Kendrapara sheep slaughtered at 2yr of age is more tender meat and lean than at 3yr of age. Feeding of Malpura lambs (3-6months) with complete feed block of saunf (aniseed) straw and eucalyptus leaves reflected lower loin eye area and chilling loss in eucalyptus leaves fed group while other quality parameters for meat and nuggets were comparable.

Study on the carcass traits of Malpura sheep at variable age (6, 7.5, 8.8, 13.4 and 90.9 months) showed that the age had significant effect on carcass traits. Slaughtering of Malpura ram lambs above 20kg of live weights resulted higher dressing-out percentage and desirable meat quality than ram lambs slaughtered at less than 20kg live weight. The Desirable carcass traits were found in Patanwadi (6 and 9 months) and Avishaan lambs (5 months). Intensive rearing system along with strategic grazing has beneficial effect on carcass traits in finisher Malpura lambs. Carcass traits of cull Malpura ewes were significantly affected by feeding complete feed block made up of Cenchurus, Crotolaria, Blepharis and Methi straw. Dietary inclusion of curry leaves and lemon grass didn't have any adverse effect on carcass traits in finisher Malpura lambs. Feeding of complete feed blocks containing guar (*Cyamopsis teteragonoloba*), urd (*vigna mungo*) straw, Anjan tree (*Hardwickia binata*) leaves, ardu (*Ailanthus excels*) and syrus (*Albizia lebbeck*) leaves and moringa, mulberry leaves and stylosanthus in the diet of Malpura lambs up to 6 months of age produced 34-35kg animal weight with desirable carcass lean, fat and bone content. However, toughness was increased in the lambs maintained on Anjan tree. Lipid oxidation was reported lower with diet of mulberry leaves in meat and meat product.

Feeding of total mixed ration containing moringa leaves, stylosanthus and lucerne, respectively for 5 months of age in Malpura lambs produced he mean pre-slaughter weights 19.00, 17.39 and 20.00kg, respectively. Dressing yields were comparable among the groups and varied from 55.13 to 56.62%. Significantly lower TBARS value was observed with moringa leaves. Feeding of silage (Chaolai+Bajra); (Chaolai+Bajra: 67.33%) + (Sejna +Bajra:33.33%); (Chaolai+Bajra:33.33%) + (Sejna+ Bajra: 67.33%) and (Senjna+Bajra) gives desirable carcass lean, fat and bone content. Adult ewes were fed diet supplemented with shrubs growing in arid region and the study revealed that feeding of silage (Naperi+Chana Bhusa) produced desirable quality of carcass. The carcass traits of Dumba lambs at 9 months of age were desirable with 47% dressing yield. The Muzzaffarnagari ram lambs fed ad libitum pala and concentrate, produced meat with desirable lean, fat and bone yield at 6 months of age. Carcass traits and dressing percentage were not affected by feeding regimes such as milk replacer compared to free suckling along with different

total mixed rations on pre weaning lambs. The meat quality indicated significantly higher lipid oxidation in group maintaining on free suckling with milk replacer.

For chevon production castration at the age of 30 days was found to be better compared to at 7 or 15 days. The dressing yield was higher in sheep than goats. But goat yielded leaner carcass which is desirable for the calorie concern consumers. It was also revealed that meat from goat carcasses was tougher than mutton. In Sirohi kids khejri or pala leaves and concentrate mixture in 50:50 ratios did not affect any carcass quality attributes. Intensive feeding of kids on complete feed consisting of roughage (tree leaves) and concentrate improved hot carcass yield to 11.73kg with dressing yield of 56.07% from 8.68 kg and 55.76% under prevailing grazing plus supplementation system. Sirohi kids on intensive or semi-intensive system provided quality carcass with higher meat yield. In different breeds of goats, slaughter studies at 7, 8, or 9 months of age indicated that after feeding them on ad libitum concentrates from 6 months of age an increase in slaughter weight and carcass weight was observed with increasing age at slaughter in all breeds except Kutchi and Marwari. The meat of Jaisalmeri goat has great demand in the market because of peculiar taste and quality. Similarly, meat was considered as good to very good in laboratory. Patties and nuggets were prepared from the goat meat and sensory evaluation rated them as very good to excellent.

Adult male rabbit provides 53.5% dressed meat yield and that of female 52.0%. In semi-arid conditions, Soviet Chinchilla breed was found to be ideal meat producer than Grey Giant, White Giant and New Zealand White. However, all genetic groups performed well and provide desirable meat production and quality traits. On the basis of muscle fibre diameter, it was suggested that production potential can be realized around 12 week of age or up to 2.0 kg body weight. Average daily gain significantly reduced with the advancement of age. The dressing yield was found optimum at 12 weeks of age. Further, lean content of the carcass increased while its bone content decreased with the advancement of age.

The supplementation of 10ml of curd diluted in 100ml of tap water and pure culture of Lactobacillus acidophilus from 42 to 84 days of age in weaner rabbits has no added advantages in dressing yield and weights of different commercial cuts (hind leg, loin and fore-leg) and pluck (kidney, liver and heart). Azolla supplementation and restricted feeding in rabbit diet revealed better carcass traits and meat quality with Azolla feeding and it could be used as unconventional feed for rabbits. Feeding of different roughages such as Cowpea (*Vigna unguiculata*), Urd straw (*Vigna mungo*), Stylo (*Stylosanthes hamata*) and Mulberry (*Morus rubra*) leaves at 25% level produced desirable carcass traits and meat quality in rabbits. Feeding of concentrate pellet diet containing 70 parts of moringa leaves, mulberry leaves, cowpea hay, stylosanthes hay, and 90 parts of moringa leaves in rabbits up to 3 months of age showed significantly higher dressing yield, loin eye area, Skin and Offal's weight in conventional feeding group and significantly lower in group fed with 90% moringa leaves.

Value addition of mutton and functional products

Several mutton products were developed mainly categorized into emulsion-based product (Nuggets, sausage, salami, loaf, bites etc), shelf stable products (pickle, snacks, cookies etc) and restructured products. The processing protocol to develop mutton soup, mutton sandwich spread and mutton cookies were standardized. Mutton based snacks was developed from meat along with other ingredients and evaluated its shelf-life at ambient storage under aerobic and vacuum packaging and found that vacuum packaging could be useful in enhancing the keeping quality of the mutton snacks at ambient storage.

In meat processing wheat or chick pea flour (@3%) in meat product formulation resulted in better yield. Restructured roast from rabbit meat chunks, sausages from spent rabbit meat and mutton nuggets had very good consumer acceptability. For natural casings hydrogen peroxide (0.06%) or peracetic acid (0.1%) can be very effective

deslimer for enhancing their keeping quality. The cost effective, highly acceptable mutton soup was developed. Feeding of vitamin E, rumen protected fat and Khejri leaves to lambs resulted in improvement in lipid stability in mutton nuggets. enrobing of mutton nuggets increased flavour and overall acceptability.

Formulation and processing protocol for snacks type mutton croquettes was standardized with (0.01%) sodium bi-carbonate in order to make croquettes more acceptable with desirable texture. The level of added fat (vegetable oil and mutton fat) was used in different combinations (10, 7 and 5%) to develop conjugated linoleic acid enriched mutton nuggets. The finding suggested that Low fat mutton nuggets can be stored for 18 days at refrigeration (4±1oC) storage. Low fat mutton nuggets were developed by replacement of added fat with inulin at 2.5 and 5% level. The control formulation contained 10% while T1 and T2 contained 7.5 and 5% added fat, respectively. Inulin significantly decreased the fat content of nuggets when added at 5% level. Further all the sensory attributes except juiciness, remained unaffected with fat replacement by inulin. Fibre enriched mutton nuggets were developed by incorporation of seedless date paste with at different (5, 10 and 15%) levels. The emulsion stability was significantly improved by use of date paste. The findings of the study revealed that 5% date paste was found optimum to improve the fibre content of the nuggets.

Excessive sodium in the diet has been linked to hypertension. Attempts were made to replace the salt content of the nuggets. The control formulation contained 2% salt (100%), while other formulations contained 42.5, 45 and 50% blend of salt replacers. The findings of the study revealed that, it is possible to reduce the salt content in the formulation up to 42.5% level without much adverse effect of the quality of mutton nuggets. The binders play an important role in imparting desirable texture to meat products and an experiment revealed that semolina/suji could be used as partial replacement to maida.

Curry (*Murraya koenigii*) leaf powder (0.5%) used successfully as natural antioxidants to reduced lipid oxidation in mutton pickle. Preservative effects of khejri (*Prosopis cineraria*) tree leaves extract (LKE) and pumpkin (*Cucurbita maxima*) seed extract (PSE) were investigated in meat model system (minced meat) at 4±1ºC by comparing with butylated hydroxyanisole (BHA). LKE showed highly preservative effect at 0.5% level and equally effective at 0.1% level while PSE was effective preservative at 2 % level. The study was envisaged to evaluate the antioxidant potential of custard apple (Sitaphal), Amaltas leaves and pumpkin seed and concludes that these have

great antioxidant potential and may be further tried in meat as natural preservatives. The trail was conducted to developed pet food from slaughter house blood waste. Comparative study on the nuggets quality made from mutton of Malpura and Dumba breed indicated that hardness values, firmness and work of shear were significantly lower in nuggets made from Dumba meat. Preservative effects of pumpkin (*Cucurbita maxima*) seed powder (10% (w/w) were investigated in meat product during storage at 4±1˚C and the TBARS values of the control and treatment didn't differ significantly.

Sheep milk and their value addition

The sheep milk was processed into natural carrot flavoured milk. The sheep milk and water were taken in 75:25% proportions and was boiled and 10% carrot pulp and sugar, few pieces of cardamom were added and milk was cooled and evaluated for physicochemical and sensory attributes. The flavoured milk had 5.86±08 pH. The sensory attributes of the milk were rated between good to very good. The sheep milk was used for preparation of paneer by heated to 85˚C and then acidified with 1% citric acid and also the processing technique was optimized for mozzarella cheese. The sheep milk khoa was used for preparation of gulab jamun with 3:1 proportion of khoa and maida. For 400g mixture of khoa and maida, 2.5g baking powder, 1kg each sugar and water were taken. The balls (30g) were made manually and deep fat fried in the ghee at around 130˚C. Sheep milk Kulfi was also prepared from milk concentrated followed by addition of sugar and stabilizer.

Citric and acetic acid used as acidulent to make sheep milk paneer and study indicated that, paneer prepared from acetic acid gave more product yield with comparable sensory attributes and soft textured paneer compared to paneer prepared using citric acid. A study was conducted on sheep milk peda to access the quality attributes during refrigerated (4±1°C) storage up to 7 days at alternate days interval in different packaging system i.e., Aerobic (T1) and vacuum (T2) packaging. Study revealed that vacuum packaging of sheep milk peda was better than aerobic packaging during refrigerated storage.

The study on milk composition of Sirohi and Patanwadi sheep milk exhibited that fat, SNF, protein, lactose and salt contents in goat milk were 4.53, 8.97, 3.27, 4.94 and 0.73%, respectively. In sheep milk fat content was increased from 3.73 (1st week) to 8.67 % (13th week).

Utilization of rabbit fur for value added items

To accrue more profit from broiler rabbit rearing, the skins of rabbit chrome tanned and converted into rabbit fur and further into valuable garments like caps, purse, hand bags, doll, key rings etc. which may fetch more value in the market. Attempts were made to develop value added rabbit fur ladies' purses in collaboration with Indian Institute of crafts and Design, Jaipur.

Textile Manufacture and Textile Chemistry

The Textile Manufacture and Textile Chemistry Division aimed to research wool fibre since the inception of the institute. All the wool that is sheared at the institute campus and regional stations is utilized for research studies and processed in the division for product development. The wool processing plant has been established in 1969 under UNDP aid. Later on, fibre physics laboratory, textile chemistry laboratory and recently composite laboratory have been added in the infrastructure along with the product exhibition room.

Research contributions 1962–1982

Evaluation of Indian wools : Both indigenous and crossbred wools were analyzed for different fibre properties. The results indicated that the fibre diameter of the native wool was improved like fine wool with 20-25 µ with below 5% medullation through cross-breeding with exotic fine wool sheep. However, the staple length of the cross-bred wool was reduced.

Breed	Fleece weight (kg)	Fibre diameter (µ)	Medullation (%)	Staple length (cm)
Northern Temperate Region				
Gaddi	0.7	29-35	5-10	8-10
Karnah	1.0-1.5	29.32	-	12.15
Kashmir Valley	1.0-1.5	27-33	6.00	5-8
Rampur Bushair	1.0-1.5	34-35	20-25	5-8
Poonchi	0.9-1.3	20.30	-	-
Northwestern Arid and Semi-arid Region				
Bikaneri	1.067	24-35	10-20	7-10
Nali	1.460	34-45	15-30	6-9
Patanwadi	1.056	28-36	20-50	6-8
Sonadi	0.409	50-60	50-80	4-5
Chokla	1.149	26-28	10-25	5-10
Malpura	0.524	40-50	60-80	5-8
Jaisalmeri	-	31-40	40-60	6-8
Marwari	-	35-40	40-60	6-9
Magra	0.760	33-40	35-45	6-9
Pugal	0.800	35.13	61.86	5.71
Muzaffarnagri	0.650	45.17	69.92	3.72
Avikalin	1.500	30-35	20-40	6-9
Southern Region				
Deccani	0.359	45-55	40-70	5-8
Ballary	0.300	50-60	40-60	-
Coimbatore	0.365	40-50	40-60	5-6
Nilgiri	0.615	25-27	5-10	5-7
Bharat Merino	2.000	18-22	<1	6-8
Eastern Region				
Chhotanagpuri	0.184	50-55	60-80	-
Shahabadi	0.240	45-50	60-80	-
Jalauni	0.455	40-50	60-80	-
Bonpala	0.200	45-50	60-80	-

Morphological studies of wool : The scales were found to have various shapes like regular, irregular, mosaic and wavelike. The size of scales varied from 14.34 (Rambouillet) to 27.48µ (Malpura hairy). The number of scales per cm ranged from 364 (Malpura hairy) to 697 ((Rambouillet). The studies on frictional properties of various wools indicated that directional frictional index varied from 0.028 (RxM, 1/2) to 0.090 (Malpura). It was observed that irrespective of the type of fibre (i.e. non-medullated and medullated), the circularity factor decreased with the increase in the major axis. The circularity factor of medullated fibre was less than that of true fibre. The circularity factor varied from 0.88 to 0.93 in exotic breeds, from 0.84 to 0.93 in crossbred and from 0.79 to 0.83 in medullated fibre.

Scale structure of native and crossbred wools

Wool	Scale size (µ)	No. of scales/cm
Rambouillet	14.34	697
Chokla (Pure)	20.18	498
Chokla (Hetero)	23.12	432
Chokla (Hairy)	22.19	450
Malpura (Pure)	15.37	650
Malpura (Hetero)	17.13	584
Malpura (Hairy)	27.48	364
R X C (3/4) Pure	15.72	630
R X C (3/4) Medullated	19.80	505

Frictional properties of wool and rabbit hair

Wool	Frictional force (g)		Directional frictional
	Along the fibre	Against the scales	Index
Rambouillet	2.171	2.366	0.077
R X C (3/4)	2.326	2.484	0.056
Chokla	1.918	1.990	0.073
Malpura	1.825	1.990	0.090
R X M (1/2)	2.346	2.603	0.028
Corriedale	2.221	2.350	0.055
Rabbit	2.227	2.429	0.076
Mohair	1.677	1.743	0.046

Stress-strain behaviour of wools : The stress-strain properties of the wools showed that in native wools (Chokla, Malpura, Sonadi, Nali, etc) the difference in tenacity is negligible (11.17 to 12.82 g/tex) even though there was a large difference in fineness (37 to 56µ). In all the cases heavy yellow wool showed lower tenacity as compared to light yellow wool. The difference in extensibility among wools was rather small. The elastic recovery studies indicated that all the wools under test are 100% recoverable immediately at 2.5% of their extension. The RxC wool behaved almost equivalent to Rambouillet from the elastic recovery point of view even at increased extensions. The results on bulk resiliency indicated that the fibre diameter and crimp/cm had 13 and 19% variability for the first and fifth cycle, respectively. The infusion of exotic blood in the native breeds has improved the quality of wool to the extent of Corriedale, these crosses were having sufficient strength to produce the yarn economically and usefully. The curve parameters regress positively with fibre diameter in pure fibre and negatively in medullated fibre. This was attributed to

the fact that pure fibre tends to be structurally stronger with an increase in diameter whereas in medullated fibre. The increase in diameter results in an increase in medulla resulting in poor elasticity.

Effect of temperature on stress-strain behaviour of wool : In general, stress fell by 70% and extension increased by 50% on changing the temperature from 25-95°C. The rate of fall of stress with temperature was sigmoidal. Up to 51°C, there was a sharp fall; between 50-70°C, it was fairly constant and above 70°C, it again fell rapidly. For temperatures above 60°C, the fibre showed slippage in the post-yield region (i.e. extension above 35%). This was attributed to the increased mobility of the molecular chains.

Stress-strain behaviour of thioglycollate treated wool : Chokla white and canary coloured wool fibres were reduced with sodium thioglycollate to know the contribution from the structural components to stress-strain properties. As the treatment reduced the disulphide bonds, the main structural backbone of the fibre, the stress value decreased and extension increased due to treatment. The change was different in the white and canary coloured wool. The yield slope of the curve at 65% RH of yellow wool was lower than white wool indicating that canary colouration modified the matrix adjoining the microfibril which weakened the fibre.

Torsional rigidity of wool : Based on torsional rigidity values, the least resistance to twisting was observed in native wools while the cross bred wools showed higher resistance to twisting. Torsional rigidity had a high correlation with fibre diameter and proportional to 3.8 powers of diameter. The diameter variation along the fibre length was measured to ascertain fibre breakage during processing. Wool fibre (22 each) from Rambouillet, Chokla and their half-bred sheep were studied for their diameter at 36 places over 3cm long fibre. The fibres of the latter two breeds were separated into pure and medullated and load-elongation curves of all the 110 fibre were obtained. Results showed that diameter depends on the genetic group but not on the different properties of the fibre. It was also found that except breaking strain, all other values were higher in pure fibre compared to medullated fibre. The main effect of medullation is to reduce the stress and increase the strain in a fibre.

Wool pre-spinning studies : The division undertook a major consultancy work from Himachal Pradesh Khadi and Village Industries Board for scouring and carding of their wool for Khadi spinning. One of the major problems faced by the industry at that time was the removal of vegetable matters, burrs, etc., from wool. The division took up this problem and optimized the carbonization process. In 1971, a consultancy project was awarded by Animal Husbandry Department, Mysore state for processing their wool. Two major All India Coordinated Research Projects were undertaken on canary colouration and manufacturing trials. The Division took lead in the manufacturing trial of graded wool projects. Some experiments were also conducted on wax recovery system, preparation of hospital/military blankets from Chokla and Nali breeds as per ISI 1681-1960 and removing highly medullated fibre in Indian fleeces.

Cross-bred wool study : Rambouillet x Chokla (F1) crossbred wool had a great potentiality for its utilization for apparel purposes. It was found that the crossbred wool can be very suitably spun up to the optimum count of 11.49Nm on the woolen system, 16.34Nm on the semi-worsted system and 28.01Nm on a worsted system with reasonable limits of end breakages at the ring frame with optimum yarn strength. Based on the results, it was proposed that efforts should be concentrated to encourage the cross breeding programme in the country on large scale by infusing exotic fine wool blood with the indigenous qualities to produce a sufficient quantity of fine wool for its utilization in apparel and other end products.

Wool Scouring : Malpura and Chokla wools had the highest and Rambouillet had the lowest percent scouring yield in both anionic and non-ionic treatments. The crossbreds (RxC and RxM) had an intermediate percent scouring yield. With non-ionic detergents, the percent scouring yield was lesser as compared to anionic detergents in all the native, exotic and crossbred wools. The scouring of wool without the addition of detergent and sodium carbonate was also attempted to minimize the damage to wool fibre by utilizing the suint present in the wools. This process was called the suint scouring process. The process was projected as best suitable for indigenous wool especially canary-coloured wools. The suint scouring process produced a fluffy soft feel and less yellow to scoured wool. However, further research revealed that the suint scouring process was slightly less efficient and time-consuming than the detergent.

Carbonization : Attempts were also made to optimize the carbonization process of wool which contained more than 5% vegetable matter. It was found that 3.5-4.5% sulphuric acid with 10min for acidification, drying for 20min at 80°C and baking at 130°C were the suitable parameters for carbonization. It was also attempted to reduce the damage to wool during carbonization by the addition of different anionic and nonionic surface-active agents (detergents). In general, the tenacity of the wool was higher with the addition of surface-active agents and anionic sodium lauryl sulphate gave better results than non-ionic detergent. Several experiments were conducted to find the chemical damage in wool using alkali and urea-bisulfite solubility tests. It was observed that alkali solubility test results did not give any clear picture regarding the damage in wool. It was also attempted to study the effect of oxidizing agents (hydrogen peroxide) and reducing agents (thioglycolic acid) on native and crossbred wools. The treated wools were characterized with X-ray diffraction photographs, thermo-gravimetric analysis, etc. The results showed that the degree of orientation of keratin decreased after both treatments. The thermal stability of the wool was reduced more with hydrogen peroxide than with thioglycolic acid.

Low-temperature dyeing of wool : The processing of wool at higher temperatures leads to fibre damage especially during dyeing. Hence, it was attempted to develop a low-temperature dyeing process using different mixtures of alcohol and water as a medium of dyeing instead of conventionally used water. The liberation of lanthionine was taken as a measure of damage to wool. The results indicated that the dye uptake percentage was greater with a water-alcohol mixture in general compared to water. The light fastness of the water-alcohol mixture dyed canary coloured Chokla wool was very good compared to water dyed wool.

Mechanical processing of wool : The processing trials were carried out in semi-worsted and worsted spinning system. There was a non-significant difference in fibre diameter at various stages of processing. However, the fibre length influenced the processing performance of the wool. There was a decreasing trend in the fibre length at different stages of processing. This was attributed to the fact that long fibres (probably medullated ones) break during carding action. The behaviour of Chokla and Corriedale wools during processing was extremely good. However, much difficulty was encountered while processing RxC crossbred and Rambouillet wools, especially during auto-levelling and combing. The possible reason for the processing difficulties was attributed to their short fibre length. In the case of Chokla and Corriedale, the fibre length was 11.27 and 11.32 cm, respectively; whereas in the case of cross-bred wools, the fibre length ranged from 5.63 to 8.7cm which clearly showed reasons for their poor performance. The second major problem faced during the processing of RxC cross bred wools was a generation of an extremely higher percentage of noils to the tune of 40% which would make them unsuitable for commercial exploitation. In industry, the normal noils percentage was kept around 15-20% at the most during that time. Hence, it was proposed to change the shearing regime for the crossbreds to increase the fibre length. The yarn tenacity obtained for Chokla and Corriedale was 6.83g/tex whereas the Rambouillet and its cross wools ranged from 4.82 to 5.70g/tex which was significantly lower. Apart from the above wool lots, variety wools like Nali, Corriedale x Bellary, Corriedale x Nellore, Malpura, Sonadi, Rambouillet x Malpura, Karakul, Dorset-Suffolk crosses with Malpura and Sonadi were processed on woollen system. Corriedale, Gaddi. Avikouillet, Mohair wools were processed on a semi-worsted system; Nali, Nali x Merino, R x C + Mohair (75:25), R x C+ Mohair (50:50) were processed on the worsted system. It was observed that fibre length had the most influencing effect in the cases of semi-worsted and worsted spinning systems. In general, it was observed that spinning to approximately 50 fibre per cross-section was normal on to the existing set of machinery on a commercial basis. The spinning of wool finer than 50 fibres was not common and economically viable. The Mohair and its blended yarn have got better tenacity and elongation than pure wool. In 1977, new crossbred wool of Rambouillet and Merino with Chokla and Nali was available. The wool was with sufficient fibre length to process in semi-worsted and worsted systems. Using this wool a higher count of 30 Nm yarn was spun. The yarn was strong enough to withstand the processing strain in further processing sequences.

Blending of wool with other fibre : Wool was blended with polypropylene (15 denier), polyester, viscose, and New Zealand wool. The wool-polypropylene blended fibre was also spun on a semi-worsted system and worsted system to the yarn of around 20 Nm count for knitting purposes. The increase in the polyester percent in the blend improved

the processing behaviour and finer counts with higher strength compared to the Viscose blend. New Zealand wool up to 30% in the blends increased yarn tenacity and elongation percentage. An increase of New Zealand wool above 30% proportion did not respond favourably.

Development of hand-knotted carpets : An overall comparison of the functional properties of Chokla, Nali, Jaisalmeri, Magra and RxM wool carpets elucidated that though Magra and Jaisalmeri carpets possessed an ideal compression and recovery behaviour but retained their initial appearance for a shorter period of their use due to higher rate of weight and thickness losses. Chokla and RxM wool carpets demonstrated excellent appearance retention combined with moderate compression values. Abrasion resistance results indicated a decreasing trend in the loss of weight of the carpet samples with the increase in the height of the pile. Among the native wools, a minimum loss of 4.20% was noticed in Chokla wool carpet in 4000 cycles of abrasion and Jaisalmeri wool carpets showed the highest percentage of weight loss. The abrasion loss values of Magra wool carpets were in between Chokla and Jaisalmeri with a 7.4% loss. Compression and recovery had shown an inverse relationship. Generally, recovery percentage decreased with the increase in pile height and increased with increased pile densities whereas the residual compression and compression behavior revealed a reverse trend to that of recovery in the same pile combinations. During the dynamic loading test, the thickness losses increased with the increase in pile height and decreased with the increase in pile height. The Chokla wool exhibited minimum thickness loss whereas the Jaisalmeri wool exhibited higher thickness loss and Mara fell in between the two. Indigenous Chokla/Nali and Malpura/Sonadi wool were blended with New Zealand wool (0-40%). The results indicated that blending of NZ wool reduced the abrasion loss. However, the indigenous wool samples were superior in respect of resiliency and thickness retention which are the most desirable properties of the carpets.

Woolenization of Jute : It was found that on treatment with strong sodium hydroxide solution (6-20%) at room temperature, jute fibre gets a wool-like appearance in respect of feel and crimp. This process was known as woolenization of Jute. The formation of a crimp in alkali treated wool was attributed to the variation of molecular orientation within the single fibre caused by alkali treatment. However, the process resulted in a 50-60% fall in strength but the elongation was also increased to the same extent. The decrease in strength was attributed to the rupture of the bond between lignin and hemicellulose.

Wool-Jute blended carpet and blanket : Two types of jute, the Tossa (42µ diameter) and White (46µ diameter) were blended with two grades of wool viz B (35µ diameter) and C (40µ diameter). Jute fibres were cut into 75mm staples to match the length of wool fibre. The blended fibre (15:85, 30:70 and 50:50 proportions) were processed on woolen as well as on a semi-worsted system of yarn manufacturing. Woolen yarns were spun to an average yarn count of 7.5Nm to produce carpets and blankets. Jute/wool blended carpets were inferior in all other properties as compared with all wool carpets. The jute/wool blended carpets showed higher abrasion loss and found not suitable for floor coverings.

Effect of TPM and fibre in cross-section for spinning of wool : It was observed a significant increase in strength when TPM was changed from 110 to 135. Further increase in TPM did not increase the strength to any significant level. The elongation percent was found to be highest at 155 TPM and then started declining. In the case of the worsted system, the TPM was optimized at 600. The yarns spun on a woolen system at 1.3 draft and 151.4 TPM were given steam treatment for 10 minutes in the tension state. It was revealed that the strength of the steam treated yarn was more than untreated yarn. For spinning a yarn of acceptable norms with yarn regularity, yarn strength, etc., the required number of fibre per cross-section was optimized at 40-50 fibre on the worsted system and 200 plus fibre per cross-section for Indian and cross bred wools. However, if the fibre characteristics were favourable, the spinnability limit was achieved at 120 fibres per yarn.

Utilization of coarse wools : Wools from Coimbatore, Corriedale and their crossbreds (1/2, 5/8 and 3/4) were processed on woolen spinning system for the preparation of blanket yarns. A yarn count of 4-5 Nm was prepared and it was found that the lea-breaking strength of half-bred Corriedale x Coimbatore was reasonably good breaking strength as compared to yarns of other lots. Further, Corriedale (25.4µ diameter, 60mm fibre length, 4% medullation) and

Malpura/Sonadi wool (53.6µ diameter, 80 mm fibre length, 85% medullation) were taken as a representative fibre of fine wool and coarse wool, respectively were blended in different proportions and processed on woolen system to find out the influence of coarse fibre of the different end product qualities. A 4 Nm yarn was spun and carpets and blankets were manufactured. The study revealed that sliver strength gradually reduced with the increase in the coarse fibre content because of the lack of cohesion. It was observed that a blend of 50:50 provided satisfactory spinning and yarn performance. In the fabric stage also, with the increase in the coarser fibre, the strength and elongation of the grey fabric in both warp and weft direction decreased. The processing loss increased with the increase of the proportion of medullated fibre.

Utilization of noils for spinning woolen yarn : The noils even though finer in diameter could not be spun in the woolen system. This was attributed to shorter fibre length. The 5% addition of proplon (3 denier, 70mm length) had improved the spinnability and yarn strength. The proplon fibre acted as a binding fibre on the yarn surface and increased the spinnability and yarn strength. However, the yarn produced from noils was quite softer. It was also attempted to spin the cross bred wools such as Dorset and Suffolk crosses with Malpura and Sonadi with the addition of 20% noils which improved the spinnability. The wool lots were drafted from 1.004 to 1.602 and the best suitable draft on the wool system was found from 1.196 to 1.310. The elongation decreased with increased drafts.

Development of serge fabric from medium-fine indigenous and crossbred wools : The worsted yarn prepared from Chokla, R×C crosses and R×N crosses were used to prepare serge fabrics following IS 2319:1969. The performance results indicated that weight /square meter varied from 358 to 399 which is below the prescribed norm of 425 g/m^2. The overall flexural rigidity showed that Chokla wool had got highest flexural rigidity and R×C (3/4th) had the least rigidity and the rest of the wool fabrics lie in between. Fibre fineness had a positive effect on fabric flexural rigidity. The relaxation shrinkage of the fabrics was well within the norms. However, a higher pilling tendency was observed in the fabrics prepared from finer wools and this was reduced with the use of coarser wools.

Development of knit-wears from Indian wools and their blends : Several blends of specialty hair fibre were spun on woolen system keeping linear density as 125 tex. These yarns were subsequently used for hand knitted fabrics using two ply yarns. The wales and courses per decimeter and stitch length were kept as 50, 32 and 1.18cm, respectively. Rabbit hair-silk blended knit goods appeared to be superior in respect of luster, appearance and feel. In order to study the effect of knit structure, plain, 1x1 Rib, 2x1 Rib, half cardigan and full cardigan structures were prepared with wool/mohair (50:50) two plied yarns with the same constructional properties. It was observed that Rib fabrics were the most symmetric fabrics. The full cardigan was bulkier and extensible with very low dimensional stability. Plain knitted fabrics were softer in feel whereas 2x1 Rib fabrics had excellent thickness and width wise elasticity, more than twice the plain knits.

Processing of rabbit hair : The rabbit hairs blended with polyester, acrylic and silk in different proportions were processed on the cotton system with the addition of 1% Nipotex F antistatic agent. The polyester and mulberry silk blends with rabbit hair resulted in stronger yarn. Rabbit hair-polyester blend in 50:50 proportions was processed on commercial cotton-spinning machinery for spinning 50Nm yarn with 682.5 TPM. The spinning performance and yarn properties were quite satisfactory. Shawls were produced using the yarn. It was observed that fibre shedding reduced considerably due to polyester blending.

Effect of storage on quality of wool : Extensive research was carried out to study the effect of temperature, humidity and light on the quality of wool during storage. The results indicated the existence of a significant positive correlation between relative humidity and wool weights. A decrease in temperature and a rise in relative humidity resulted in a gain of wool weights. Likewise, an increase in temperature and a fall in relative humidity resulted in a loss in wool weights in a different type of wool both in raw and scoured conditions. Variations in wool weights due to atmospheric fluctuations were observed to be more in raw wool as compared to the wools stored in scoured forms. No significant

effect of storage under different temperatures and relative humidity conditions during various seasons was observed on wool fibre tenacity and bulk resiliency. The scoured lots of wool of different breeds showed a higher degree of damage during the different seasons of the year as compared to the lots in the raw form under identical conditions of storage. The moth resistance properties of wool in greasy and scoured form were also studied by treating with 2% Dielmoth insecticide. The insecticide-treated lots exhibited less damage compared to the untreated lots.

Research contributions : 1982 - 2002

Development of lightweight blankets : The indigenous wools (Chokla, Nali etc) were blended with polyester filament yarn (PFY) waste and blanket quality yarn was spun. The warp and weft wise breaking strength and abrasion resistance of the blanket were higher compared to all wool blankets with appreciable weight reduction. The blanket weight of 324 g/m2 was reduced to 266 by blending 60% PFY.

Spinning of Indian wools on DREF-2 : Nali wool was processed on the worsted card and the material was sent to Austria for its spinning on friction machinery. The yarn received (0.45, 1, 1.5, 2 and 3.5 Nm) was converted into a carpet pile and fabric. The yarn produced was comparable to ring-spun woolen yarns for tenacity and breaking elongation. The carpet pile performance was good for the yarns spun without filament as core. The yarns having core were unable to maintain pile structure and the carpets lost their appeal. The fabrics produced were quite good with very high abrasion resistance making them suitable for furnishings.

Mohair processing : Mohair is a speciality hair fibre difficult to process for lack of cohesion due to its smoothness and absence of crimp in the fibre surface. Mohair was blended with Merino wool and acrylic fibre in varying proportions. Yarns of 20 Nm linear densities were spun by blending at the gilling stage. The inclusion of wool and acrylic improved the cohesion and facilitate the spinning of mohair. The blended yarns had tenacity in the range of 5.1 to 6.6. The uniformity of Merino blends was superior to the cross-bred sheep wool blend. The 50:50 blend of Mohair and wool had shown optimum qualities and a further increase in Mohair proportion increased the yarn variation.

Camel hair processing : The average diameter of Camel hair fibre ranged between 27-38µ, fibre length from 51 to 67mm, crimp was absent, 0.5 to 0.7% grease and vegetable contamination were found to be in between 3 to 5%. Among the four coloured lots, the brown and deep brown coloured was selected for the spinning trial. The coarse black coloured camel hair created processing problems. Camel hair lots along with two blended lots (60% Camel hair and 40% wool and 60% Camel hair and 40% polyester) were processed on woollen spinning system. It was observed that coarser camel hair got removed preferentially as fly/card droppings. The camel hair blended fabrics made by using all wool yarn as warp and all camel hair and camel hair/silk waste blended yarn in filling direction were softer after scouring and milling due to migration of camel hair to the surface. The natural colour of the fabrics was quite attractive and the fabrics could be used as over coating. However, cropping was necessary to remove the protruding coarser beard camel hairs.

Processing performance of Bharat Merino wool : Bharat Merino wool of SRRC, Mannavanur had longer staple lengths (6.7cm) with an average diameter of 23.0µ. However, wool of Mannavanur was found to have higher contaminates (23%) of sand/dust, etc. The scouring yield was approximately 44%. The combing loss of carded sliver was 30%. The wool was spun into the yarn of 20 Nm and converted into the fabric of 190g/m^2. The combing loss was reduced to 13% with the graded wool and yarn of up to 35Nm was spun. The Avikanagar wool of 3.6cm was spun into 2.5Nm yarn and blankets made out of the above yarn had a desirable softness, fullness and warmth.

Processing performance of Avikalin wool : The Avikalin wool was converted into carpets and compared with the carpet made from Nali wool. Abrasion loss was lower in Avikalin carpets compared to Nali wool carpets. However, the resiliency and recovery properties were better in the latter one. The resiliency and recovery from compression improved with higher pile density and higher pile height.

Carpet performance of New Zealand wool : Ten carpets prepared from a blend of non-medullated and modulated fibre were subjected to the visual appeal and handled the test. The visual appearance of carpet made from about 80% medullated fibre gave the best carpet visual appeal and handle. This was attributed to the limpy nature of fine wool

carpet piles. However, considering the abrasion loss it was concluded that 50% medullated fibre content could produce the best carpet. The other study indicated that New Zealand wool was more compressible and had less recovery compared to Bikaneri Chokla wool. The addition of Bikaneri Chokla helped in better performances. However, abrasion loss was more in Bikaneri Chokla wool due to higher medullation.

Lustre wash of carpets : Carpets made out of Avikalin, Magra and Marwari wools were washed with alkali-hypochlorite. The chemical washing resulted in the removal of coarse medullated fibre with improvement in the fineness of the pile. The fibre loss was more in Magra and Marwari compared to Avikalin carpet. Due to washing, the resiliency was improved a little bit whereas compressibility was reduced. There was no change in the recovery properties. Carpets made from Uttaradha, Shyamgarh, Magra and Gujarat wool were given moderate luster wash treatments to increase the visual appeal. The carpets made from Uttaradha and Shyamgarg were scored first place followed by Magra and Gujarat wool.

Survey and analysis of mandi wools of Rajasthan : Rajasthan has ten major wool marketing centres (Mandi). Three wool mandies namely Bikaner, Beawar and Kekri are internationally known. Four wool mandies Jaipur, Barmer, Jodhpur and Jaisalmer have national status, whereas Churu, Pali and Sri Ganganagar are the regional wool marketing centres. The domestic and imported wools of every divergent quality are traded in these wool mandies. A comparison of quality characteristics of wool from different wool mandies indicated a large scale divergence in wool quality attributes. The March clip wool was white/tinged white, July and November clips were pale yellow while, September clip wool was dark yellow. The processing losses of autumn clip wools were higher than corresponding spring clip wools. Among the domestic wool, Uttradha (Bikaneri Chokla) followed by Magra, Marwari and Chokla were lustrous.

Fluorescence and reflectance : The fluorescence at 365nm was in the order of Nali > Magra> Marwari wool. At 405nm, there was no significant difference among wools, whereas, at 436nm, Nali scored lowest while others did not differ significantly. The reflectance of Magra and Marwari were similar and significantly higher than Nali wool. The fluorescence at 450 and 470nm was higher in Beawar Chokla whereas, at 510nm, the reflectance was more in New Zealand wool. It was inferred that New Zealand wool was more lustrous. Wool samples collected from the field showed that luster differed significantly with respect to locations, age of the animals, diameter, month of sampling and year of collection. It was observed that luster was increased after chemical treatments. The acid hypochlorite treatment improved the luster of the samples more than that of the alkali hypochlorite treatment.

Indian wools and their blends with New Zealand wool : New Zealand wool (NZ) and its blends with Beawer Chokla (BC) 40:60, 50:50, 60:40 had diameter 31.04, 33.76, 35.90 and 37.50 µ and medullation 7.51, 19.90, 49.67 and 61.13%, respectively. The compressibility studies were carried out at 0.9 and 5.0 kg loads. The bulk of the blend increased with the increase in the proportion of indigenous wool.

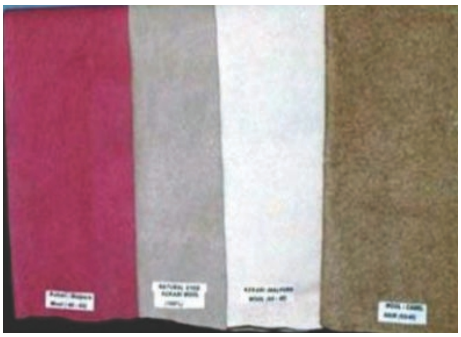
Studies on natural dyeing of wool : Natural dyes are well known for their eco-friendly nature. Several natural dyes were identified for wool and dye was extracted. The wool materials were dyed with and without the use of metal salts (mordants) like chromium, copper, iron, alum, tin, etc. Barks of acacia, eucalyptus, magenta root, henna leaves, tea waste, onion skin, wattle bark, wall nut fruit, etc., were used in dyeing the wools. The colour produced on wool was fast to washing.

Development of handloom woven carpet : The wool fineness varied from 28-41µ whereas medullation varied from 21-47%. Generally, 100% wool was being utilized in Bikaner carpet weaving units. The two ply or three ply woolen yarns were used for carpet making. The pile height varied from 7.0-9.3mm and pile density 24 to 29/inch^2. The pile weight varied from 890-1300g/m^2. The resiliency (43-55%) and compressibility (33-47%) of the carpets were good. The life of the carpet estimated to be 6years for carpets with pile height 5-7mm and 12-14 years in carpets with pile height 11-13cm.

Blending of wool and speciality hairs with synthetic and natural fibre : Gaddi synthetic wool was blended with non-shrinkable acrylic fibres, spun into 25 Nm yarn and converted to knitwear. Bharat Merino wool and polyester

(30:70) were blended and five types of fabrics were made which had bulk varying from 2.06 to 3.4cm3/g. Aerial density varied from 182-280 and thickness 0.47 to 0.62. Rabbit hair was blended with Bharat Merino wool in 20:80, 40:60 and 60:40 and spun into yarn of 12 Nm with 377 twist per inch. The tenacity and elongation of the yarn increased with the increase in rabbit hair content. Rabbit hair and acrylic fibres (50:50, 60:40) were spun on dref-2 system. From the yarn properties, it was concluded that rabbit hair could be blended with acrylic up to 40% for good quality yarn of 2/20Nm. The yarns were used to prepare the shawl. The shawl was found bulky with higher thermal insulation. The shawl had low stiffness (610 mg-cm) inferring a good handle. Camel hair (27.21µ diameter and 59 mm fibre length) and polyester waste (80:20) were blended and spun into yarn using dref-2 system. Equine fibres were processed for different value added products. The horse and donkey fibre (diameter 40-160 µ) were blended with indigenous wool and processed on dref-2 system using acrylic as core yarn. The yarns were used to produce furnishing fabrics. Considering the colour, equine fibre were sorted into black fine, black coarse, brown and grey. The fineness of black and black coarse fibres were 42.1 and 52.5 µ, respectively whereas, the brown and grey fibre were 46.5 and 56.5 µ. The tenacity varied from 8-9g/tex and elongation varied from 19-26%. The camel fibre scored lower tenacity and elongation than equine fibre. Donkey hairs were blended with wool in different proportions for producing certain cloth in a natural colour. Pure wool, Wool-acrylic blended blankets were manufactured to optimize the performance and to reduce the cost. Very coarse yarn of about 0.5Nm was spun by hand from goat hairs (70-80 µ fibre diameter) and utilized for making goat hair Patti and durrey. The fineness of yak fibre varied from 36 to 46µ. Though the fibre was quite coarse, its bundle tenacity and elongation percent were adequate for utilization in blanket, carpet and felt preparation. Shawls out of rabbit hair / Pashmina blends were got prepared from the yarn to observe the effect of blend level of rabbit hair and Pashmina fibre. Yarns were spun out of Ramie-Polyester blends in 20:80 and 40:60 and 50:50 proportions. The yarn performance was quite satisfactory.

Blending of wool and Angora rabbit hair with cotton : A collaborative project with CIRCOT, Mumbai on short-staple wool-cotton blends processing revealed that the short staple fine wool (Avivastra) could be blended with medium and fine cotton in different proportions and processed on cotton spinning system for 32 and 48 cotton counts. The wool-cotton blends were used to prepare different value added products. The blended products were dyed in a single bath using different natural dyes like ratanjot, henna, Haldi with good fastness properties. The blended products were dyed with reactive dyes in a single bath at different pH to obtain solid shades. Similarly, Angora wool was blended with cotton and polyester. The blends were then processed in a cotton spinning system.



Survey of felt industries : Among handmade felt manufacturing units, the installed capacity was ranging from 50-100 kg/day. Production efficiency varies from 70 to 80%. The annual production per unit was ranging between 10000-15000kg. It was estimated that total handmade felt produced in the country is about 0.6-1.0m kg which consume 1.0-1.5million kg of raw wool, synthetic waste and low quality cotton during 2003. Among the machine made felt manufacturing units, the installed capacity was varying from 150-200kg/day. These units run on an average efficiency of 70-80% and total felt production per annum varied from 18000 to 40000k. Considering 40 machine made felt units, the annual production of machine made felt is about 1.2mkg which consumes about 1.5-2.0mkg of raw wool and other synthetic fibre. Among wool fibre, medium-coarse Indian wool and fine merino waste (noils) are used. Virgin Merino is also used as source for quality products. Among Indian wool Chokla and Sekhawati wools are commonly used.

Polyester, viscose, acrylic and cigarette filter in the form of waste also serve as raw materials for this industry. The proportion of these fibres was restricted up to 20% in hand made felt and 30% in machine made felt. The handmade felt is generally used in handicraft and floor covering items. However, most of the units surveyed at Jaipur also manufacture felt for industrial application of lower density 0.31-0.35 g/cm^3. The felts used for Industrial applications include washers, channels, rings, strips, filters, bubs and baits padding, oil seal, gaskets, etc. Various

kinds of woolen felt products are used in automobile, packing, defence, leather industry, railways, filter industry, glass industry, etc.

Development of hand-made felts : The medium quality wool, coarse wool, camel hair and rabbit hair were used to prepare the felt. All the blends were dusted, opened and carded as per normal practice. The opened carded web of fibre was laid down manually in the form of a bed keeping in view that an almost equal density of fibre was laid per unit area. The bed was impregnated with an emulsion of desi soap in water by sprinkling the emulsion by hand and rolling the bed. The fibre bed was left for about 4 hr to allow all the fibre to absorb the desired moisture. After that, the bed was rigorously rubbed with the help of a hand. Simultaneously mending of thin places was done by putting extra tuft of fibre and rubbing till a compact structure was achieved. Felt of 4'x6' size was prepared and washed to remove extra alkali present in the felt. The washed felts were dried, cut to size and ornamentation was done by stitching thin pieces of felt of different colours by hand. The felts were prepared to keep 5mm thickness and 1.0kg/m^2 weight. However, thickness and weight had varied from 4.6 to 6.6mm and 0.8-1.2kg/m^2 in medium wool-camel blends and 3.0-4.6mm and 0.46-0.8kg/m^2 in Rabbit hair blends.

Objective evaluation of hand-knotted carpet : Best-fit equations for THV (Total Hand Value) obtained from regression analysis shows that THV mainly depends on the thickness and pile density of carpets. The coefficient of regression was 0.715 and best-fit equation was THV (Predicted) = (-)0.847+0.124 Thickness+0.023 Pile density. The empirical equation is obtained for abrasion loss is Abrasion loss (%) =1.64+0.035 Medullation (%). The regression coefficient is 0.60 significant at 99% confidence level. Similarly the empirical equation for TAV is Visual appearance at cut pile TAV = (-) 4.35+0.023 Pile density+0.1 Compressibility. The regression coefficient is 0.75 significant at 99% confidence level.

Wool - Jute heterogeneously mixed carpet yarn : Jute obtained in the form of sliver is blended with Magra wool top on gill box. One passage of gill imparts heterogeneous blending of wool jute in the sliver. The slivers were fed into Dref-2 spinning system and a yarn of 2 Nm was prepared. The ratio of wool: Jute in the yarn was maintained as 82:18. Yarn spinning particulars were consisted of yarn delivery rate- 80m/min, drum speed -1200 rpm and feed rate -1.82m/min. These yarns were dyed with metal complex dyes. The dye was absorbed by only the wool component and Jute was left undyed. As a result, a unique shade is obtained with a variation in colour at irregular length intervals. These yarns were converted into tufted carpets with a special appearance and feel. The marketing intelligence revealed that the carpet sample had good demand.

Research contributions: 2002 - 2012

Processing and product manufacturing from Camel hair : Camel hairs were procured and sorted according to fineness into fine, coarse and brownish black. Kid camel and adult camels were sorted separately. In kid hair fine, coarse and black were 59, 16 and 25%, respectively. Similarly, in adult camel hair the brown, coarse and black hair was 67, 11 and 22%, respectively. The adult camel hair brown was blended with Uttaradha (Magra wool) wool at 20 and 40% levels. Similarly, the camel hair was blended with VSF at similar levels. The fine kid camel hair was processed on the miniature spinning system in blend with VSF at different blends levels and the yarns of approximately 30 Nm could be prepared which indicates that hosiery yarns can be prepared. The adult camel hair blended yarns with 20 and 40% with Uttaradha wool and VSF was processed on a woolen system of yarn spinning. The same blends were hand spun also. The tenacity of machine spun yarns was found to be superior because of yarn regularity and uniform insertion of twist. All the yarns were converted into blankets fabric on handlooms keeping the warp of wool. The fabrics were subjected to the process of scouring, milling, raising, decatising and stentering. The blankets met the relevant B.I. standards thus indicating the potential of camel hair fibre utilization in blends with wool for blankets. The machine spun yarn prepared blankets did exhibit better performance and rank correlation studies

established the same. The thermal insulation did not exhibit any significant variation. The blended camel fibres were also converted into Hand-made felts and they were tested for abrasion loss at 1000 cycles against a standard abradant, compressibility and resiliency. The test results revealed a superiority of 20% blended products. The different blended yarns were also converted into handmade durries keeping cotton yarn as warp. It was revealed that the Durries prepared from pure wool were best followed by camel wool blends and machine spun yarns.

Hand knotted carpet samples were prepared from different types of wools, camel hair blends and also from handspun yarns. The pile height kept was 12 mm and after sample preparation, these were clipped and neutral wash treatment was given. The test results indicated that abrasion loss on 1000 cycles is within limits. Compressibility, resiliency and recovery values were reasonably good. The visual appeal and handle values of the carpet were good. Since the camel-wool blended carpets exhibited nearly equal performance as that of pure wool carpet, it was inferred that carpets of good performance characteristics can be prepared from camel hair in their natural colour limitation being dyeing of camel hair in pastel shades. This can also be overcome by keeping camel hair yarn as base material and designs introduced by pure wool dyed yarns.

Processing and product manufacturing from goat hair : The common goat hair is obtained from many domestic breeds (Marwari, Mehsana, Ghiluwadi, Zalawadi, Kutchi, Gaddi, etc.). The average fibre diameter was 69±5μ and the fibre length ranged between 42 to 76mm. The tenacity was 8 to 12g/tex with the breaking extension of 25±3%. Goat fibre being very coarse, it was not possible to spin it on the conventional machinery. Therefore, all the coloured fibres were hand-spun on a wheel Charkha into single yarns. Thereafter each of the yarn was doubled also to minimize the variations in yarn irregularity. Each single yarn and the doubled yarn was evaluated for performance characteristics. The results indicated a high amount of variation in all the measured properties, which is obvious due to the hand spinning procedures. The variability was removed to a good extent in the doubled yarn. The yarn breaking elongation was also on to a lower range as compared to woolen and camel yarns. The fibre and yarns both being coarse were converted into handmade Durries and Handmade carpets keeping warp of cotton yarn. The doubled yarn druggets fulfilled the norms of IS 697 whereas the single yarn druggets were nearer to it. The independent rank evaluation studies of druggets indicated a preference for Red and White coloured ones as compared to Black and Bagari. Carpets were also prepared from Goat hair yarns in suitable quality with 12 mm pile height. The carpet performance was evaluated and the test results indicated lower variation in respect of performance characteristics amongst the different colored carpets. However, the abrasion loss is relatively higher with slightly lower recovery values. The handle values reveal the repeat pattern as in the case of druggets i.e. red followed by white. It is pertinent to mention here that the coloured carpet specimen reflected a highly glossy lustrous surface appearance.

Development of high quality blankets : High quality check blankets using different colour patterns were developed by optimizing different wool mixes. Indian wool of different fineness mixed in different proportion was spun into 4 Nm yarn on woolen spinning system. Fine cross bred wool: indigenous Chokla wool: Nylon in the proportion of 45:50:5 was found as a optimum blend for good quality blanket. The blanket of BIS specifications was woven on power loom. The chemical finishing treatments viz., milling, decatizing and raising were given to enhance softness and dimensional stability of blanket. The blanket possesses soft feel and excellent thermal insulation properties.

Quality carpet from Indian wool-nylon blends : Indian carpet wool in pure form gives excellent resiliency property to the carpet. However, it has higher abrasion loss during usage due to higher percentage of medullated fibre which adversely affects the life of carpet. To improve abrasion resistance and other functional properties of the hand knotted carpet, Nylon-6 (3 denier) was blended with Magra wool in different proportions. The yarn was spun on the woolen spinning system with 3.5 Nm. The yarn was dyed into different colours using metal complex dyes. Anti-moth treatment was also applied simultaneously. The computer aided design (CAD) system was used to develop the design on paper. The paper design was converted into

an intricate designed hand knotted carpet of 144 knots per inch with a pile height of 10 mm. The carpet was chemically treated using the standard technique. The blending of nylon up to 10% level improved the spinnability as well as yarn quality in terms of tensile strength and lustre. Carpet made from wool-nylon (90:10) gives a very good appearance as well as abrasion resistance without adversely affecting resiliency property.

Development of handloom woven carpet : For enhancing productivity and profitability of carpet manufacturing, handloom weaving was introduced. It can produce plain carpet for wall to wall floor coverings. The technique was standardized using various constructional parameters such as pile height, density and ply of yarn. A mono-colour carpet of 1500 g/m^2 could be produced with pile height of 8-12 mm. The carpet costs cheaper and affordable for middle income group consumers. However, the life of such carpet is shorter than hand-knotted carpet.

Development of shawl from Bharat Merino wool and its blends : Bharat Merino wool, a fine cross bred wool graded for longer staple length and scoured into three bowls scouring machine to the extent of <0.5% residual grease content. The wool was processed on a semi-worsted system and finer yarn of 56 Nm was spun. The quality shawl was manufactured to confirm BIS specification as well as other quality norms.

Angora rabbit hair: Bharat Merino wool blended shawl : Angora rabbit hair products are always in high demand due to their special attributes like high thermal insulation and superior softness with light weight and thickness. The blending of Angora wool with fine crossbred wool was carried out using the modified cotton card at a slow speed to avoid breakage. The blends were then processed into yarn using a semi worsted system using a gill box, roving frame and worsted ring frame. The blended yarns were then woven into a shawl in a 2/2 twill weave pattern on a handloom. Shawls were developed from blends of Angora rabbit hair and Bharat Merino wool using the proportion of Angora rabbit hair (70%): Bharat Merino wool (30%). Blended shawl possesses excellent whiteness, soft feel and good thermal insulation property.

Improvisation in whiteness and softness of shawl : A process for improving whiteness and softness of Angora rabbit hair: Bharat Merino wool blended shawl was developed. In this process, bleaching using H_2O_2 followed by finishing with a cationic softener was done in the same bath. The processed shawl shows 30% higher whiteness and 20% improved softness as compared to the conventionally processed shawl.

Economically viable natural dyes : Economically viable natural dyes from different sources like silver oak, onion peel-off, saffron, cochineal, walnut, henna, sisham leaves and madder root for woolen yarn were identified. Natural dyes extracted from the above sources were extracted by conventional aqueous extraction method and applied to Pashmina shawl and other woolen products in presence of mordants such as aluminium sulphate, stannous chloride, and ferrous sulphate. A wide range of colours ranging from orange to grey, black, yellow and green was developed using the selected natural dyes. The fastness properties of the dyed samples were very good. Hence these dyes have the potential for eco-friendly dyeing of the wool shawl as well as carpet.

Non-woven felt for technical textiles : The processing techniques like fibre selection, scouring, mixing, carding, hardening, felting and other chemical finishing treatments were standardized for the development of apparel and technical felts. Inferior grade rabbit wool, which had little textile application for quality goods, was blended with short-length crossbred sheep fine wool in various proportions. The blend optimization indicated that up to 40% inferior rabbit wool can be blended with wool for making superior quality lightweight and extra white felts; converted into value added products like Jackets and women ruffles. These products had enhanced product quality and consumer acceptance with better luster, durability and thermal insulation value. These felt are also found suitable for surgical application in medical textiles. Technical felts were also developed using blends of spinning wool waste (50%) and coarse wool (50%) with a thickness of >6 mm. The felts were dyed in attractive colours using natural and synthetic dyes and made

into Namda of three different dimensions viz. 6'x9', 5'x7' and 4'x6' with attractive embroidery works. These products had enhanced product quality and consumer acceptance.

Software for forecasting quality of carpet : Software named "Module for predicting performance characteristics of hand knotted carpet" was developed using a database on the performance of hand knotted carpets. Fibre characteristics such as average fibre diameter, hetero fibre and medullation and carpet construction parameters i.e. carpet thickness, pile height and pile density are used as input parameters to predict carpet performance in terms of Carpet Hand Value (CHV), abrasion loss, compressibility, resilience and recovery after dynamic loading. The software is capable to classify the carpet into five categories i.e. poor, average, good, very good and excellent. It can predict these properties within the range of error ± σ value.

NAIP on Pashmina fibre : Research efforts were carried out jointly by CSWRI, Avikanagar and SKUAST-K under the National Agricultural Innovation Project entitled "A value chain on enhanced productivity and profitability of Pashmina fibre" with the thrust of the utilization of Pashmina for its cost-effective value addition and its suitability for blending with other natural fibre in order to produce varieties as well as products of high quality at a reasonable cost. Technologies developed are summarized below:

Study on manual v/s machine dehairing : Pashmina was procured from All Changthangi Pashmina Growers Association, Leh Ladakh. Half of the Pashmina was dehaired manually in Kashmir valley while half was dehaired on machine. Fibre diameter and bundle strength showed non-significant difference whereas fibre length and co-efficient of friction showed a significant difference between the treatments. Scanning electron microscopic images clearly showed surface damage in case of machine dehaired Pashmina fibre.

Pedal operated charkha for pashmina spinning : The traditional charka used for spinning pashmina fibre was modified to improve its efficiency. The improved charka proved efficient by 74% in terms of time and 80% in terms of remuneration as against traditional one.

Development of machine spun yarn using nylon as carrier fibre : Pashmina fibre is very difficult to spun in the machine due to its very soft, short and slippery scales which create lapping and static charge during carding, sliver making and spinning processes. The nylon was blended with pashmina in the ratio of 50:50 and 60:40 proportions at the gilling stage followed by spinning on the ring frame. By this process, a yarn of 2/48 Nm was produced. A shawl type fabric was manufactured out of the produced yarn. The nylon portion of the fabric was removed by treating it with hydrochloric acid. The produced fabric was compared with conventionally hand spun made pashmina shawl fabric and found that there was a significant difference between the two fabrics in terms of softness, thermal conductivity. However, the machine spun yarn made fabric showed 60% lower extension and 50% higher abrasion loss. The SEM results showed that the machine spun yarn made fabric had a minute deposit of dissolved nylon in a few places compared to the hand spun yarn made fabric.

Use of PVA as carrier fibre : The pashmina fibre was spun in a machine using poly vinyl alcohol fibre (PVA) instead of nylon as carrier fibre. PVA fibres are soluble in hot water. To remove the PVA from the fabric, the fabric is treated with hot boiling water instead of hydrochloric acid. The advantage of this technique is that pashmina fibre does not get damaged in hot water as was the case with HCl. This method of spinning is considered as eco-friendly as well as cost-effective.

Development of size-box for improvement of weaving efficiency : Sectional warping machine has been introduced which improves the efficiency of warping and maintain uniformity in tension and avoid entanglement of yarns on beam. Under the process, a size box has been introduced between creel and sectional warping machine. The section of the warp was passed through between sizing and squeezing rollers. The sizing roller was immersed into a size paste which was taken by a sizing roller upon the top of the roller. The section of warp yarn was touched by the sizing roller at the top and the yarn gets immerged with size paste. An excess amount of size paste got removed by a squeezing roller mounted on the top of the sizing roller. In order to separate threads from each other, a reed has been fixed before sizing the box. Conventional sizing was not suitable for woolen and worsted warp because of their

stretchability and heat sensitivity. Cold sizing was found to be one of the alternatives to solve this problem. Poly-vinyl alcohol (3%) was found suitable sizing material for pashmina and pashmina blended yarns. The weaveability of the shawl was improved by 40% as compared to traditional weaving using the developed method.

Value addition of Pashmina : The shawl made of silk filament or silk blended yarn has a better lustre and visual appearance as compared to pure Pashmina. The blending of rabbit hair also improved the lustre of the shawl. Shawls made of Pashmina-Nylon blended yarn after dissolving Nylon by chemical treatment improves lustre significantly. The softness was found to be decreased after blending wool, rabbit hair, or silk. Shawls made of machine spun Pashmina Nylon or Pashmina PVA as well as Pashminas silk, wool blended yarns gave highest total hand value followed pure Pashmina shawl, Pashmina wool as well as rabbit hair wool blended shawl. The relaxation shrinkage of the shawl made of pure Pashmina and the blended yarn is within the acceptability of ±2%. The formability of the Pashmina shawl was lower in comparison to suiting fabrics. The extensibility of pure Pashmina shawl was ranging between 5-6% at 100g load. The blending of wool/silk/rabbit hair enhances the extensibility. Extension in biaxial direction was higher in PVA/silk blended shawl as compared to pure Pashmina shawl. The bending rigidity significantly lowered in Nylon or PVA blended shawl as compared to pure Pashmina shawl. The shear rigidity did not show significant differences between pure Pashmina and blended shawl. The shawl made of silk filament was thinnest followed by pure Pashmina and blended shawl. The bending rigidity showed a significant negative correlation with the softness of the shawl. The thickness at 100 load showed a significant correlation at 95% confidence level with smoothness.

Development of natural dyes for Pashmina fabrics : The dyeing of pashmina fabric using natural dyes is a definite value addition to the product. However, there are some problems associated with the use of natural dyes on Pashmina fabric. The major problems are the non- availability of suitable dye in bulk, poor fastness properties. In order to solve these problems, a comprehensive natural dyeing process with abundantly available natural materials was developed. The locally available materials like saffron flower petals, walnut husk, onion peel off, henna, pomegranate rind, etc., were used for dyeing. A wide variety of shades from yellow to blue, grey, etc., were produced on Pashmina fabric. The fastness properties of the developed shades were very good.

Dyeing with pomegranate rind : The rinds of pomegranate contain colour compounds such as 1-O-Isopentyl-3-O-octadec-2-enoyl glycerol, 1-O-Trans, cis, trans-9,11,13-octadecatrienoyl glycerol, Luteolin and Tricetin. These substances were tested as dye on Pashmina wool with promising dyeing properties. The colours obtained on the Pashmina fabric using pomegranate dye extract are pale yellow, bright yellow, orange and dull green.

Dyeing with cochineal insect extract : Generally, the Pashmina shawls are dyed with very bright purple and scarlet colours. There is a lack of such colours in the plant based natural dyes. In order to address this problem, cochineal extract obtained from insects was attempted. Pashmina fabric could be dyed with a natural dye extracted from a cochineal insect into scarlet red colour and cochineal dye was exhausted between 80 and 95% at 50-60°C in 120-150minutes. The K/S value is ranged from 0.526 to 0.816 with very good washing (4-5) and light fastness (6-7) at this standard condition. A coordination complex could be formed between functional groups of Pashmina wool polymer and metal cation/dye molecule and that complex might be entrapped in between polymer chains. It was concluded that this natural dye could be given solid shade on pre-mordanted Pashmina wool at 60oC in 120minutes through a strong co-ordinate complex between dye-metal ion-fiber.

Dyeing with other sources : The process of dyeing Pashmina fabric using Henna, Silver oak, Indian Tulip leaves, Dhol Kanali root, Madder, etc was optimized. Based on this, it is possible to dye the Pashmina fabric using natural dyes comprehensively with good washing and light fastness properties.

Economics of natural dyeing : Cost analysis of dyeing of pashmina shawl using natural sources shows that artisans get a profit of Rs.400/- with an investment of Rs.100/- per shawl. The shawl gets a premium price due to the eco-friendly nature of the product.

Development of natural dyes with anti-microbial and anti-moth properties : The natural dyes apart from colouring the textiles also provide anti-microbial and anti-moth properties. The saffron flower petal dyed Pashmina shawls showed antimicrobial efficacy against S. aureus. However, the saffron, onion-dyed materials did not show anti-moth properties, whereas henna, walnut, sesame dyed materials had shown anti-moth properties.

PCR based method for identification of Pashmina fibre : By DNA based analysis method it is possible to distinguish Pashmina from wool. However, when the different animal fibre is mixed and subjected to conventional processes like dyeing, finishing, etc, there is difficulty in extracting intact DNA. Hence, an attempt was made to extract intact DNA from the processed fibre. From the intact DNA from sheep, Pashmina and Angora wool, 12S ribosomal RNA gene fragment was amplified in PCR by species-specific primer and was confirmed by sequencing. This PCR-based technique was able to amplify genes from DNA isolated from chemical and dye treated animal fibre as well as readymade woolen garments like a shawl. Simple duplex PCR was able to amplify and identify sheep wool from Pashmina $\geqslant$ 10% of total volume. The developed DNA based analytical method can be used as a quality control tool to measure purity and authentication of prepared garments like pure Pashmina shawl.

Research contribution: 2012-2022

Engineered carpet from coarse medium wool : Carpets from coarse and medium coarse wool with 10 mm pile height were developed using a handloom. Chokla and Magra (50:50) wool gave better quality carpet compared to Avikalin and Chokla: Avikalin (50:50). The medullated fibres improved compressibility, resiliency and pile recovery of the carpets due to the small voids in their structure.

Fibre diameter measurement using a computerized microscope : A study was conducted to measure wool fibre diameter and medullation using an advanced computerised projection microscope with image analysis software and results were compared with conventional microscope method. The variations in fibre diameter measured by two methods were significant at 5% level. However, the standard deviation and coefficient of variation of fibre diameter were lower for the computerized microscope system than the conventional microscope method. The new system provides quicker, reproducible and more accurate results. It also requires less manpower as compared to a conventional system. The data can be retrieved at any point.

Spinning performance of JK wool blending with Australian Merino wool : In order to improve spinnability and enhance the quality of product from indigenous wool (JK wool) was blended with Australian merino wool in a proportion of 25:75, 50:50 and 75:25. The blends were subjected to roving and spun into yarn of 32 Nm with 16 TPI on NMC charkha. The prepared yarn has good characteristics in terms of strength and evenness. It was concluded that blending indigenous JK wool with Australian merino wool to the extent of 50% is permissible in Khadi products.

Spinning performance of wool-cotton blends on Khadi system : The crossbred short wool produced in J&K, Himachal Pradesh and Uttarakhand state has a shortcoming of lower fibre length (<40 mm) and is unable to process on semi-worsted spinning system. The blends with cotton in three proportions viz. 10:90, 20:80 and 70:30 (W:C) were prepared. The modified cotton preparatory system was used to prepare roving of 2.1-2.4 Nm and spunned into 24 and 32 Nm yarn on khadi charkha. All three yarns were knitted on hand operated flat knitting machine with 10 gauge, 1x1 rib structure and cover factor of 13-15. The developed knitted fabrics were evaluated for different low stress

mechanical properties and found that knitted fabric having wool @ 10% is suitable for hosiery as undergarments. Wool-cotton blends in 20:80 and 30:70 proportions are suitable for men/women outer wears and jackets, respectively. The prepared yarn with 30% wool blend is also used to prepare designer shawls by varying the denting and drafting order during the weaving process.

Newer natural dye sources for wool with anti-moth properties : Shisham leaves (Dalbergia sissoo) and Yellow Root (Berberis lyceum) were used to dye the wool fabric with and without the use of mordants. The colours developed were yellow and brown. The light fastness properties of Shisham leaves dyed fabrics were excellent. The protection of woollen products from moth attacks is an important concern. Anti-moth properties can be imparted by using suitable natural dyes The shisham leaves and yellow root dyed materials have antimoth properties. It was found that the addition of mordants during dyeing increased the moth resistance properties of the dyed materials. Among the mordants, stannous chloride and ferrous sulphate mordanted and dyed fabrics showed improved moth resistance properties as compared to aluminium sulphate mordanted fabrics. Besides that, the screening of natural dye such as sisame, ajwain seeds, custard apple leaf, walnut husk, myrobalan, henna and silver oak revealed that they possess anti-moth properties. The phytochemical test indicated that higher content (>20%) of tannin imparted anti-moth properties to wool in addition to dyeing. The natural dyes viz., sisame and madder root contained 32.5 and 22.5% tannin, respectively have anti-moth properties as compared to onion and saffron (4-8% tannin).

Enzyme finishing of wool products : A protease enzyme based finishing process was developed for tweed fabric produced from Chokla wool to improve the handle and softness. The optimum enzyme concentration, pH, time and temperature of treatment were 3 g/L, 8-9 pH, 45min and 70°C respectively. The developed enzyme based finishing process improved the handle/softness of tweed fabric to the accepted level to be used as a tweed fabric. The protease treatment significantly reduced the fibre shedding property of Angora–Bharat Merino shawls.

Enzyme treatment for Angora–wool blends for pilling resistance : Fibre shedding during the preparation of shawls from Angora is a major problem. Protease enzyme treatment and silicone softener were tried to reduce pilling and fibre shedding. Shawl prepared from Angora: wool (60:40) after treatment showed a significant decrease in pilling and fibre shedding as well as improved its handling

Quality norms for Pashmina shawls : The low stress mechanical properties determined for shawl fabrics using SIRO FAST. A significant difference in the SIROFAST properties has been found among pashmina shawls prepared using hand spinning, machine spinning and blending with other fibres. Based on this, norms were formulated to distinguish and identify the pashmina shawl manufacturing technique.

Removal of kempy fibres for better utilization of coarse wool : The South Indian coarse wool has some inherent drawbacks like coarseness (60 μ), high medullation (62%) and high amount of kempy fibers (27%). Hence, it is not preferred for carpet and felt production. This coarse wool was passed through a cotton card with a modified speed ratio which removed about 70% of kempy fibres. It showed improvement in fibre fineness by 36 and 35% and an overall reduction in medullation%. Such kemp free wool was blended with fine wool (55:45) and the blend was used to prepare blankets. The blended yarn was 30% finer than the yarn made of coarse wool. Better quality of yarn produced out of the coarse wool by a modified process and optimized blend ratio. The yarn was then converted into blankets.

Wool based geo-textiles for agricultural application : The use of coarse wool in geo-textile for improving water retention, fodder yield and soil fertility has been studied. Wool felt loose wool mat and raw wool dust were used as geo-textiles for barley crop showed improvement of 71% germination, 25% moisture retention, 57% green fodder and 23% crop yield. Soil properties (electrical conductivity, organic carbon content) and concentration of micronutrients (copper and manganese) were also improved.


Handicraft woollen products : Different types of handicraft products like felts, home furnishing articles (like wall hangings) ready for showcase with novel designs and colour combinations were developed from coarse and medium coarse type wool.

Development of diversified knitted garments from native wool and speciality fibres : The indigenous fine crossbred wool viz. Bharat Merino, J&K Merino combed, J&K carded wool and speciality hair i.e. Angora and Pashmina blends in proportion to 50:50 were prepared to develop diversified knitted apparel products. To improve the durability and appearance 30% polyester has been blended with reducing the speciality hair component. Six different yarns with a linear density of 36 to 42 Nm with average yarn realization of 87.5% which was exceptionally good considering blend with Angora /Pashmina. The wool and Angora / Pashmina blended yarn observed to tenacity (g/tex), elongation% and unevenness (U%) in range to 2.86-3.99 g/tex, 5.26.8% and 22.9-27.0% respectively. The yarn produces from angora : wool blends have lower strength and higher imperfections which is not desirable for knitting. The blending of polyester improved the yarn tenacity by 35% to 5.49 g/tex and yarn elongation and unevenness by > 90% to 10.1% and 14.2% respectively. It is elucidated that the addition of 30% polyester enhanced the yarn strength and improved the spinning performance without losing the luxury of wool and Angora. The polyester blended speciality hair yarns are successfully knit into double jersey knitted fabrics on the double flatbed knitting machine. However, being polyester as component fibre (30%), fabrics are found difficult to dye due and shade variation. The prepared knitted fabric has been finished to anti-moth (Eulon 0.2%) and softener (amino silicon 0.5%) Both fabrics were converted into a product (ladies cardigan) with market acceptability.

Coarse wool felt as technical textiles for young lamb protection in winter : Coarse Malpura wool soft milled felt with 1000 g/m^2 was prepared and belted jackets for young lambs are fabricated for physiological study. Young lambs adopted well the jackets without any adverse effect but expected body weight growth was not observed. In another way to protect infant lambs in peak, a winter felt-based lamb incubator was designed and developed under the NICRA project. The indoor temperature of the developed lamb incubator was observed to be 3°C higher compared to the normal lamb shed with a curtain cover. The felt-based lamb incubator can reduce the cold stresses of infant lambs during peak winter.

Development of thermal insulated fabric for high altitude regions : The body temperature, relative humidity and air motion are the decisive factors for comfort level in humans under cold stress conditions. Apparel act as a barrier to the free exchange of heat to the environment. The microclimate is to balance between the rate of heat production and the rate of heat disposal. A breathable protective clothing system loses 60-70 % of its total insulation in wind conditions at higher altitudes. Thermal insulation of textile fabric/ensemble is due primarily to the still air within fabrics and yarns. Fiber type significantly affects surface temperature changes and moisture vapor pressure at the inner fabric surface during dynamic moisture transfer. The Angora fibre has special attributes laddered hetero typical medulla with regular rings arranged in uniserial or multi serial series with entrapping of still air in the medulla, fibre can acts as a climatic chamber thus estimated to 3-5 times warmer than wool. A low fibre density of 1.13 g/cm^3 compared to wool 1.32g/cm^3 and good bulk resiliency made it more suitable for insulation material. CSWRI developed pure Bharat Merino wool and its Angora fibre blend (50:50) yarn with a linear density of 2/32 Nm were then woven into fabrics with 2/2 twill structure on the handloom with 201 and 182 g/m^2 respectively. Fabric ensembles were prepared with 1 to 4 layers of Bharat Merino wool (BM) /Angora blended fabric as mid-layer and stitched with two different impermeable outer layer fabric viz. laminated fabric and thermally bonded fabric while high density 100% polyester fabric was used as interlining. The single-layer fabrics for ensembles viz. laminated outer coat, thermal bonded outer coat, inner lining polyester, 100% BM and Angora/BM (50:50) measured to the thermal resistance of 2.36, 2.20, 2.1, 2.13 and 1.96 Tog respectively. Ensembles of laminated outer layer fabric observed higher thermal resistance values thaa ensemble with thermal bonded outer layer fabric attributed to higher thickness, weight and entrapped air in the said ensemble. The highest thermal resistance value is observed with 4 layer BM/Angora (50:50) fabric in mid-layer with laminated outer coat and polyester inner lining to 16.7Tog. The prepared fabric ensemble is suitable for high altitude cold stresses with low wind speed. Increase in layers for more than two in the mid-layer the thermal resistance increases linearly. High thermal and bulk properties of Angora fibre are attributed to better performance of Angora blended fabric in mid-layer of an ensemble.

Development of polyester-wool knitwear : Using semi-worsted spinning machinery, six types of yarns were prepared and their unevenness, imperfections and hairiness of different yarn were recorded. Four types of knitted fabrics were prepared from 100% Australian Merino wool yarn, 100% polyester yarn, polyester/Merino wool yarn and polyester/ Angora wool yarn in a fully automated flat knitting machine. T-shirts were prepared out of these yarns.

Wool-cotton blended blankets with improved softness : Cotton was blended (5-30% level) with wool (Bharat Merino and Chokla) and prepared seven types of blankets. The plain wool fibre yarn was found to possess higher elongation (5.6 to 6.9%) than that of wool/cotton blended yarns. An increase in the proportion of cotton has resulted in a more cool feeling to touch. Maximum smoothness was observed for the cotton: wool blend ratio of 30:70. This study has demonstrated that up to 30% cotton can be blended with medium and fine wool in preparation of woolen blanket using woollen spinning system. The cotton blend improved the softness, smoothness, look and feel of the blanket.

Optimization of blends for carpet from Chokla/Magra/New Zealand wool : Magra and Chokla wool were blended with New Zealand wool. The woolen yarn was prepared from a mix of New Zealand wool and native wool in the proportion of 100:00, 75:25, 50:50 and 25:75. The yarn counts for different blend yarns were varied from 3.5 to 4.0 Nm except for yarn of 25% New Zealand: 75% Magra wool (3.37 Nm). After dyeing the yarns, handloom carpets were prepared with a pile height of 10 2 mm and a pile density of 1200 g/m^2.

Carpet compression and performance properties : Wool from Avikalin sheep was mixed in a proportion of 25, 50 and 75% with Magra wool and spun the yarn of 3.5 4.0 Nm linear density on woollen spinning system. The carpet with 50% Avikalin wool mix was observed a higher pile density to 1631g/m^2 due to a coarser yarn count to 3.5 Nm. The fibre

characteristics of pile yarns were well in the range of ideal carpet wool (30-40µm fibre diameter and 30-40% medullation). An improvement in carpet compressional properties was observed on mixing of Avikalin wool in the proportion of 75%. Even with the higher pile density of 1631g/m², the carpet with 50% Avikalin wool mix showed the highest value for carpet compressibility (45.1%), followed by 44.5% for carpet with 25% Avikalin wool in the mix. The performance properties of the prepared carpet were evaluated in terms of pile fibre abrasion loss for the first 1000 cycles of abrasion and durability factor. Mixing of Avikalin wool at the rate of 25% to Magra wool is found permissible for similar compressional and higher durability factors.

Preparation of activated carbon from agricultural residues : Activated carbons were prepared from oil cakes of almond, coconut, mustard, rice bran using ball milling and filtration methods in the presence of H_2SO_4 and H_3PO_4. After preparing the activated carbon, moisture content, bulk density, methylene blue value, porosity, pH, TDS, FTIR, SEM and particle size analysis were performed for the characterization. The highest methylene blue value (165), and least particle size (110 nm) were observed for 1N H_3PO_4 coconut (Ball Milling). The least bulk density (0.592 g/cc) was observed for 2.5N H_2SO_4 almonds (Ball Milling). The highest porosity (0.369 ml) was found with 2.5N H_3PO_4 mustard (Ball Milling). The highest moisture content (16.22%) was observed for 1N H_3PO_4 coconut (Filtered). The methylene blue value and colour removal efficiency were enhanced for all the adsorbents after ball milling because of the higher surface area. In general, the moisture content of the activated carbon reduced after ball milling.

Extraction of madder dye by fermentation : Madder dye was extracted through fermentation using aerobic and anaerobic methods at 27°C temperature and 65% RH. For fermentation, the ratio was kept as 20% sugar and 10% yeast on the weight of the dye. The madder dye was kept in the yeast and sugar solution for the different duration (1, 2, 4, 6, 8 days). The resultant colour was filtered and used for the dyeing of cotton and wool. The dyeing and fastness performance showed extraction of colour by fermentation method. Aerobic fermentation produces better colour than the anaerobic method. The optimum duration for the extraction was 24h at pH 5.0. The washing fastness of the dyed fabric was found good.

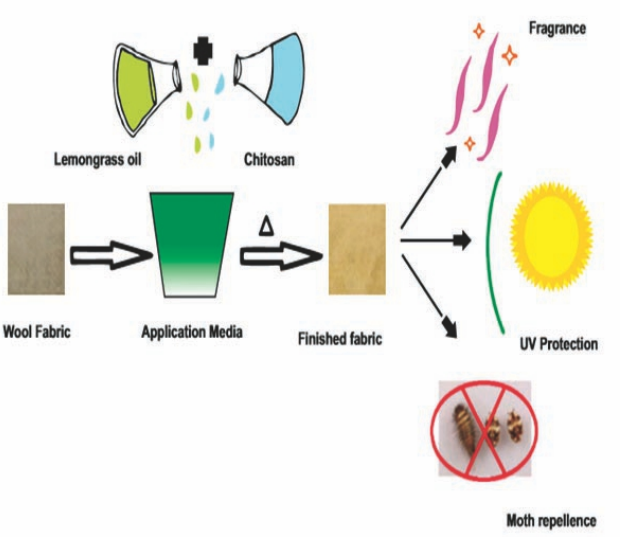
Dyeing of woollens using chick pea extract : The outer covering of chickpea (an agro-processing residue) was extracted with water and used to dye the wool fabrics at different temperatures without any mordant. It was found that the dye has good affinity to wool. Treated fabrics showed a good dye uptake and adequate wash, light and rubbing fastness properties. The dyed fabrics exhibited good ultraviolet protection properties and excellent resistance against S. aureus and E. coli.

Fire retardant finish of wool / eri silk union fabric using nano kaolinite : Nano kaolinite was applied on wool/eri silk union fabric for fire retardant finishing. For enhancing the washing fastness, 0.1% acrylic polymer was applied. The highest Limiting Oxygen Index (LOI) of 35 was obtained for the optimum concentration of 2.5% of kaolinite. The physico mechanical properties of the treated fabric were not affected after treatment.

Water repellent finish of wool /Eri union fabric using nano-titanium dioxide : Nano titanium dioxide was synthesized from titanium isobutoxide. The synthesized nano particles were applied on wool/Eri union fabric for imparting water repellence. The results inferred that the particles size of the synthesized nano particles was>100 nm. The nano finished fabric possessed a high water contact angle of 155°, indicating that it became super hydrophobic. The time to absorb one drop of water by the fabric was 90 min.

Aroma finishing of wool fabrics : The scoured wool fabric was treated with 5-20% concentrations of lemongrass oil along with 0.25% chitosan by a pad-dry-cure method. The treated fabrics had a high aroma and showed strong resistance to the abrasion up to 10 cycles, while at 50 abrasion cycles aroma score dropped by around 40-50%. Further, approximately 75-80% aroma was lost after 100 abrasion cycles. During abrasion and washing, no significant difference in the aroma was found among the variously treated samples. However, the subjective assessment after 30 days showed the positive effect of concentration. The mean score indicates strong retention of aroma on wool fabric even after three months. This long-lasting effect may be useful for various wool products such as apparel, carpets, upholstery, curtains and other home textiles.

Multi-functionality of lemongrass treated wool fabrics : Lemongrass oil was successfully applied to woolen textiles with and without chitosan binder. The FTIR spectra confirmed the presence of lemon grass oil and chitosan on the wool fabric while SEM showed that the chitosan was attached to the surface of the wool fabric. During the treatment, the fabrics got a yellowish shade and their colour strength increased with the concentration of lemongrass oil. Among mechanical properties, bending modulus and flexural rigidity of the fabrics were increased due to the presence of lemongrass oil and chitosan. The higher concentration of lemongrass oil in combination with chitosan resulted in the enhancement of moth mortality and UPF. The fabric damage was low (0.32%) than the prescribed limit (2%). The aroma of the treated fabrics was found to retain after five washes, ten abrasion cycles and even after 90 days of application.



Nanoparticles to improve color strength in the dyeing : The effect of nano-silica and nano titanium on the dyeing of cellulosic fibres with madder dye was studied. The metal nanoparticles were prepared by sol-gel method from respective precursors. Various concentrations of the nanoparticles were added during dyeing. The dye was characterized by FTIR and phytochemical analysis. The post dyeing results inferred that there is a considerable improvement in the dye uptake and fastness properties of the dyed fabric after introducing metal nanoparticles. The SEM and EDX analysis confirmed the presence of nanoparticles on the fabric surface. The physico-mechanical properties of the fabric were found almost intact after dyeing.

Biosynthesis of nanoparticles and their applications on woolens for functional finishing : Silver nanoparticles were synthesized from silver nitrate using eucalyptus and neem extract. This novel method of synthesis avoids the conventional chemical method with NaOH. The particle size of AgNP synthesized using neem and eucalyptus leaves was 129.0 and 60.5 nm, respectively. The biosynthesized AgNP using eucalyptus leaves was further analysed using FE-SEM which confirmed the particle size of 30-65 nm. The synthesized nano-Ag particles were applied on woolen through the exhaust method. Box and Benhan experimental designs were adopted to find out the optimum concentration, duration and temperature of the treatment. The nano-Ag treated fabric was analysed for its ultraviolet protection factor. The results inferred that eucalyptus extract produced much smaller nanoparticles with better stability. The application was effective to produce high protection fabric against UV light. The UPF value (>50) of the treated fabric was excellent.

Shrink resistant finishing of woollens using enzymes : The wool fabric was treated with transglutaminase, lipase, laccase and protease enzymes at various levels to achieve shrink resistance. The optimized concentration for each enzyme; transglutaminase, lipase, laccase and protease showed 7.94, 4.87, 4.32 and 2.97% area shrinkage, respectively compared to 13.28% of the control fabric. FE-SEM images showed the surface scale modification of scoured and enzyme treated wool. The tensile strength and extension of enzyme treated fabrics were found comparable with the control fabric, while frictional and handle properties were significantly changed in favour of enzyme treated fabrics. The yellowness and whiteness of the control and enzyme treated fabrics were also comparable. The single-step enzyme process was sustainable and easy to scale up due to comparable mechanical, frictional, handle, whiteness and yellowness properties.

Shrink-proofing of wool using biopolymers : An effective and eco-friendly biopolymer treatment was developed to improve the shrink resistance of wool fabric. The wool fabrics were treated with gum arabic, chitosan and wheat starch biopolymers using a simple pad-dry cure method. FE-SEM images confirmed a film-like polymeric coating on cuticle

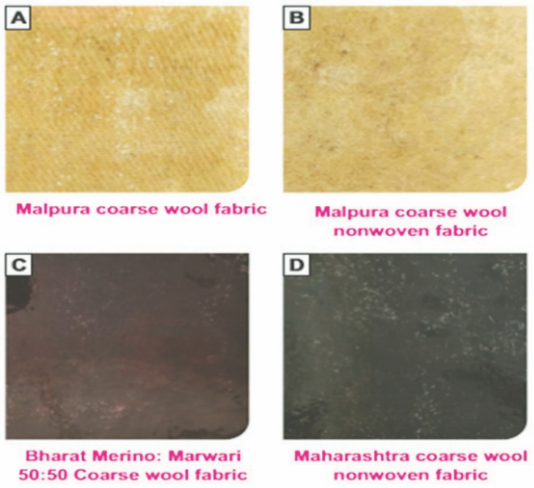
scales of biopolymer treated wool fiber surface. FTIR test confirmed the presence of biopolymers on the wool fabric. Friction properties changed substantially after the biopolymer treatment.

Chitosan biopolymer modified the tensile and bending properties of wool. Whereas, no significant changes in tensile and bending properties were observed in the case of gum arabic and wheat starch coating. The wheat starch coating also showed comparable yellowness and whiteness index with the untreated fabric. The color strength also improved after the biopolymer treatment. The area shrinkage of wool fabric was improved significantly because of biopolymer treatment which covers the scales of the cuticle layer and due to that scales did not migrate at other places during washing. Among all the biopolymers, wheat starch at 0.5% concentration was found most effective for obtaining the least area shrinkage (3.58%) compared to 11% with the untreated fabric. Biopolymer coating using wheat starch and gum arabic is a novel approach to achieve sustainable shrink resistance fabric without deteriorating intrinsic and unique properties of the wool fabric.

Quilt from coarse wool : The carded coarse wool was processed on the needle punching nonwoven line to obtain a lofty sheet of around 250-450 g/m^2. This sheet was cut into 5x7' size. A fine thread count cotton woven sheet was used to cover the nonwoven sheet on both sides and the cloth cover was stitched with geometrical patterns to avoid movement sheet within the fabric. Prepared quilt comforter was subjectively assessed for aesthetics, softness, smoothness, warmth, and breathability and found to have mean values of 3.5 to 4.5 (0-5 scale). Thermal insulation and warm/cool feeling assessed were in the range of 0.234 to 0.300 mK/W and 0.13 to 20.16 W/cm^2, respectively.

Use of coarse wool in braiding : Coarse wool was used as a core material wrapped with a sheath of various natural and synthetic fibres. A braided rope was produced using 16 spindle maypole braiding machines. The water absorption capacity was higher (289%) for wool sheath braided rope as compared to cotton sheath braided rope (142%). Jute braided rope was found to absorb 57% less water in comparison with wool braided rope. The thickness of coarse wool braided rope was between 4.9 - 8.1 mm. The rope was used as weft on a handloom to produce various products like picnic mats, yoga mats and foot mats.

Composites from coarse wool : Coarse wool reinforced composites were developed from coarse Malpura/Magra wool blend fabric using the hand-layup technique. The areal density, thickness, yarn count and fabric cover factor of the fabric were 485g/m, 2.50mm, 3Nm and 22.42, respectively. The fabric was modified to improve interfacial adhesion with the resin. These fabrics were used as reinforcement embedded with the epoxy resin matrix with 40:60 v/v proportions. In hand- layup technique, 25 kg weight was found optimum over the composite size of 20 x 20 cm. The curing time of 24h showed the highest tensile strength compared to 36 h and 48 h. The composite did show mechanical strength of >30 MPa. Later on, wool composite samples were developed using a compression moulding machine. The products like false ceiling and wall panelling from wool composites were prepared at bulk in the size of 1.5x1.5'. These sheets were used in the exhibition room of the division to showcase the technology and its end uses.



Mechanical properties of composites : The mechanical properties of composites were measured on a universal testing machine (Instron 5965) with ASTM D638. Maharashtra Deccani wool composite showed the highest tensile strength (34 MPa) while Malpura wool composite registered the least tensile strength (25 MPa) and attributed to the

differences in the areal density of various non-wovens. The flexural property of composites was measured on a universal testing machine (Instron 5965) with ASTM D790 and obtained a similar trend. Good adhesion was found between Maharashtra non-woven and epoxy resin which is responsible for less void present in the material, eventually resulting in high strength. Flexing and impact test measurement of

Sound insulation properties of composites : These were measured using an in-house designed setup. Maharashtra Deccani wool composite material showed higher noise reduction coefficient (0.874) as compared to Karnataka Deccani (0.771) and Malpura (0.749) composite material. The sound insulation properties were found dependent on the thickness and areal density of the base material. Maharashtra Deccani nonwoven had a high areal density (415g/m^2) as compared to Karnataka Deccani (374g/m^2) and Malpura (364g/m^2).

Value addition to camel wool : Training on machine shearing of a camel was organized at NRC on the camel, Bikaner during 18-22 August 2020. Total 52 camel calves belonging to Bikaneri, Jaisalmeri, Kachchhi and Mewari breeds were sheared. The average GFY was 416.5, 178.9, 148.9 and 142.9g in Bikaneri, Jaisalmeri, Mewari and Kachchhi camel calf, respectively. Camel hairs are an admixture of medium fine and highly medullated coarse fibres. In order to improve the quality, hair from both calf and adult camel was processed with mechanical dehairing technique for one passage. The fibre characteristics of Bikaneri camel calf were exceptionally better than other breeds. A single passage to dehairing machine for hair from Jaisalmeri, Kachchhi and Mewari camel calf showed an improvement of 8-29% in fibre diameter and 12-19% in medullation. This quality improvement process thus increases the proportion of fine fibres which will help to improve the spinnability of camel calf wool and make it suitable for the development of hi-value textiles from its blending with fine wool. The camel wool was blended with BM wool (30:70) and good quality shawls have been prepared with a rich look of the inherent natural colour of wool.

Sapling bags : The sapling bag is prepared from a coarse wool nonwoven. It is a viable and sustainable alternative to conventional plastic bags. This bag is suitable for agriculture and horticulture plants. The bag offers air and moisture to pass through which gives natural conditions for the sapling to grow better. The bag can retain moisture for a long time without being wet. The degradation rate of the bag is slow (almost 3 months). Even after degradation, the material offers nitrogen to the soil which enhances soil fertility. The plant germination and plant growth have been found significantly better compared to the plastic bag.

To conclude, the textile division immensely contributed to the success story of the institute. In the last ten years, the division filed 07 patents and obtained full patent rights. Six external funded projects were completed besides training, consultancy, extension and entrepreneurship incubation activities. The division is now aiming to go beyond boundaries to do interdisciplinary science towards the betterment of sheep rearer, wool industry and service to the nation.

Broiler Rabbit Production

The thrust areas of research in broiler rabbit production aimed to study (i) body weight /growth, reproduction and carcass traits of different breeds of broiler rabbits, (ii) genetic and phenotypic parameters of different breeds for growth / reproduction and carcass traits, (iii) feed conversion efficiency and economics of rabbit production in different feeding management systems, (iv) the influence of various variables on carcass quality and value addition of rabbit produce, (v) the disease profile and health aspects in different breeds of rabbits.

Growth Studies

The rabbits are born as litter consisting of as high as 14 kits at a time with an average litter size of about 6. It has been observed that in large sized litters mortality is very high due to poor body weights and low milk availability. Hence, a litter size of 5 to 8 is the most appropriate from production point of view. The kit opens its eyes around 10days of age and starts smelling and slowly starts taking feed. The milk yield in doe peak on 21days after kindling and starts

decreasing afterwards. The kits are weaned at an age between 28-42days depending upon the environmental temperature and weight of the kits, so that it can withstand the weaning stress. The kits at the weaning must weigh between 500 to 700g, however, may almost double their weights up to weaning, if managed well.

Rabbits are highly susceptible to heat stress as they have few functional sweat glands and have a difficult heat output situation when environmental temperatures are high. In the semi-arid region, the rabbits show lower body weights from April to August and improvement in body weights as environment becomes favorable. Studies on thermoregulatory responses of SC and WG rabbits in the semi-arid environment have demonstrated that the period from October to March is favorable for rabbits, while the April to July period is stressful. As compared to WG, SC is more tolerant to hot environmental conditions because of its ability to achieve higher respiration rates i.e. higher evaporative cooling.

The survivability of rabbits varies among different age groups. The survival rate in kits (0-6 weeks) ranged from 70.83 (NZW) to 83.17% (SC). During winter, kits generally die of hypothermia and in summer due to hyperthermia. In weaner (7-12weeks) and grower (13-24weeks) the survivability varied from 82.89 (SC) to 95.85% (NZW) and from 93.70 (GG) to 97.38% (SC), respectively. In adult, it ranged from 82.44% in WG to 88.25% in GG.

The growth of the young during the suckling period, especially during the first three weeks, greatly affects their later performance. Apart from milk yield, the liter size and doe's nursing ability also influence the pre-weaning growth. The average birth weight ranged from 46.08 (BB) to 54.57g (SC). The body weights at 6weeks of age ranged from 708.1 (BB) to 764.4g (WG). The 12-week weight ranged from 1554.60 to 1580.6g showing no marked breed difference. The body weight at 12weeks is of crucial significance as the broiler rabbit is usually marketed and slaughtered at this age. The growth is fastest during 7-12 weeks period. Under experimental ad libitum complete diet feeding system, average weight of 2.0 to 2.3kg at 12 weeks has been achieved at this Institute. Now efforts are being made to achieve 2.0kg body weight at 12 weeks by increasing the milk yield of does and improving the feed accessibility to the weaner rabbits under routine management. The litter size at birth (LSB) ranged from 6.46 to 7.26

while the litter size at weaning (LSW) ranged from 4.92 to 6.17 in different breeds. High LSB and LSW were recorded in GG and WG breeds. Similarly, high litter weights at birth (LWB) and weaning (LWW) were recorded in GG and WG breeds. The average LWB and LWW ranged from 325.34 to 390.82g and 3023.80 to 3488.22g, respectively. At ICAR-CSWRI, it has been found that Soviet Chinchilla, New Zealand White, White Giant, and Grey Giant perform well in semi-arid conditions, and produce meat of desirable quality and quantity. However, Soviet Chinchilla excel other breeds in meat production. An age of 12week or approximately 2kg body is optimum for dressing yield and meat production with respect to fibrosity of meat.

Growth performance of broiler rabbit

Age	Body weight /animal	Feed intake
At birth	40-60 g	Mother milk
1st week	80-120g	Mother milk
2nd week	150-250g	5g /day
3rd week	300-400g	10g/day
4th week	400-500 g	20-30 g/day
5th week	550-650 g	30-40 g/day
6th week (weaning)	700-800 g	50-60 g/day
Two month	1.2-1.5 kg	60-80 g/day
Three month (laughter age)	1.8 -2.0 kg	100-120g/day
Six month (adult age)	2.7-3.0 kg	150-180g /day
Adult breeding sire	3.5 – 4.0 kg	200-250g/day
Adult breeding doe	3.7-4.2 kg	200-250g/day
Pregnancy and lactation	3.0-4.0 kg	250-300g (*ad libitum*)

The recent data on broiler rabbits breeds (2018-2019) like SC, NZW, WG and GG revealed that the average litter sizes at birth were 5.85±2.2, 6.71±2.0, 5.75±2.1and 5.62±3.0, respectively while the average litter sizes at weaning were 5.45±2.1, 6.11±2.1, 5.64±2.1 and 5.37±2.9, respectively. Average litter weights at birth were 347.21±120.0, 399.86±104.5, 364.11±147.3 and 365.94±157.0g, respectively in SC, NZW, WG and GG while the corresponding average litter weights at weaning were 2.72±1.08, 3.33±1.14, 3.15±1.21 and 3.07±1.82kg, respectively. Between weaning and 12weeks of age, the average daily gains were 21.50, 18.40, 18.40 and 20.82g for SC, NZW, WG and GG, respectively. The doe weights at mating and kindling were 3.63±0.44 and 3.51±0.36, 3.27±0.64 and 3.17±0.42, 3.59±0.36 and 3.63±0.32, 3.83±0.40 and 3.64±0.23kg in SC, NZW, WG and GG, respectively. The incidences of kit mortality were 8.5, 5.38, 1.14 and 5.81% in SC, NZW, WG and GG, respectively. The study revealed that New Zealand White had better performance for litter sizes at birth and weaning as compared with other breeds. Grey Giant was fastest growing breed in the pre-weaning period, but Soviet Chinchilla managed to surpass other breeds in the performance of growth rate in the post-weaning period. Grey Giant had the highest body weight at 84 days, followed by New Zealand White. Grey Giant was the heaviest breed at mating and kindling, and New Zealand White was the lightest breed at mating and kindling. The White Giant breed was the best breed in survival performance in the kit stage while Soviet Chinchilla breed had the lowest kit survival.

Reproductive studies

Reproductive performance of 4 broiler rabbit breeds i.e. GG, WG, SC and NZW, reared under in sub-temperate climatic conditions revealed that among 4 breeds, the litter size at birth (LSB), litter weight at birth (LWB) and litter weight at weaning (LSW) were higher in GG followed by WG, SC and NZW. The LSB and LSW in GG breed differed significantly from SC and NZW. Season had significant effect on LSW with higher values during spring (5.68±0.24), followed by summer (5.29±0.30), winter (5.13±0.25) and autumn (4.17±0.49). The body weight of doe at service significantly influenced fertility. The fertility increased as body weight increased. The age of the doe at mating had a significant effect on LSW, with

higher values for does more than 2yr and less than 1yr old compared to 1 to 2yr old does. The parity did not affect any of the parameters studied. It is concluded that these factors affect the reproductive performance of rabbit does. Grey Giant breed showed the highest litter size at birth and weaning, and the highest litter size and weight at weaning was in spring. In another study, it was found that under sub-temperate climatic conditions during winter weight of doe at mating and kindling, litter size at birth, litter weight at birth and litter size at weaning and litter weight at weaning was significantly higher as compared to summer and rainy seasons.

Environmental Studies

The kit mortality was significantly higher during winter while the weaner mortality was significantly higher during rainy season. At 84d, the live weight per doe, slaughter weight, dressing percentage and liver weight were significantly higher during winter than summer and rainy. Similarly, the gain in weight and meat weight at 84 and 98d were significantly higher during winter. The weight of raw pelt and processed pelt were recorded significantly higher during winter while no difference in the area of processed pelts during different seasons could be observed. No difference in the biological performance could be observed between sexes in any of the seasons. Roughage analysis revealed comparatively higher crude protein percent and lower crude fibre percent during summer and rainy seasons than in winter. The roughage dry matter intake was comparatively higher during summer and rainy seasons vis-a-vis constant amount of concentrate supplied during all the three seasons. The digestibility of dry matter was significantly lower, whereas that of crude fiber, acid detergent fibre and cellulose were negative during winter. Interestingly, the feed: gain was exceedingly well during winter than in other seasons and was concluded as the best season for production of rabbits under sub-temperate Himalayan conditions.

Nutritional studies

The major constraint in rabbit enterprise is the feed cost alone, therefore, every effort should be directed to maintain feed quality with curtailed feed cost and to utilize every bit of the feed into animal protein. Nutrient requirements and dietary recommendations must be related to the increased performance levels and prescribe the amount of each essential nutrient that will result in maximum production. Since, feed is the single largest factor representing around 65% of total cost of rabbit meat production, more and more emphasis is to be given to minimize the feed cost in large production units.

Plane of nutrition has significant effect on the growth during 10-24 weeks of age. Studies indicated that 15% higher levels of protein and energy recommended by NRC (1977) could be used for diet formulation of rabbits from 6-18weeks of age. Diet containing 18-19% CP and 2.5-2.8Mcal/Kg DE is required to achieve a commercially viable growth rate of 28-30g/d in growing kits. The effect of different plane of nutrition worked out for growing kits indicated that rabbit require 91g DM, 13g DCP and 255 Kcal DE/kg W0.75 to gain @28g/day. Under Indian tropical conditions, the digestible energy and digestible proteins for grower and reproductive rabbit does were 2500Kcal and 130g/Kg and 2700Kcal and 120g/Kg, respectively. There is considerable variation in the range of these values for temperate and tropical countries and could be due to environmental conditions and growth rate of the animals. Complete feeding of rabbits on roughage was found to be economical. Most of the organized farms depend mostly on locally available forage(s), which are supplemented with pelleted concentrate according to physiological state and level of production desired. Though the intakes of feed were higher, the performances reflect lower efficiencies and gains and suggested need to supplement concentrates for optimum production. In the northern

Himalayan tract where Black locust (*Robinia pseudoacacia*) and Mulberry (*Morus alba*) are available abundantly could serve as fodder source fulfilling 20-25% of total diet in grower rabbit. Leaves of Maggar (Bamboo), Khirk (*Celtis eustralis*) and Robinia can be fed to improve voluntary intake but should not be supplemented as sole roughage as they contain incriminating factors. Likewise, Sirus leaves should not be fed as forage resource due to presence of incriminating factors. Loss of body weight in rabbits was observed when Biul leaves up to a level of 42% along with concentrate were fed. Thus it was concluded that the levels of forage supplementation should be about 30% for Biul; even though the level of tannins in this species of top feed was negligible. The tree leaves available in semi-arid region of country like khejri (*Prosopis cineraria*), Pala (*Zyziphus nummularia*), Ardu (*Ailanthus excelsa*), etc. can either be incorporated as roughage sources in complete diets at 15% level or fed as free choice in separate hay feeder to grower rabbit. Tree leaves like Nevaro (*Ficus hookeri*) and Kabra (*Ficus infectoria*) available in north eastern region of the country could serve as a good fodder source at 25-30% of total diet, in grower rabbit. Looking in to the usefulness of tree leaves as forage sources, few attempts were made to utilize and incorporate common top feeds in rabbit feeding system.

Probiotics supplementation, more specifically *Lactobacillus acidophilus* (@ 107 CFU/g concentrate) improved digestibility and utilization of nutrients, body weight gain and feed conversion ratio with apparently no significant changes in carcass traits, composition and fatty acid profile. Moreover, improved digestive efficiency through optimization of the composition of the gut microbiota has a direct impact on feed costs. Feeding of Vigna mungo crop residue and Stylosanthes hamata hay at 25% level improved FCR, keeping quality of meat and modified the fatty acid profile of LD muscle in rabbit with higher PUFA and n-3 fatty acids and reduced SFA, SCFA and TI and found economic. In another study, rearing rabbits through conventional feeding system yielded higher growth performance and better FCR due to higher nutrient utilization. However, higher proportion of concentrate pellets in conventional system increased feeding cost per unit gain. Pellets made with 70% mulberry leaves lowered feeding cost, yielded better fatty acid profile and improved the shelf life of meat and nuggets. Similar results were also obtained by feeding of stylosanthes hay pellets. Hence, for getting better growth performance and improved quality attributes of meat and its product, level of mulberry leaves and stylosanthes hay in complete feed pellets is not recommended at 70% and should not exceed preferably beyond 50% in complete feed pellets. Moringa leaves incorporated at 70 and 97% percent level in diet had lower fat content in meat and its longissimus thoracic muscle fat revealed higher C18:3n3 and ∑ n-3 fatty acids with lowered thrombogenic index value. Upon storage pf nuggets made from meat of moringa fed rabbits revealed lower pH, TBARS, total plate count, psychrophilic count, pseudomonas count and higher redness value compared to control. Hence, it is concluded that adding moringa leaves at 70% level in rabbit pellets is advantageous and yields higher growth and improved functional attributes of meat and meat-products compared control and sole moringa pellets.

Angora Rabbit Production

Animal fibre had always been preferred by mankind to cover and protect from external environments both in raw and processed form. With the emergence of new innovations / technologies, the animal fibers use had attained newer heights in global scenario and the elitist of the fashion garments are based on such fibers. In addition, a significant GDP of many countries is governed by the animal fibers primary by sheep wool. Additional four fibers - Mohair, Angora, Cashmere and Alpaca are also used. In India, use of Angora fibre in manufacturing of apparels, knitwear products, woollens and other textile products is significant and its demand is increasing with the time. Hairs or wool obtained from the Angora rabbits are known as Angora, which is preferred over Cashmere, Mohair, Wool and Alpaca due to its fineness, warmth, fluffiness, odourless, lightness and anti-static property to repel the dirt. In addition, Angora being about 8 times warmer than sheep wool and for this reason, it is used either in pure or blended form for making the garments, throughout the world. Since, blending of angora is preferred with other fibers to make yarn and other products, it is required in very little quantity.

Historically, rabbit domestication can be traced to the late Middle Ages and dates back around 1000 to 800BC. Around 116-27BC, the rabbits were thought to be kept in enclosures called Laporaria (stone walled pens) for rearing and domestication of rabbits was attributed to catholic monks. With passage of time several types of rabbit were evolved and during the 16th century, several breeds of rabbits were known. Rabbits were classified as early as 1606 by Olivier de Serres, into three types, viz. wild, semi-wild or warren (raised inside walls or ditches) and domesticated (hutch-bred) rabbit. Angora rabbit is considered to be originated in Ankara, Turkey and spread from there to Europe and other parts of the world. The Angora rabbit industry came into existence in Europe during 17th and 18th centuries and the use of Angora in garments was appeared in 1870. The modern Angora industry based on intensive rearing combined with selection was started in 1930's. Later, Americans developed several breeds through selective breeding of rabbits imported from Europe. At present, there are about 45 recognized breeds of rabbits in the world with total estimated population of about 709 million rabbits. Four major Angora rabbit breeds recognized by the American Rabbit Breeders Association (ARBA) are English (British), French, Giant and Satin, of which French and German are two major commercial Angora breeds. Angora rabbits are reared throughout the world, both for meat and fibers because of some of the husbandry advantages associated with these over other domesticated livestock. The advantages are:

- Angora rabbit rearing can be practically done under any set up like rural, peri-urban and urban.
- The value of raw Angora wool per unit of weight is 40 to 50 times higher to that of equivalent greasy wool of sheep.
- One kg Angora could be produced by 30% less digestible energy as compared to 1kg sheep wool.
- Angora rabbits are herbivore and do not compete with human for food.
- Space requirement of Angora rabbits is less as compared to other livestock.
- These animals are excellent converter of plant proteins of a little value into high-value animal protein in the form of meat and wool.
- About 50 Angora rabbits could be reared on kitchen waste.
- About 100 Angora rabbits can be managed easily by a household without affecting daily routine.
- Angora rabbits with concurrent pregnancy and lactation with short generation interval can multiply very fast. A single female can produce as many as 30-40 offspring in a year.
- Angora is considered premium product; as these are directly influenced by the fashion industry. Moreover, it

can be blended easily with natural and synthetic fibres to produce quality products, which had demand in most of the developed countries.

- Angora has been found to possess medicinal properties and its garments are recommended for arthritis because of its electrostatic properties.
- Angora rabbit meat is categorised as white meat, which is rich in poly unsaturated fatty acids and low in cholesterol. Meat is usually advised to persons having cardiac problem and hypertension.
- Rabbit manure is very rich in nitrogen contents and could replace inorganic urea on per unit basis in agricultural and horticultural crops. It can be used for organic farming, thereby, indirectly yielding higher returns for agricultural and horticultural crops or products.
- Rabbit faeces can be used for vermi-composting for additional income from sale of compost. Moreover, dried rabbit faeces can be added up to 10% in the ration of rabbits without affecting production and thereby, reducing the feed cost.
- Angora rabbit rearing can sustain multifarious activities in the area and can generate employment for youth, woman and skilled artisans, thereby, improving the social status.
- An Angora rabbit unit comprising of about 100 adult rabbits can generates an additional income of about Rs.3000-4000 per month.
- More so, in many developing countries, with shrinking land holdings due to continuous increase in population, reduced grazing areas and changing climatic conditions; the traditional livestock rearing has become difficult and uneconomical and there is shifting towards smaller sized animals like rabbits for steady and sustainable income, and nutritional security against protein hunger.

In India, rabbit rearing of indigenous stock as a pet had been a fancy since ages. The rabbit as a commercial livestock was introduced into the country by private sector long back but was kept in isolation. The Angora (British Angora) rabbit farming was started during 1962 by Mr. Butter Worth at Dharamshala in Himachal Pradesh (the then Punjab). Thereafter, some individuals and agencies made efforts to spread Angora farming in Kullu, Mandi and Kangra districts of Himachal Pradesh and Nilgiri hills of Tamil Nadu. Around 1979, Indian Council of Agricultural Research (ICAR) established the Division of Fur Animal Breeding (DFAB) at Garsa, Kullu (Himachal Pradesh) under the Central Sheep and Wool Research Institute (CSWRI) to initiate the scientific/ research work on British Angora (BA) and Russian Angora (RA) imported from UK and USSR, respectively under Indian sub-temperate conditions. Initially, the research efforts were initiated to understand and evolve suitable strains adaptable to local conditions and develop packages of practice for small and large-scale production. After initial success in its endeavours, the North Temperate Regional Station (NTRS), Garsa introduced German Angora (GA) in the year 1986, 1992 (purchased locally) and 1997 (imported from Germany) and is continuously improving the Angora rabbit germplasm by scientific breeding and management. The improvement in GA, BA and RA stocks (breeding and general flock) at NTRS Garsa has been consistent and continuous with passage of time. Moreover, the crossbreds as well as purebred GA have better adaptability, less reproductive problems, better mothering ability, higher wool yield and better wool quality under natural rearing conditions in India.

Hilly regions of the country (between 4000 and 6000 ft. above mean sea level) with colder climate have been found to be suitable for Angora rabbit production under natural and conventional system of rearing. The Angora rabbit can be reared successfully in areas having temperature range between 5 to 30°C and relative humidity levels of 60-70% under conventional housing system. However, between 15-25°C of ambient temperature the Angora feels much

comfortable and produces more wool. On the other hand, at around 30°C temperature, the feed consumption reduces as much as by 30% and the wool yield starts decreasing significantly. Further, quality of fibers is influenced by the environmental conditions like temperature, humidity, rainfall, etc. to a larger extent. Unfortunately, these natural climatic changes cannot be avoided and producers or farmers only have to modify the rearing systems and introduce new innovations to mitigate the influence of climate change.

Nationally, the North temperate Regional Station, Garsa has now been recognized as germplasm centre for pedigree Angora rabbits and making superior germplasm available to farmers, Universities, NGOs, different developmental agencies and private entrepreneurs in the states of Himachal Pradesh, Jammu and Kashmir, Uttarakhand, Rajasthan, Sikkim, Meghalaya and West Bengal (Darjeeling hills). In addition, training program on Angora rabbit farming are conducted regularly for farmers, NGOs, private entrepreneurs, etc. and technical knowhow is provided to the stake holders. An appreciable number of rabbitries had been established in the states mentioned above, which are producing the Angora to meet the local demand of the handlooms, khadi institutions, wool cooperatives and textile industries. With the initiatives and aid support from UNDP through the Central Wool Development Board (CWDB), the Angora rabbit farming, aimed at generating the employment and foreign exchange earning potential, have been extended to the hilly areas of Uttarakhand, Darjeeling and Sikkim. On account of such integrated efforts, these states also making steady progress in Angora farming and local germplasm centers are also being set up for providing rabbit germplasm in these states.

Study on estimation of direct and maternal effects on growth and wool yield traits in German Angora rabbits exhibited that maternal effects had higher importance at weaning and declined with the advancement of age. Significant influence of maternal permanent environmental effect was observed on weaning and post-weaning body weights. The estimated repeatability of doe effects on body weights were 0.37, 0.22, 0.18 and 0.28 at weaning, 84, 126 and 168days body weight, respectively. Maternal effects especially due to permanent environment had higher importance at clip I and found to be declining in subsequent clips. Weaning weight had moderately high genetic correlations with clip I (0.57) and II (0.45), but very low (0.11) with clip III. The modest rate of genetic progress is possible for body weight traits of Angora rabbit through selection. Further, weaning weight could be considered as desirable trait for earliest indirect selection for wool yield in view of its high genetic correlation with wool trait.

Study on population structure and genetic diversity of a nucleus flock of German Angora rabbit through pedigree analyses on pedigree records of 6145 animals born between 1997 and 2020 showed that the pedigree completeness levels for the whole pedigree were 99.12, 97.12, 90.66, 82.49 and 74.11% for 1st, 2nd, 3rd, 4th and 5th generations, respectively, reflecting well maintained pedigree records. The maximum inbreeding, mean inbreeding coefficients and average relatedness for the whole analyzed pedigree were, 36.96, 8.07 and 15.82%, respectively. The mean maximum generations, mean equivalent generations and mean complete generations were 10.28, 7.91 and 5.51 with 0.85, 1.19 and 1.85% rate of increase in inbreeding of, respectively. The corresponding effective population sizes were 58.50, 27.05 and 42.08. The effective population size computed via the individual increase in inbreeding was 42.83. Probability of gene origin measures including the effective numbers of founders (fe), ancestors (fa), founder genomes (fg) and non-founder genomes (fng) were 18, 16, 6.22 and 9.50, respectively. The fe/fa ratio in the reference population was 1.12, indicating absence of strict genetic bottleneck. Six most influent ancestors explained 50% of genes (fa50) to the gene pool, which might have led to reduction in genetic variability and increased the level of inbreeding in the reference population. The average generation interval was 1.51 years and longer for the sire-son pathway. The population showed upward trend in inbreeding coefficient as well as average relatedness and a decline in effective population size over time and generations. Increasing inbreeding coefficient and declining effective population size will have negative impact on population and genetic variability.

The improvement in the germplasm could be judged from the wool production performance and fibre characteristics detailed as below :

Wool yield (g) in Angora rabbit

Clip\Year	2001	2002	2003	2004	2005
German Angora breeding stock	164.3±4.7	152.8±2.9	170.4±4.3	199.2±3.1	212.4±2.1
1st	150.7±5.6	157.5±4.6	153.9±4.7	194.8±4.2	189.8±2.1
2nd	147.7±4.2	159.5±4.6	161.4±4.9	169.2±3.9	184.3±3.5
3rd	150.9±3.5	165.3±4.0)	185.0±5.0	172.3±3.7	184.5±2.4
4th	143.5±5.2	177.9±6.8	205.0±5.2	193.4±4.5	207.0±1.8
5th	757.1±5.3	813.0±4.3	875.7±7.5	928.9± 6.2	956.7±4.8
Annual					
German Angora general stock	122.9±3.8	110.5±2.9	157.7±1.9	165.3±2.0	175.5±1.6
1st	145.2±2.4	142.3±3.7	163.6±2.5	173.2±2.1	177.1±1.5
2nd	163.3±2.4	157.4±4.8	152.2±2.5	153.2±1.9	169.9±1.6
3rd	139.6±3.1	138.8±4.5	151.8±3.1	153.0±2.2	155.5±1.6
4th	133.7±2.6	146.7±4.4	178.7±3.6	172.5±2.6	164.0±2.0
5th	704.7±5.8	695.7±7.8	804.0±2.6	817.6±4.5	842.1±4.1
Annual					
British Angora					
1st	92.5±8.1	107.3±2.4	135.6±6.7	155.6±4.7	144.9±4.4
2nd	108.3±11.7	108.3±3.9	114.7±5.9	135.0±5.6	129.4±5.8
3rd	99.7±11.9	110.8±4.1	124.8±4.5	98.3±4.8	127.3±6.0
4th	92.1±5.2	107.2±3.0	151.6±4.9	106.9±6.0	128.0±5.9
Annual	392.6	433.6	526.7	495	529.57
Russian Angora					
1st	112.7±6.2	99.5±3.7	116.9±6.1	137.7±4.5	147.5±3.9
2nd	116.9±5.0	119.3±5.8	107.6±4.7	121.4±4.7	136.1±3.7
3rd	102.8±4.9	103.6±5.4	121.8±4.8	95.7±4.6	136.2±5.4
4th	94.1±3.2	117.6±5.3	129.4±5.1	99.7±9.3	136.7±2.0
Annual	426.5	440.0	475.7	454.5	556.39

Fibre characteristics of wool from different breeds of Angora rabbits

Genotype	Fibre fineness (µm)		Fibre length (mm)		Medullation (%)
	1980's	Present	1980's	Present	
GA		12.55		54.9	2.62
BA	11.80	13.20	45.5	61.5	3.12
RA	11.77	12.75	48.9	56.9	2.88
GxB	11.56	12.73	42.2	60.3	2.89
GxR	12.45	12.59	52.5	62.1	2.60
GxRxB	11.64	12.68	55.7	61.9	2.70

Performance of German Angora rabbit

	2018-2019	2019-2020	2020-2021
Body weight (kg) at			
6 week	0.735±0.013	0.516±0.011	0.591±0.014
8 week	1.053±0.016	0.723±0.016	0.811±0.022
10 week	1.350±0.020	0.972±0.020	0.992±0.025
12 week	1.650±0.020	1.223±0.025	1.254±0.031
14 week	1.880±0.020	1.464±0.024	1.443±0.027
16 week	2.100±0.020	1.692±0.028	1.606±0.030
18 week	2.270±0.020	1.851±0.026	1.799±0.038
20 week	2.320±0.020	1.919±0.030	1.868±0.036
22 week	2.420±0.030	2.089±0.035	2.028±0.040
24 week	2.560±0.030	2.199±0.035	2.129±0.054
Reproduction			
Doe's weight at service (g)	3076.81±29.98	3027.81±64.25	3024.40±57.69
Doe's weight at kindling (g)	3047.53±38.15	2948.28±68.23	2977.56±55.40
Litter size (no.) at birth	6.40±0.39	5.53±0.37	5.11±0.28
Litter size (no.) at weaning	5.94±0.40	4.88±0.36	4.58±0.29
Litter weight at birth (g)	296.96±15.77	251.27±15.64	263.29±13.91
Kit survivability (%)	86.56	88.02	90.42
Wool production (g)			
Adult			
Clip I	117.34±1.96	112.38±2.44	116.31±2.23
Clip II	114.28±2.12	107.91±2.42	120.35±2.72
Clip III	113.53±2.04	100.68±2.03	107.30±3.47
Clip IV	106.34±2.33	103.37±2.21	110.93±3.57
Clip V	97.70±2.44	107.31±2.29	118.70±4.10
Progenies			
Clip I	15.50±0.42	12.12±0.36	15.44±0.54
Clip II	69.19±1.64	56.58±1.34	62.79±1.90
Clip III	-	101.64±2.47	83.40±3.13
Clip IV	-	106.10±3.91	123.09±5.83
Clip V	-	109.32±3.67	-
Wool characteristics (Clip II)			
Staple length (cm)	6.42±0.05	6.28±0.06	6.22±0.08
Fiber diameter (μ)	13.08±0.08	13.30±0.10	13.15±0.08
Guard hairs (%)	1.80	1.78	1.31

The German Angora Rabbit population was re-established from a small population to more than 500 animals following orders from the Council to resume breeding from August 2017 after a ban on breeding for three years. The rabbit flock could be conserved in the farm by careful selection and mating of the animals with least inbreeding. The present Germen Angora population was established from a small number of individuals. The flock is closed genetically till date and thus subsequent loss of genetic diversity is expected.

In India, the fluctuating angora wool prices have steadily acted as impediment in adoption of Angora rabbit farming. The situation has become more drastic not only in India but in rest of world as well, consequent to WTO agreement, as coarser Angora from china is available at cheaper rates leading to slump in the global markets. Over the years, fluctuation of Angora market price in India ranged from Rs 300-1200 per kg and never stabilized. Due to yearly variability in Angora prices, the producers are getting discouraged and confused. Since, the cost of all inputs has been increasing steadily, the Angora producers at present are hardly meeting out the expenses from the sale of Angora. Moreover, there is no relief or intervention from state or central government to Angora producers. Because of all these circumstances, Angora producers are feeling helpless.

To get the Indian Angora rabbit farming revitalized, make it profitable enterprise and to protect the producer's interests, there is a strong need to redraw the strategies against price fluctuations, marketing, climatic changes, etc., so that Angora rabbit farming could be undertaken on large scale. Few of the steps in this direction could be :

- Angora is a premium produce with huge export potential. Hence, private entrepreneur should be encouraged for farming under controlled environment rather than restricting its propagation in the hilly areas only. Moreover, in National context, goals must be set for export of angora yarn and its products than raw fiber.
- Introduction of contractual system of Angora rabbit farming with concept of Angora based farming (which includes all components from production to utilization) than Angora farming to make angora more demands oriented and profitable.
- Availability of assured market through linkages between the Angora producer and processor (wool processing industry, handlooms, etc.), and remunerative prices for Angora through market intervention scheme in the form of minimum support price (MSP) and regulation of Angora import under OGL system by the government.
- Development of organized and strong marketing facilities for Angora and its product, regulated by independent national agency.

Transfer of Technology

The Transfer of Technology and Social Sciences (TOT&SS) section came into existence in 1975 as Division of Extension and ORP with the objective to transfer the technologies of sheep production as well as fibre technology to farmers, rural artisans and wool industry. Through a flagship project "Integrated approaches for improvement in productivity of sheep, goat and rabbit under field conditions through transferable technologies", in which every division of the institute is involved and TOT&SS has been instrumental in reaching out to the farmers with CSWRI technologies. Four field centres that cover 20 villages are our strength, but added more villages during the 12th plan. The TOT programme of the Institute is very popular among the farmers of this region and there is great demand for Institute technologies. Our extension/field workers are in constant touch with the sheep farmers of the adopted villages and solve their problems promptly. In addition, the benefits of the newer technologies are demonstrated in the farmers flocks itself for wider acceptance of the technologies. Over the years there has been a marked improvement in the socio-economic conditions of the farmers of this region due to the adoption of these newer technologies. The Institute also reaches out to the farmers through participation in livestock and agricultural exhibitions all over the country, organization of sheep/kisan melas, Kisan sangosthis, field days, health camps, veterinary days, exposure visits of farmers from all over the country and through off and on campus training programmes by experts scientists. Newer tools like SMS Alert Services, ICT and Radio Farm School have been initiated. The Institute has developed various simple and cost effective transferable technologies for the benefit of the sheep sector after testing these technologies in the field. One of the major mandates of the ICAR- Central Sheep and Wool Research Institute is to transfer improved technologies on sheep and rabbit production to farmers, rural artisans and development workers through its transfer of technology programme at its main campus and its regional centres. The main objectives of this programme are:

- To test and transfer the technologies being developed for increasing meat and wool production of sheep and rabbit.
- To survey and evaluate the productivity of sheep in the field conditions.
- To motivate farmers to increase sheep production by adopting improved practices of breeding, feeding, reproduction, disease control, feed resource, wool utilization, marketing, etc.
- To create awareness of sheep farmers about improved animal husbandry practices.
- Impact assessment of institute developed technologies.

Operational Research Project (ORP): The ORP on sheep and wool development programme was initiated in 1975 by adopting 20 villages. The major findings exhibited that the flock size varied from 10 to 150 sheep. On an average the flock comprised of 48 ewes, 21 lambs and one ram at the time of survey. Bigger flocks had 1-3 rams but smaller flocks normally did not have ram. The body weight of ewes varied from 20 to 25kg and rams weighed up to 45kg. The lambs continued to suckle for 5 to 6months. There were very few migrating flocks in the area. However, 22% flocks do migrate to smaller distance (up to 20km) during the lean period (April to June). Ponds were the usual source for watering the flocks; however, they were totally dependent on wells in summers. The sheep were watered 2-3times in a day in summer and once in rest of the seasons. Sheep were grazed around watering points about 11-12hrs in lean periods and about 8hrs during rainy season. The lambs were grazed along with adult sheep. About 18% sheep farmers fed pala and 19.5% fed methi to their sheep during summer season. The quantity of green fodder did not exceed 350g/ewe/day. During lean period, some breeders fed cluster bean stover, barley, wheat straw, etc. About 50% sheep breeders offer supplementary feeding to rams during breeding season and lean period. Rams were always kept with the flock. No concentrate mixture or green fodder was given to flush ewes. Usually no good shelter was provided to flock. Only 22.5% breeders had small kachcha houses and 37.5% had small thatched roofs to save their sheep from rainy and cold weathers. The covered area was hardly 9square feet per sheep. Though, the sheep

came into heat round the year but the major breeding season was after rains in monsoon when about 42% sheep came into heat. About 35% sheep came into heat in February to April. The sheep were covered with natural service with native rams only. Artificial insemination was not practiced in the area. No treatment was given to naval cords of the lambs' after birth. The average birth weight of the lambs was 1.93kg. The average marketing age of the lambs was around 10month. No concentrate mixture was given to lambs raised for marketing. Most of the breeders sold the lambs to middleman on head basis. Most of the breeders washed their sheep before shearing but they did not use dip after shearing. Shearing was done by khatik only, no shearing machine was practiced. Shearing was done twice a year except in few cases a third shearing was also done in June before monsoon. An average flock of 48 sheep yielded 38.25kg wool with an average of about 800g/sheep/yr. Skirting of wool was unknown to the farmers. Most of the breeders sold the wool to middle man, while the wool was still on sheep, on the basis of per animal. The breeders did not practice docking and castration in sheep. Teaser rams were not kept in the flocks. The prevalent diseases were enterotoxaemia, worm infection, ecthyma, naval ulceration, piroplasmosis, FMD, etc. The mortality rate in sheep was found to be 18.78% before the ORP was started in 1975. Enterotoxaemia was reported after grazing of sheep in *Rabi* harvested fields and its occurrence continued up to September. Bottle jaw was seen round the year, however, it was more prevalent in February-March and July to September. Foot infection and Piroplasmosis were prevalent in rainy season while FMD occurred in winter season. Vaccination against enterotoxaemia and Sheep Pox was not much known amongst the breeders. The findings formed the basis for application of improved technologies in the field in the future.

Institute Village Linkage Programme (IVLP): This programme paved a new path for economic upliftment of resource poor farmers through participatory approach. Through participatory approach, shepherds problems were identified and prioritized as per their need and available resources. Shepherds along with scientist's team in participatory mode developed technical modules that highlighted their problems. Interventions were designed to test the technology for solving the constraints which may restrict the increase of benefit from sheep rearing. Shepherd practice and Institute developed practices were tested under shepherd management and resources situation and replicated according to convenience. In such a way shepherd and Institute participatory approach enabled us to solve the constraints being faced by the sheep owners. Non-adoption of improved technologies developed at various research Institutes is one of the important reasons for low productivity of sheep. Inappropriateness of technologies resulting from non-consideration of farmers' real life situations were recognized as main reason for non-adoption. After going through the results, it was felt that such model of sheep production should be replicated in every village for increased prosperity in rural areas.

Mera Gaon Mera Gaurav (MGMG): This programme is a farm centric mission which targets to translate knowledge from research labs to farmers' field to address farm-oriented problems in a wholesome manner in order to provide livelihood security to the villagers. In the present scenario of Indian agriculture, when the technologies are generated at a much faster rate than ever before, some innovative extension approaches are required to keep pace with this development and enhance the adoption rate too. This need is also evident from the shift of national emphasis from the agriculture production component to farmers' welfare. Under This programme institute cover 45villages by nine teams of scientist of different subjects. Activities carried out during last five years (2015-20) includes visits (307) to villages by teams, interface meetings/gosthis (200), trainings (60), demonstrations (101), mobile based advisories (54), literature support (135), awareness campaigns (137), input support (7) and linkage with other agencies (63).

Sansad Adrash Gram Yojana (SAGY): The Institute has adopted four villages namely Kantoli, Sitarampura, Deebru and Naya Gaon in Sansad Adarsh Gram Yojna. Kantoli gram panchayat has been adopted by Sh. Sukhbir Singh Jaunapuria under Sansad Adarsh Gram Yojna for development of village which will serve as a model for other villages of the area. A total of 18flocks (850 sheep) in gram panchayat were adopted and activities like health camps, vaccination of flocks, Kisan goshthies, Swachatta awareness camp, etc. were undertaken in these adopted villages.

Farmer First Programme (FFP): Farmers tend to face problems related to production and natural resource management but they might not have found out solutions to overcome them. In such situations, researchers, extension professionals and farmers work together and find appropriate ways through assessing different solutions.

Under this concept farmers participate in the research process with scientists. During the production process, farmers often evolve new ideas to improve their cultivation and natural resource management activities. This creates a space for researchers, extension worker and farmers to design and organize new experiments. In 2016, the programme was implemented in six villages (Arinya, Bassi, Chosla, Dechwas, Soda and Garjeda) of Malpura tehsil and scientist facilitated by farmers to conducted experiments on their field on modules based on activities pertaining to livestock, fodder, crop, horticulture, natural resource management, enterprises and integrated farming system. Front line demonstrations on kasuri methi, wheat, mustard and barley crops were conducted in the project area. Elite germplasm of sheep and goat were also distributed to farmers for their breed improvement along with facilitated semen from elite buffalo bull for artificial insemination.

In addition, Schedule Caste Sub-plan (SCSP) scheme was implemented, in 2019, by the Institute with the objectives (i) to increase the income of the target population by way of various income generating schemes, skill development and infrastructure development and (ii) to reduce the poverty among the target population and bring them above the poverty lines. A baseline survey of the target SC population was conducted and BPL, widow and handicraft families/persons were selected for knowledge and skill development in the field of agriculture, animal husbandry and related allied sectors. Under skill development activities, trainings programmes were organized on advances in sheep, goat and rabbit production and woollen handicraft and garments manufacturing and designing for a total of 410farmers/rural artisans/rural women. After successful training, agriculture and animal rearing inputs, sewing machines and other inputs were provided for generating self-employment. Elite germplasm of sheep (97), Sirohi goats (120) and rabbits (170) were also provided to BPL families and widow ladies for their livelihood security. Front line demonstration on improved varieties like mustard, wheat, barley seed spices were also conducted for enhancing the crop yield. These activity helped beneficiaries to enhance their family income which resulted in improve the socio-economic status of their family. Further, Tribal Sub plan (TSP) is also in operation for sustainable improvement in the livelihood of down trodden tribal communities of tribal dominated districts (Banswara, Dungarpur, Pratapgarh, Sirohi, Dausa) of Rajasthan.

Impact of transferable technologies

Genetic improvement of sheep flocks: The improved germplasm (Avishaan, Malpura, Patanwadi, Dumba, Bharat Merino and Avikalin sheep) are regularly distributed to interested farmers for improvement of their flocks. The survey in the villages (around CSWRI) indicated that there are mainly three types of sheep, native (Malpura), crossbreds (half-breds) and mixed type (quarter breds and natives). The crossbreds weighed more at 3 and 6month of age than the other two types. The wool yield was 25% higher in crossbreds than natives. The wool quality in terms of diameter and medullation was better in the crossbreds. However, due to lack of grading and organized marketing the crossbred wool does not fetch better price. Only well to do farmers come forward to rear crossbred sheep. It was observed that farmers prefer Marwari and Kheri sheep being sturdy and well adapted for migration. Avikalin ram which need special care during lean period (April-June) has shown considerable improvement over its native contemporary Malpura breed with regard to GFY and wool quality. Avikalin can be used as an improver breed for cross breeding the coarse wool breeds to increase carpet wool production. The results obtained from Bharat Merino revealed that the genotype is a promising substitute of import of fine wool sheep as an improver breed. The comparison of growth performance of genetically improved Malpura rams distributed to the farmers' and their base line appraisal showed that the performance of progeny of genetically improved rams was better than base line under local feeding system. These results clearly establish the superiority of genetically improved rams over local bred under local conditions. In year 1975-76, non-descript breeds in farmers were with body weights at birth, 3, 6, 9 and 12month to the tune of 2.52, 9.74, 13.84 and 19.46kg, respectively. Farmers were provided elite rams and along with other management interventions, during 2007-12 the average body weights in field flocks were 3.49, 14.00, 20.16 and 28.36kg at birth, 3, 6, 9 and 12month of age, respectively. Further, during 2012-17, the corresponding figures were 3.42, 15.80, 21.97 and 29.69kg, respectively. In last 20 years (2001- 2020) Institute has supplied 1649 superior ram to farmers on book value in TOT area. Besides rams, Sirohi bucks and broiler rabbits were also supplied to farmers.

Improved health management in farmer flocks: Sheep health services were provided to the farmers at their doors. The sheep were regularly and timely treated for different ailments along with emphasis on application of planned flock health calendar particularly vaccination and deworming. Prior to adoption of health calendar, mortality in farmer's flocks was around 22-25% in 1976. The planned health inputs resulted in reduction of mortality to around 12-13% in 1984-85 and around 5.0% since last 3decades. The application of above mentioned practices cost around Rs.60-70/sheep/year. Economic consideration revealed that a farmer maintaining a flock of 100sheep can save around Rs75,000/- per annum just by preventing the animals against diseases to avoid mortality.

Artificial insemination in the field flocks: The CSWRI has developed protocols for artificial insemination and estrus induction and synchronization in sheep. This can provide greater multiplication of an elite germplasm. The artificial insemination has showed 55.49% successes in farmer's flocks. Given the relatively low input and significant return, artificial insemination of sheep is beneficial for maximum utilization of elite rams. AI in combination with estrus synchronization is gaining popularity in recent times due to better awareness among sheep farmers of its benefits in terms of additional lambs and more income every year.

Improved feeding practices for sheep flocks: The Institute has developed technologies for utilization of various feed resources, agricultural waste and industrial by-products in sheep feeds and established feeding technologies to improve the growth rate in lambs. In field condition, the surplus lambs are marketed at 20 to 25kg body weight achieved at 9 to 12months of age. Whereas, under intensive feeding on 50:50 concentrate and roughages based ration, 25kg finishing weight could be achieved at the age of 125days. A farmer raising 100lambs unit for mutton production required to invest Rs.9,200/- as non-recurring and Rs.66,000/- as recurring expenditure and could receive a total of Rs.71,250/- from live animal sale to contractor or Rs.82,500/- if slaughtered. Thus, a net profit of Rs.5,250 – 16,500/- in 90 to 100days of feeding could be obtained. In addition to routine grazing, the concentrate supplementation @1% of the body weight improved the body weight of lambs. Supplementation to sheep during later part of pregnancy resulted in 31.54% increase in birth weight of lambs over the control which gave Rs.493/- as net return with 3.95 benefit:cost ratio. Most of the quality roughage has low bulk density, which create problem during storage and transportation. These problems are overcome by converting them into complete feed blocks (CFB). The CFB consisted of roughage and concentrate in 70:30 ratios with 5% of molasses for easy binding. The cost of feed block including cost of preparation was Rs.6/kg. The blocks have many advantages like ease in transport, palatable in nature, lower in space requirement for storage and lower losses during transport. Production of fat lamb is a promising commercial mutton production programme that can prove as a boon for meat industry. Malpura weaner lambs (2 months age) are capable of achieving 25kg body weight at about 5months of age under intensive feeding on composite ration of the ratio of 60% concentrate and 40% roughage. The major advantage of this technology is that sheep owners need to rear the animals only for about 5months. Further, farmers will get the handsome profit after 5months and this profit would be at par or even more than when the lambs are reared for 12months under extensive grazing system. By considering all the inputs required for raising the lambs to attain finishing weight of 25kg it is estimated that net profit of about Rs.370/- per lamb on slaughter basis and Rs.100/- on live animal sale basis can be obtained.

Low quality of nutrients restricts the utilization of dry and non-conventional roughage by ruminants. The treatment of 100kg dried roughage (straw+ stover/grasses) with urea (1kg), mineral mixture (1kg) and molasses (10kg) resulted in better utilization of poor quality roughages by adult ruminants. Mineral mixture for improving production, reproduction and health in sheep consisted of di-calcium phosphate (73.90%), calcium carbonate (6.50%), zinc sulphate (0.10%), copper sulphate (0.10%) and sodium chloride (19.4%). At the dose rate of 40-50g day in cattle/buffaloes and 25-30g/day in sheep and goats results in enhanced milk yield and weight gain, reduced diseases incidences, and improved wool yield and quality.

***Feed and fodder resource development*:** Feed and fodder resource development programmes are being undertaken to encourage the sheep breeders to adopt newly evolved feed and fodder technologies keeping in mind the rejuvenation of degraded pasture lands though supply of high yielding varieties of grass, legumes and fodder tree.

Reseeding pasture with cenchrus and clitoria gave 5-6 times more yield than the grazing lands in the villages. The demonstrations motivated the sheep breeders to undertake improved methods of cultivation as well. Several management and biological techniques *viz*. closure sowing, introduction of improved grasses and legumes, fertilization and cutting techniques have been standardized for enhancing biomass production and quality of these grasslands.

Wool quality evaluation and utilization: The quality of wool from sheep flocks of ORP area was evaluated to demonstrate the improvement due to crossbreeding programmes in their flocks. Village artisans were trained regularly on the utilization of wool in the cottage sector. In recent years, women in particular were trained to spin Bharat Merino wool on hand charkhas and production of sweaters and pullovers. It was realized that though technologies were developed for wool utilization (as such or in blends with other fibres), but these could not be much utilized by the weavers, artisans and even by the industrialist. Regarding value addition of the raw wool, awareness on sheep preparation for shearing, practical skill in selection of shearing tools, equipment, shearing site and preparation of clip and marketing of wool has been developed among the sheep farmers. In general, 20-25% farmers sold their wool on weight basis against the sheep head basis (75-80%). Sale of wool on weight basis thereby enhanced the income by Rs.5-6/kg wool as compared to sheep head basis. Lack of proper grading of wool before marketing coupled with the highly unorganized nature of the farmers expose them to the exploitation by the buyers.

Handloom woven blankets technology for rural artisans: The blending was carried out with fine wools of around 20 and staple length below 50mm having insignificant heterotypic fibre component. The crossbred sheep wools of this low fibre length cannot be utilized for apparel manufacturing. The blended yarns prepared in the ratio of 70:30 and 50:50 of native and crossbred sheep wools were spun on woolen system and approximately 2.5±0.5 Nm yarns were prepared. After dyeing the yarns, the blankets of stripe and check designs were prepared on handlooms.

Technology for wool and camel hair blended products: Since Rajasthan and adjoining states have a sizeable population of camels, nearly one million kg of camel hair becomes available. In order to promote their utilization and to derive economic value, grey camel hair was blended with wool in different proportions after grading it according to colour and fineness. The results indicated that 30% blend of camel with native wools yields best results. The yarns were spun on woolen system. Similarly, the carpet samples also performed equally well. Camel hair is generally available @ Rs.15/kg as against Rs.60/kg for wool. Thus, the camel hair blankets are cheaper by Rs.50 or so per piece. Similarly, handloom woven carpets may be cheaper by Rs.100 to 125 per square meter.

Handmade felts production technology: Inferior grade rabbit wool, which had little textile application for good quality goods, was blended with short length fine crossbred sheep wool in various proportions. The blend optimization studies revealed that up to 40% inferior rabbit wool can be blended with wool for making superior quality low weight extra white handmade felts. These felts can be converted into value added products like jackets, women ruffles, etc. Little embroidery work further enhances the value addition. Studies revealed that such products would have greater demand providing employment in the rural/cottage sector.

Organic sheep manure Avikhaad from wool waste: The wool waste, sheep manure and crop waste is taken in the ratio of 30:50:20% respectively. In the mixture, compost culture is mixed @300g per tonne. In order to maintain around 60% moisture in the mixture, water is sprinkled on the mixture. The mixture is turned at 40-45days interval. The mixture so prepared is converted in the manure after 110-120days. Due to presence of wool in manure, it has higher water holding capacity compared to other fertilizers as wool has natural property of water holding.

More lamb per sheep from prolific Avishaan: Avishaan, a three breed prolific sheep, truly a 'Make in India' initiative is capable of fulfilling the dream objective of “Doubling the farmers' income” through production of more lambs per ewe per lambing, more mutton, more milk to sustain the multiple lambs, more wool and more survivability. It produced 72% more lambs than native single lamb bearing Malpura sheep. Total body weight harvested at 3 months of age was 35% more than Malpura. Avishaan lambs attained slaughter weight of 24.36kg at 6months of age.

Technical literacy, extension education and Survey of sheep breeders: The socio-economic survey conducted on sheep breeders in TOT areas indicated that out of the total adopted sheep breeders 28.4 and 7.0% belonged to

Schedule caste and Schedule tribe communities. Sheep farming and agriculture were the main occupations of 45.8 and 53.5% farmers, respectively, while 55.6 and 24.8% have sheep husbandry and agriculture as subsidiary occupations respectively. Further 52.1 and 47.9% were joint and nuclear sheep breeder families, respectively. The average land holding of the sheep breeders was 4.02ha out of which 22.83% land was irrigated. Survey conducted in 1991-92 revealed that 5.67% sheep were crossbred with average flock size of 64. The body weights at different growth stages were higher in crossbreds than local breeds. The greasy fleece production of cross breeds was also higher than native breeds. The fibre diameter of native and quarter bred sheep wool was 41 and 26µ with medullation of 70 and 30%, respectively indicating the improvement due to crossbreeding. Crossbred in the adopted area had wool of 32µ and mixed flocks wool had of 36µ. Overall morbidity in adopted villages ranged from 43.8-64.9% while, mortality in adopted villages varied from 2.44 to 8.65%. At present the emphasis is on rearing of native breed of sheep. The sheep breeders were aware of the modern health technology practices like vaccination.

The efforts were made to motivate the farmers by making extension approaches and using different media. Some of the salient ones were publication of pamphlets, prassar patra, organizing and participating in exhibitions, fairs, kisan gosthies, Mobile SMS advisory, talks and news coverage on radio and television are being taken up regularly. Besides Institute activities, news was regularly published in newspapers particularly in Hindi. Farmers and women trainings are also being organized regularly to develop the skill among the farmers in adopting newer technologies. The impact of Institute in terms of gain in knowledge, attitude and socio-economic status of adopted farmers was found significant as compared to non-adopted farmers. Socio personal traits *viz*. education and socio-economic status has a positive and significant relationship with knowledge level of respondents about improved sheep production technology. Majority of adopted respondents (98%) had medium to high knowledge level while in case of non-adopted respondents majority of respondents (86%) had low and medium knowledge level. This showed that CSWRI had a significant influence on the knowledge level of sheep breeders. The survey conducted to study the benefits derived out of the technology passed on to sheep farmers revealed that the gross income increased by an annual rate of 8% from Rs.8,800/- in 1981 to Rs.26,100/- in 1989. Highest benefit: cost ratio was observed to be 2.38 in case of small farmer category with a livestock configuration of 66 sheep, 24 goats and 4 bovine and with land holding size of 1-2ha. This combination of livestock configuration and land holding size along with free grazing area has generated maximum net returns of Rs.13,400/- per sheep breeder in 1990 in the semi-arid areas. Different queries received from the farmers on problems faced by them regarding sheep production were regularly answered and whenever required scientific and technical personnel visited such farmers flocks to alleviate their problems.

Grassland and Forage Agronomy

Grassland and Forage Agronomy Section initiated research work on productivity and suitability of natural vegetation as fodder for sheep and goats. In initial years, cenchrus pastures were established with introduction of improved varieties, their testing for productivity, nutritive value and compatibility in forage production system was assessed. Cultivated fodder suitable to semi-arid areas like cowpea, cluster bean, lucerne, berseem, sorghum, pearl millet, oats, barley etc. were tested with number of different genotypes and explored for enhancing yield. Later on, in order to harvest quality fodder from pasture land, exotic and native perennial legumes (*Dolichos lablab,* Siratro, Atylosia*, Clitoria ternatea,* Stylosanthus spp.*)* were introduced and evaluated in combinations with cenchrus in different ratios with varying fertility levels. Based on preliminary results, agronomical package were developed for raising cultivated fodder, cenchrus pasture production and thereafter, studies were conducted on carrying capacity and stocking rates of rangelands and improved pastures.

In 1990's, different land use systems were developed with emphasis on enhancing fodder production per unit area per unit time. In this line, two tier and three tier systems were studied with different fodder trees suitable to semiarid regions. Tree growth, their leaf fodder, green as well as dry fodder were assessed for production and compatibility to underneath associated grasses, legumes and cultivated crops along with their nutritive value. Later on, tree management aspects were taken with regards to lopping time, lopping interval, lopping intensities with varying age of tree. Research on growth enhancing measures followed after establishing management aspects. In the beginning of 21st century, allelopathic effects of fodder tree in agro-forestry and silvi-pastoral systems were studied. Besides plain land, attempts were made to establish pasture on undulated topography, efforts have been made to convert it into productive for fodder production. In this context, watershed approach was tried and pasture establishment / silvipastoral system were developed on sloppy land / rolling topography. In recent past, research has been concentrated on enhancing the income of farmer along with maximizing food, fodder and fuel production per unit area per unit time and reducing climatic risk to ascertain production under unpredictable climatic behavior. Different land use systems with proper geometrical set of fodder tree, fodder bush, grasses and cultivated fodder and food crops were integrated to harness the maximum benefits from natural resources. Further, to strengthen the economic condition of the farmer, fruit trees were incorporated in prevailing pasture and silvipastoral system as agro-horti-pasture system. In order to bring unproductive land into cultivation, research work on salt affected land and water was also initiated in last decade and forage cropping sequences were suggested with proper ameliorative measures on salty land.

Pasture establishment, management and renovation: The natural grassland consisted of 9 species of grasses/sedges and 18 species of forbs. *Aristida adscensionis* was the predominant grass followed by *Perotis hordeiformis, Eragrostis ciliaris, Digitaris adscendens* etc. *Indigofera cardifolia, Tephrosia strigosa, Zornia diphylla, Borrevia hispida and Crotolaria burhia* were the forbs of major availability. The total yield of natural grassland was 10.41 q/ha (73% of grasses and 27% of forbs). *Aristida adscensions* contributed about 48% of the yield followed by *Perotis hordeiformis, Eraqrostis ciliaris, Indigofera cardifolia, Zornia diphylla, etc*. Reseeding of pasture yielded about thrice as much as rangeland. Dry matter yield from cenchrus, cenchrus + clitoria and clitoria was 26.64, 28.66 and 31.04q/ha, respectively. The ground cover under the vegetation in rangeland was found to be 5.76% (4.02% under grasses/sedges and 1.74% under forbs). *Aristida adescensionis* made the largest contribution in ground cover followed by *Cyprus* spp., *Crotolaria burhia* and *Eragrostis ciliaris*.

Among different methods of cenchrus establishment, line sown of pellet gave the highest yield, though it is costlier one. Out of various legumes (cluster bean, moth and cowpea) tried along with cenchrus; all gave more yields than cenchrus alone. Broad casting and inter-sowing of legume did not have any impact on total fodder production. The highest production of cenchrus was recorded on harvesting at 5cm height from the ground level after 30days of germination. Out of four varieties of cenchrus (IGFRI-3108, IGFRI-358, Pusa Giant and Pusa Yellow Anjan), the

highest production and number of tillers were recorded in Pusa Yellow Anjan on the basis of two cuttings after establishment year. Application of 40kg N/ha produced higher DM yield than 20kg N/ha. A Split application of nitrogen either through soil or foliar were better than single application of nitrogen in terms of dry fodder production. Among the split application, full fodder application was better than rest of the methods. The DM was highest in *Panicum maximum* at pre-flowering, flowering and post flowering. At maturity, maximum dry matter was recorded in blue panic.

Twelve varieties of *Pennisetum pedicilatum* were evaluated and IGFRI-866 variety was found to be the most suitable for semi-arid conditions in terms of fodder production. The DM yield of rangeland was higher with foliar application of 20 or 40 kg N/ha. Foliar nitrogenous fertilizer application of rangeland showed good yield response however, undesirable and poor quality grass species responded more to the fertilization leading to change in botanical composition of rangeland towards undesirable species. The decrease in herbage yield was to the tune of 56.06% due to grazing as compared to production ground cover and of 31.84% due to grazing as compared to production grazing/browsing. The crown cover of top layer was 18.83 and 13.27% under production and grazing, respectively. Considerable changes in physical properties of soil (bulk density and filed capacity) were not observed due to grazing and production.

Survivability of cenchrus plant in horti-pastoral system reduced slightly in third year as compared to second year after planting. Four levels of sheep manure viz., 0, 5, 10 and 15t/ha and three levels of nitrogen viz., 0, 30 and 60kg/ha were evaluated. Increase in cenchrus yield with increase sheep manure doses up to 15 t/ha was observed. Addition of urea did not produce any extra beneficial effect. Sheep manure @10t/ha replaces 60kgN/ha. Soil organic matter and available K improved by manure application.

Five varieties of Napier hybrid were tested and variety BN 86061 yielded 238.49q/ha green fodder followed by NB 21 (53.56q/ha). Pala yield was at the maximum in bush cleaning + N-25, P-40 and tiller cultivation. Application of 325 kg N and 25 kg P followed by tiller cultivation produced 50 % more dry fodder than untreated 6 year old cenchrus pasture. Three growth regulators viz., zibbralic acid (ZA), indole acetic acid (IAA) and indole butyric acid (IBA) at 50, 100 and 150 ppm were tested for germination of cenchrus. Seed soaking for 16 hr with 150 ppm of ZA gave highest germination of *Cenchrus ciliaris*, however, at par germination of *Cenchrus ciliaris* was recorded with 8 hr seed soaking in IAA at 100 ppm. The highest shoot length of cenchrus seedling was with 100 ppm GA at pH 8.0 after 10days of germination. Increased growth regulator concentration beyond 100ppm and pH beyond 8.0 drastically reduced growth of seedling. The maximum germination of cenchrus seed was recorded with 10ppm GA at pH 7.0. At higher pH beyond 8.0, sulphuric acid (70% soaking and then washing water) was better than growth regulator.

Mixed cropping and forage quality improvement: Among different legumes, *Dolichos lablab* produced maximum dry matter per plant followed by *Clitoria ternatea*, *Siratro* and *Atylosia searaboides*. Sewan grass (*Lasiurus sindicus*) did not perform well under semi-arid conditions. The dry forage yield of *D. lablab* was maximum with application of sulphur @40kg/ha. The yields of cluster bean (cluster bean) were higher at the seed rate of 4-8kg/ha with positive effect on nursing of cenchrus pasture during establishment. Relatively higher production was obtained from cenchrus: dolichos in 1:1 proportion compared to 2:1, 3:1 and cenchrus alone in both grass. Maximum fodder was obtained from the plant population when harvested at late flowering stage and with the application of 15kg P_2O_5/ha. Application of 20 kg N was found good enough for forage production from *D. lablab*, however, maximum seed was collected at 45kg N/ha. Phosphorus has no effect on forage production but 40 kg P_2O_5/ha had pronounced effect on seed production. Mixture of cenchrus and *D. lablab* (1:1) gave maximum yield of 12.48q/ha after application of $NaNO_3$ (@20kg/ha). The dry forage yield from dolichos was 17.02 q/ha after treatment with $Na_2B_4O_7$. The mixture of cenchrus and dolichos yielded maximum fodder under two cutting system while, *Clitoria ternatea* was second in fodder yield. The maximum dry fodder (76.11q/ha) and crude protein (9.46 q/ha) was obtained from the mixture of cenchrus and dolichos in the ratio of 50:50.

The highest dry fodder production (59.06q/ha) was recorded with the mixture of cenchrus and dolichos. The yield of other forages were in the range of 28.82 to 45.24q/ha whereas lowest yield (28.82q/ha) was recorded from *Cenchrus setigerus* alone. From mixture of cenchrus and clitoria, 45.24q/ha dry fodder was obtained. Maximum production was observed when 60 kg N/ha in the form of sheep manure (9 t/ha) was applied in mixed pasture of cenchrus and dolichos in alternative strips. The inter cropping of cowpea and moth found to increase 5 and 2 times higher dry fodder yield of cenchrus. Application of wool dust (@200kg/ha) does not affect the cenchrus production, however, production of *D. lablab* was equally good at fertilizer treatment of 40 kg N + 60 kg P_2O_5/ha.

Maximum dry fodder (41.0q/ha) from single cutting was obtained when the carpet legume was sown at spacing of 30 x 30 cm and harvested at late flowering or pod swelling stage (90 days after germination). Effect of dose of phosphorus application was not evident on dry fodder yield. The inoculation of rhizobium (@15-20%) during sowing resulted in increased the nodule weight per plant. In low rainfall year (375mm) the highest production was recorded from the mixture of pearl millet and carpet legume in the ratio of 1:2 and 30cm raw spacing, where as in high rain fall year (1000mm) the maximum fodder was obtained from the mixture of maize and carpet legume. In case of total crude protein, the mixture of pearl millet and dolichos in the ratio of 1:4 and 1:6 with 30cm raw spacing were at par with pure dolichos, thus to obtain maximum benefit in terms of fodder production as well as crude protein, inter cropping the pearl millet in the main crop of dolichos in the ratio of 1:4 with 30cm row spacing under rain fed condition of semi-arid region was advocated. Erect type and spreading type varieties of dolichos were at par in terms of fodder production per unit area and time.

Maximum yield was recorded when *Cenchrus ciliaris* was sown in lines + broad casting of dolichos seed followed by cultivator. Similar results were also observed over cenchrus + clitoria. The application of P_2O_5 increased yield over control, however levels of P_2O_5 (20, 40 and 60kg/ha) were at par in dry fodder yield and grass legume ratio. Among the legumes the highest crude protein was recorded in Siratro at pre flowering stage. At the remaining stage crude protein was the highest in dolichos. At maturity the crude protein content was lowest in velvet bean. Among the grasses the highest crude protein content was found in *Cenchrus ciliaris* at all the stages of growth.

Sowing of clitoria at row spacing of 30cm produced higher dry matter yield than other spacing. Harvesting of forage at 40 days interval produced maximum dry matter yield. Maximum grain yield was produced with pure pearl millet followed by pearl millet + clitoria and maximum dry fodder yield was obtained when pearl millet inter cropped with cenchrus. Spacing of 40cm between two rows of pearl millet gave the highest grain yield and dry matter production. The maximum dry matter yield of maize was obtained when sown in association with berseem with full seed rate.

Tillage operation gave appreciable increase in germination of legumes. Stylosanthus gave maximum number of plants/m^2 followed by clitoria, dolichos and siratro. Pelleting of legume seeds increased the neem germination by 16% over no pelleting. Grain and fodder yield was almost similar on sowing of pearl millet under single and paired row pattern. The grain yield of pearl millet was not affected by legume introduction, however, dry fodder yield increased due to legume incorporation recorded maximum with cowpea followed by dolichos and cluster bean. Among different legumes, cowpea gave maximum fodder yield followed by cluster bean, dolichos, siratro and stylosanthus. Inter-seeding of legumes in paired cropping of cenchrus gave maximum fodder yield followed by inter-seeding in normal rows, alternate cropping and strip cropping. Among different legumes, cenchrus + dolichos gave the highest forage yield. Grass legumes mixed pasture gave the highest yield than grass alone. Among various shrubs, *Sesbania sesbane* found best growing with better establishment. Dhaincha increased organic matter of surface soil layer (0-15cm) to the maximum while the *Leucaena leacocephala* increased organic matter of sub-surface soil layer (15-30cm).

Introduction of cowpea in rainfed cereal gave maximum crude protein yield followed by dolichos and cluster bean. Paired cropping was superior to normal cropping. In semi-arid conditions, among legumes, Pusa bean produced higher dry matter followed by velvet bean and Atylosia. Among cenchrus spp., *Cenchrus ciliaris* 358

produced higher yield. The crude protein was highest in Atylosia followed *by Stylosanthus hamata* and *Desmodium infortum*. *Cenchrus ciliaris* and *Clitoria ternate* produced maximum DM during December.

Maximization of food and forage production through land use system under agroforestry: Khejri densities were tested for performance of pearl millet and maximum grain yield of pearl millet was recorded in association of 50trees/ha, however, dry fodder yield (stover) was higher in control. Khejri, babool, ardu, neem, dicrostachys alone or in alternate rows and in mixed plantation exhibited that *dicrostachys* registered the highest survivability while ardu showed the lowest one. Khejri found to be slowest growing tree, however, neem showed the lowest crown spread at the age of three year. The soil status and cenchrus pasture was not affected by plantation of fodder tree up to three years of age. In established ber orchard, cenchrus, pearl millet, green gram, clitoria as pure stand and mixed were evaluated with various levels of N and P. Maximum fruit yield was with the application of 20kg N and 20kg P_2O_5/ha and under pearl millet + green gram crop combination.

Natural, single, double and multi-tier systems were studied for fodder production. Cenchrus yields from all the systems were higher over natural pasture. Growth of ardu was better in two-tier system. The production for 5 years in

natural land, single tier (seeded pasture), two tier and three tier silvi-pasture was to the tune of 16.59, 19.20 and 23.74q/ha, respectively. The three and two tier system provided 9.5 and 6.25 q/ha tree fodder. Five-year study showed the leaf fodder and fuel wood yield were 3.01, 6.81, 0.92, 3.67 and 0.11, 2.80, 0.10, 0.28kg/tree in ardu, neem, siris and babool, respectively. The average net income over four years was highest in ardu pasture system. Ardu, neem, siris and babool having cowpea, sesamum, pearl millet, cluster bean, black gram, green gram and moth as associated crops showed highest production of green leaves, dry leaves and fuel wood in association of ardu followed by siris and babool. Highest increment in plant height and collar diameter was observed at 50plants/ha followed by 25plants /ha density. Under the horti-pasture system dry fodder yields were compared in open space and in association of ber and aonla. The green and dry fodder yield of other rested crops were at par in aonla and ber association with open field conditions, though highest with aonla association, however, grain yield of all the crops were highest in open space. Dicrostachys, mulberry and zinja with ardu were studied for the performance along with cenchrus grass in the multi-tier system. Total biomass in ardu + zinja was at maximum followed by ardu + dicrostachys and ardu + mulberry. Zinza grow tallest and dicrostachys had maximum collar diameter. Ardu grew at maximum in combination with mulberry.

The highest green fodder yield (154.69q/ha) was in multi-tier system (Ardu + pearl millet + cowpea) followed by two-tier, however in multi-tier, maximum dry fodder yield was with sole pearl millet followed by cenchrus +cowpea. Dry fodder production from cenchrus, cowpea and their combination increases progressively with increasing level of fertilizers in all land use systems. The highest dry fodder yield from crop and grasses and their combinations was in single-tier system followed by two and multi-tier system. Growth parameters and yield of cenchrus were comparatively higher in association of ardu tree in comparison to other fodder trees. Application of 60kg N and 50kg P registered highest cenchrus production in association of all fodder trees. In a tree-crop interaction study of agroforestry system, dry fodder, seed yields and biomass of various crops of semi-arid areas was maximum in association of ardu which was significantly higher to neem association and at par with open field, siris and babool association.

The maximum increased in grain and straw yield when application of chemical fertilizers as well as sheep manure at recommended doses was applied both in crops and aonla plant. Cropping pattern also has significant effect on dry fodder and seed production. Maximum yield of seed was obtained in cluster bean followed by groundnut and

lowest seed yield was in cowpea. Applications of sheep manure @ 5 t/ha gave significant higher seed and straw yield as compared to control treatment. Green fodder production was the maximum under cluster bean-oat cropping sequence followed by cowpea-oat system. Sheep manure application significantly increased green and dry forage yield of oat at both cuts. Cluster bean varieties (RGC-936, HG-75 and local) were tested with fodder trees ardu, babool, siris and neem. The maximum grain and dry fodder yield of cluster bean HG-75 was obtained in association with ardu. HG-75 produced maximum total biomass in association of ardu tree, which was significantly higher to other cluster bean varieties in any agro-forestry system except RGC-936 in association with ardu. In a horti-agro system study, moth and cluster bean were taken in association of fruit trees (ber and aonla) and sown in different ratios. Total biological yield was significantly higher in open space than ber and aonla association. Application of 10 t sheep manure/ha recorded significantly higher yield over no use of sheep manure in agro-horti system. The maximum increase in grain, straw and biomass production was with fertilization to both crops and aonla. Among the cropping pattern, cowpea-oat gave maximum green fodder than rest of the system.

Higher green and dry fodder was recorded in *Cenchrus setigerus* than *Cenchrus ciliaris*. Application of NPK fertilizers @40:40:20kg/ha to grasses and 500g urea+750g SSP+750g MOP to ber plant was found statistically at with the treatment of sheep manure applied @10t/ha in grasses and 20 kg sheep manure in ber plant. However, maximum dry fodder and yield production in grasses were obtained when the sheep manure applied @5t/ha and 10kg sheep manure in ber plant along with 50% doses of recommended inorganic fertilizers (20:20:10kg/ha in grasses and 250g urea+ 375g SSP+375g MOP in ber plant). Ber fruit yield was not influenced significantly due to grass species. Increase in application of sheep manure (0-15t/ha) resulted in considerable increase in cenchrus and ground nut yield, under different tier systems. Cenchrus + groundnut in 1:1 ratio yielded the highest biomass (37.2q/ha) in two-tier system. The three-tier system registered 8.49 and 24.33% higher biomass yield in comparison to two and single tier system. Dry fodder and biomass production of ground nut in strip cropping was significantly higher as compared to sole crop.

Average fodder, seed and biomass yield of various crops in three tier agro-forestry systems were significantly higher as compared to two tier and open field condition. Three year average revealed that three tier agro forestry system registered 3.68 and 16.74% higher seed yield, 4.73 and 12.2% higher dry fodder and 4.83 and 14.74% higher biomass in comparison to two and single tier system. Cenchrus grass production was also higher by 3% and 10.4% in three tier compared to two tier and open field. All the arable crops (pearl millet, ground nut and green gram) produced almost similar dry fodder, seed yield and biomass yield when sown either sole crop or in combination with cenchrus as strip in the ratio of 3:2.

In another study, effect of solar reflectance and CO_2 concentration on crop productivity under ardu based agroforestry system in semi-arid region revealed that in 3-tier agroforestry system, higher CO_2 concentration was observed that might have resulted in higher crop growth rate (CGR) in comparison to two-tier agroforestry system and open field conditions. As a result, average productivity (dry fodder yield, grain yield and biomass yield) of various crops was significantly higher in 3-tier agro-forestry system which was higher by 4.71 and 12.95% in dry fodder yield, 5.43 and 22.57% in seed yield and 4.85 and 14.34% in biomass yields in comparison to two-tier agro-forestry system and open field conditions, respectively.

Allelopathic effects of tree leaves were studied for germination and subsequent growth of cluster bean and pearl millet. Significant reduction in growth parameters was observed in 12hr soaking compared to 4hr soaking and significantly higher plant height was observed in association of ardu, siris and open compared to neem and babool. Average growth attributes, dry fodder and biomass production of cowpea, cenchrus, cluster bean and pearl millet were recorded the highest in association of ardu which were observed at par with siris association and open field conditions and significantly higher to that neem and babool association. The total biomass yield was the highest with cereal crops viz. cenchrus and pearl millet compared to legume crops. Yield attributing characters dry fodder and seed yield of various arable crop viz. groundnut, moth, cenchrus, cluster bean were not significantly influenced either growth in open filed or in association with fruit trees as agro horti-pasture system. However, *Cenchrus setigerus*

registered significantly higher growth and yields in comparison to *Cenchrus ciliaris* in agro horti-pasture system. Among fertilization levels, application of 40:40:20kg NPK/ha through sheep manure and chemical fertilizers (50:50) resulted maximum green fodder, dry matter and seed yield. Maximum Green fodder (153.46q/ha) and dry matter yields (35.99q/ha) were recorded with the *Cenchrus: Dolichos lab lab* (1:2 ratio).

Top feed resources, their establishment and management: Babool and ardu registered higher dry fodder than khejri at one lopping at the interval of 6 months. In case of babool difference in dry fodder production/tree/year was noticed between two lopping at 6 months. Four tree species *viz*. *Acacia nilotica, Leucaena leucocephalla, Bauhinia racemosa* and *Dichrostachys nutans* with two spacing (55 and 44m) were evaluated. *Dichrostachys nutans* had maximum survivability (92.7%) whereas *Leucaena leucocephalla* had minimal survivability (30.5%). In khejri, all yield attributes except length of clear bole have significant association with each other. The joint contribution of bole height at girth, length of clear bole, length of crown, diameter of crown was having 70.38% variability in fodder yield of khejri, however crown diameter alone explain 67.84% of variability and thus can be utilized for prediction of dry fodder yield in khejri. A prediction equation derived was:

Dry fodder yield (kg) = - 12.77 + 4.88 (Crown diameter)

In case of ardu similar study suggests that yield attributes jointly contributed 73.99% variability in leaf fodder yield which is highly significant. The number of active branches and diameter (at breast height) can be taken as criterion to predict the ardu leaf yield and the prediction equation is

Leaf yield (kg) = - 2.98+ 0.02 (Number of active branches) + 0.36 (Diameter of trees at breast height)

Khejri gave the highest production (12.04kg) followed by ardu, zinja and kakeda. Cost of lopping was the lowest in case of khejri followed by ardu, zinza and kakeda. Twenty different fodder trees were evaluated for crude protein in four season *viz.* summer, winter, autumn and spring season. Crude protein content did not exhibit any appreciable variation in all the tree species. However, its content was higher during spring and rainy season. Dry matter yield continue to decline from February to May. Top feed yield from ardu during summer and winter season was 0.73 and 1.90q/ha, respectively. Under Dicrostachys plantation, DM yield was 14.2q/ha in February, 4.4q/ha in May, 17.3q/ha in rainy season and 13.1q/ha in November.

Fodder trees (Babool, ardu, dicrostachys, neem, khejri) in alternate and mixed rows were evaluated in cenchrus pasture. The CP content ranged from 11.90% (khejri) to 15.18% in ardu. Alternate pattern of row gave higher CP content. The effect of intensity, interval and age of lopping on natural regeneration, growth, fodder yield and nutritive value in ardu, khejri, neem and dicrostachys showed that difference in dry fodder yield in young trees lopped twice a year were marginal where as it was higher in old trees. Older tree contained lower leaf moisture than younger trees. Ardu can be lopped fully twice a year in the month of December and May-June at any stages of its age. Fully-grown neem can be lopped fully once in a year during December-January. However, young tree of neem can be lopped fully twice a year during December-January and May-June. Reverse is true for Khejri. Young khejri plant can be lopped fully only once in a year, however, old tree can be lopped up to 2/3rd twice a year in May-June and November -December. Comparative study on freshly planted and 5-6 years old ardu, neem, siris and babool fodder trees showed that the highest increment in crown diameter and plant height in neem, siris and babool was recorded with the application of 10kg sheep manure +220g urea +240g DAP per tree.

In survey of ardu in 18 districts of Rajasthan, one new species of Ailanthus was identified which is different in morphological as well as inflorescence characteristics than *Ailanthus excels*. The specific epithet has been derived from the place Avikanagar as *A. avikanian*.

Package of practices for cultivated fodder: Cowpea variety Russian Giant and E4216 resulted in higher fodder yield compared to P7, 7/12 Red, No. 10, Jodhpur and K-147. Among 8 varieties of cluster bean, Malpura Giant and T-3 were superior in dry fodder production over test one. Further, Durgapura Safed and FOS-277 also observed better than T-87, T-16 and local one. Cowpea variety Russian Giant yielded the highest dry fodder when applied with 40 Kg N and 60kg P/ha, while Malpura Giant variety of cluster bean yielded maximum with the application of 20kg N and 6kg

P/ha. In case of moth bean (*Phaseolus aconifolius*), yield remained unaffected by N and P application. In sorghum cultivation spraying of 2-4 D @2 kg/ha was able to control weeds. Phyto-toxicity of 2-4 D on sorghum was observed beyond 2kg/ha. The highest dry matter was obtained from Algerian variety of oat with the application of 100kg N/ha but the dry matter production per day was the highest in case of Kant variety. Trace elements were applied to lucerne crop in the form of $CaSO_4$, $MgSO_4$, $ZnSO_4$, $FeSO_4$, $Na_2B_4O_7$ and Sulphur @20kg /ha except $Na_2B_4O_7$. Though, the highest green and dry matter production was registered with the application $FeSO_4$ but no significant variation in dry matter accumulation was noted amongst micronutrient.

Application of GA proved significantly better in terms of dry matter production of cowpea EC-4216 only up to 45 days of sowing. Application of GA did not give significant response in *Dolichos lab lab.* Out of 18 varieties of cowpea, C-25, FOS-1 and NP-3 were found to be superior over to other varieties in respect of fodder yield as well as resistant to aphid attack. Strip cropping of cenchrus and dolichos in the ratio of 50:50 across the slope followed by cenchrus furrow (60X20 cm) was found to be a suitable technique for the establishment of mixed pasture of cenchrus and dolichos on rolling topography (1-2% slope) with respect to fodder production.

The highest grain fodder was recorded in OS-8 variety of oat, however maximum dry matter yield was produced by Pusa oat-1. The highest crude protein yield (16.8 q/ha) was from VPO-121 followed by OS-8. Four varieties of oat (Kent, Fulghum, 2688 and 3921) taken @ 1 and 2 kg/ha with three N levels (0, 40, 80 kg N/ha) exhibited that the Kent variety gave the highest dry matter yield (69.9 q/ha). The dry matter yield of Japanese Sarsoon was the highest when crop was sown at the rate of 1kg seed/ha.

Maximum green fodder yield of Lucerne (36.00 q/ha) was recorded when fertilized with 120 kg P_2O_5 /ha. No effect of cutting management was assessed due to single nipping in all the treatments. In single cut entry, maximum seed yield from first cutting was obtained from OS-10 followed by PO-2 and OS-7, however, in two cut entries HDF-114 yielded highest seed yield. The seed yield from second cut was highest in UPO-1. Application of 120kg P_2O_5/ha produce significantly higher seed/ha. Two cuttings of lucerne were significantly better in seed production, number of seed/floret than others. Three cutting gave highest seed/1000 grains. Dry matter was highest in four cuttings. The seed yield and number of branches per plant was the maximum with 120kg P_2O_5/ha, however dry matter yield, 1000 grain weight was higher in 40kg P_2O_5/ha. Foliar application of phosphorus did not show any effect.

Among the organic fertilization, significant improvement in DFY and biological yields of hybrid napier and Indian bean were observed with the application of Avikhad in comparison to sheep manure. Intercropping of groundnut and dinanath grass in 3:1 ratio and cutting of dinanath grass between 60-75 DAS could produce acceptable amounts of good quality forage than the sole cropping, and it can be an available alternative to sole cropping of groundnut in a double cropped system of semi-arid regions.

Cowpea followed by maize alone produced higher green fodder as well as dry fodder yield. The line sowing (45X15cm^2) along with application of 60 kg N and 50 kg P was better for fodder production. Sorghum variety PG 3060 performed better than MP-Chari under similar conditions. The green fodder yield of Jumbo and MP-Chari of fodder sorghum was highest in 4 days irrigation interval followed by 6 days interval. Increasing levels of fertilization up to 120kg N and 50kg P progressively increased green fodder yield. Jumbo variety yielded higher green fodder yield than Hara Sona and MP-Chari. Among the varieties 'SSG-5001' produced the maximum green forage (556.9q/ha) and dry matter yield (9107.5q/ha). The green and dry fodder yield increased considerably with increasing level of N from 0 to 120kg/ha. Remarkably higher green forage and dry matter yields, net return and benefit: cost ratio were obtained with the application of FYM @10t/ha as compared to no application of FYM.

Sorghum genotype SSG-887 gave higher green and dry fodder yield as compared to other genotypes (SSG-1000 and ASSG-117). The green and dry fodder yield was increased linearly with increase in additional dose of zinc up to 20kg/ha. The green fodder, dry matter and seed yield of cenchrus and moth bean were increased remarkably with different intercropping system. However, these were the higher in two rows of cenchrus and one row moth bean. Amongst the cowpea varieties, EC-4216 was found significantly superior over 'RC19' and 'Kohinoor' varieties. Green

and dry fodder yield of cowpea were recorded higher with increasing level of phosphorus up to 60kg P_2O_5. Green and dry fodder was also increased significantly with the application of bio-organic manure (sea weed extract @ 15kg/ha). Among fodder cowpea varieties 'EC-4216' had highest yield potential when P (60kg P_2O_5/ha) and bio-organic manure (15kg/ha) were applied combined.

Bio-fortification of forages for augmenting sheep production: In earlier study (three decades back), a significant increase in growth and yield attributes of cluster bean was recorded with application of Zn up to 20kg/ha. The maximum seed yield (2.55t/ha), stover yield (7.32t/ha), crude protein content (27.15%), protein yield (168.10kg/ha), gum content (26.95%) and gum yield (179.96kg/ha) were recorded with application of Zn 20kg/ha. The quality traits *viz*., ADF (16.06%), NDF (52.03%), cellulose (17.51%) and lignin (0.34%) were also highest in cluster bean seed when Zn was applied @20kg/ha. The higher yield attributes were recorded with RGC936 followed by RGC1017, BG3 and BG2 varieties. In recent studies, among the biofortification sources, application of Cu @5kg/ha + Zn @10kg/ha registered significant improvement in biomass production both the crops i.e., hybrid Napier and Indian bean. Dry matter intake (DMI, g/d) was significantly improved ($P<0.05$) with feeding of Zn fortified Napier hay and likewise, digestibility of dry matter (6.7%) and neutral detergent fiber (5.6%) was significantly higher over control. The intake of major and trace minerals was significantly higher in Zn fortified Napier group due to increased dry matter intake but no change was observed in balance of these minerals except Cu and Zn which was relatively higher in respective fortified Napier hay. No change was observed in the values of various blood biochemical parameters with feeding of fortified and non-fortified Napier hay; however, the level of serum alkaline phosphatase level was 35.8% more in Zn fortified Napier hay group. Increase in alkaline phosphatase level is an indicator of improved Zn retention as Zn is the cofactor of the mentioned enzyme.

Wasteland development and their conservation: Rangeland improvement was carried out through protection, sod seeding, scrubbing and fodder tree plantation, gully plugging and grassing the waterways. Sod-seeding with grass legume mixture gave satisfactory results in improving degraded natural land. Khus (*Vetiver* spp.) followed by panipulla (*Saccharum munja*) were effective with V-ditch contour bund in conserving higher moisture and reducing run off. The highest survivability was observed in panipulla under both conditions i.e. with and without V-ditch contour bund. Green and dry fodder yield of cenchrus was also highest with vegetative barrier panipulla along with V-ditch contour at upper as well as lower most contours.

Study on different moisture conservation measures at the time of planting of various trees revealed that use of pond mud, pond mud + sheep manure and polythene sheet resulted in significantly higher survival of trees up to 75days of planting in comparison to control and only sheep manure. In burnt pasture at 30 and 60days of sowing, V-ditch contour bunds significantly increased plant height and plant population, tillers/plant, spike length, seed yield, dry fodder yield and biological yield of cenchrus in comparison to without V-ditch contour bund. V-ditch contour bund increased the seed yield, dry fodder yield and biological yield over without V-ditch treatment by 16.05, 49.95 and 49.54%, respectively. Further, place of planting at lower side contour bunds reveals 15.57 and 16.70% higher dry fodder and biological yields over upper contour bunds, respectively. Further in third year of pasture establishment. The dry fodder and biomass production was higher by 11.75 and 11.67% respectively at below V-ditch in comparison to above V-ditch contour bund. In varying slope study, the highest dry fodder and biomass production of cenchrus was recorded up to 5% land slope progressive increase in land slope (5-20%) significantly reduced these parameters. Thus, 'V'- ditch contour bunding is an effective soil and moisture conservation measures in establishing cenchrus pasture at sloppy degraded lands in semi-arid regions. At lower riches of sloppy land, higher soil moisture status resulted in higher production of cenchrus as compared to upper riches. Progressive increase in land slope significantly reduced the growth parameters and cenchrus yields. The highest dry fodder and biomass production were recorded up to 5 % land slope.

Among fodder trees babool registered highest survivability in comparison to ardu and neem when planted inside V-ditch contour bund. The highest dry fodder yield of cenchrus was recorded in line sowing treatment which was significantly higher to pelleting and broad casting sowing methods, but observed to be at par with pelleting and line sowing treatment. Line sowing resulted in 7.34 and 24.07% higher dry fodder yield in comparison to pelleting and line sowing and pelleting and broad casting sowing methods.

The place of planting at upper, middle and lower contour could not registered significant variation in growth parameters of cenchrus and other grasses and their yield however, biomass yield was comparatively higher towards lower side of the slope *i.e.* lower contours with V-ditch contour bunds, among tree species babool, registered considerably higher survival as compared to ber and aonla. Maximum survival was observed when tree species were planted inside V-ditch followed by above V-ditch planting and outside V-ditch planting.

The collected soil and water samples in farmers field reveal that most of the soil and water sample were observed to saline and alkaline having high pH, low organic carbon and poor available nutrients. To ameliorate the salt affected soil, the application of gypsum and FYM improved the soil health and the crops green gram and mustard produced higher yield and biomass production in gypsum treated plots as compared to control. Application of gypsum in soil and saline irrigation water as well as green manuring (dhaincha and cluster bean) brought about significant improvement in soil properties *i.e.* reduction pH of soil and water, increased organic carbon and slight reduction in bulk density. The gypsum treatment of saline water produced higher growth and yield attributes of barley crop as compared to control.

Amelioration of salt affected lands for fodder production in semi-arid region: Application of gypsum and FYM brought about significant improvement in soil health and water quality. Applications of these soil ameliorants caused significant reduction in pH of the soil and water, increase in organic carbon and slight reduction in bulk density and thus improved soil physio-chemical properties and water quality and increased fodder crop yields in problematic area.

Arid Region Campus, Bikaner

The Arid Region Campus (ARC) of ICAR- Central Sheep and Wool Research Institute was established in July 1974, as Division of Carpet Wool and Karakul Pelt Production near Beechwal village at Bikaner. The campus is located at 28.3ºN latitude and 73.5ºE longitude at 236 meters above mean sea level in the heart of Thar Desert. The average annual rainfall is low (250 mm) and erratic. The temperature varies between sub-zero (-2°C) during winter to 49°C during summer. The centre has 636 hectares of land. The area is undulating having ranges of sand dunes covering about 25% of the land surface. The pasture is dominated by sewan (*Lasiurus sindicus*) and dhaman (*Cenchrus cilliaris*) grasses with khejri (*Prosopis cineraria*) trees and bushes (*Zizyphus spp., Calligonum polygonoides*). An area of about 50-60ha is under irrigated legume crop cultivation and horti-crop systems.

During early phase, ARC had been involved in developing technologies related to pelt production from Karakul and its crosses with three different native breeds (Malpura, Sonadi and Marwari) and activities on carpet wool production were strengthened. Later, in addition to Animal Genetics and Breeding, Animal Nutrition, Animal Health and Grassland and Forage Agronomy and Textile-processing components were strengthened at the ARC. Magra, Marwari and Chokla are the three major breeds of sheep that are being maintained and improved by selective breeding at this centre for carpet wool production.

Karakul and pelt production

The karakul sheep is famous for production of quality lamb pelt. The animal is fat tailed, produce coarse carpet wool and adapted to wide range of climatic conditions. The pelt colour of Karakul is generally black with some colour variation. The pelt can be classified in to four categories, Jacket (characterized by presence of semi-circular piped curls of medium size), Caucassian (characterized by presence of semi-circular curls of walnut type with little overgrown hairs), Ribbed (presence of narrow feathery and small pipes arranged parallel to the ribs on the body of lamb) and Flat (lacks curliness, sometime broad feathery curls). The pelt is lustrous and is good in look and feel.

A flock consisting of 200 ewes and 50 rams was imported from then USSR during 1975 and kept at ARC (CSWRI), Bikaner. In order to study the performance of this breed under cold arid conditions, a flock of 50 ewes and 10 rams was transferred to Jammu and Kashmir during 1976, where they were stationed at Kumbhathan near Kargil in Ladakh district. Five rams were also transferred to Avikanagar for cross breeding programme on pilot scale. During initial two years up to 1978 only pure breeding was done, thereafter cross breeding was under taken. The breed could adapt well at the campus with a survivability of 82-89%. The average birth weight ranged between 3.2 to 4.0kg (pooled average 3.6 kg) during different years. The average 6 and 12 month body weight of lambs during different years ranged between 15.7 to 22.5kg (pooled average 25.6kg) and 22.2 to 28.8kg (pooled average 25.6kg), respectively. The adult weight of imported animals ranged 35.6 to 40.9kg during different years, while during same year's farm bred Karakul had average adult weight that ranged between 26.4 to 35.7kg. The annual greasy fleece yield was 1.76kg. The reproductive performance was also satisfactory with 80% annual lambing on tupped basis.

The Indian Karakul sheep were developed from pooled group of 3/4th of Karakul crosses with Malpura, Marwari or Sonadi. The performance of Indian karakul was compared with that of Karakul. The pelts obtained were lighter and there was possibility of obtaining different colour lines other than black from the base of Indian Karakul. Out of 850 lambs evaluated, 50% had Jacket type, 7.6% had Ribbed type, 35% had Caucassian and 3.9% had Flat type pelt. After crossbreeding of Karakul with native breeds, the proportion of Jacket and Caucassian type pelt decreased. The pooled average of half-bred in respect of Jacket, Caucassian, Ribbed and Flat was 28.6%, 33.0%, 11.1% and

22.9%, respectively. With the 3/4th Karakul inheritance pelt quality of cross-bred improved and had 50% Jacket, 27% Caucassian, 10.9% Ribbed and 9.3% Flat type pelt.

Selection and improvement in Marwari sheep

Marwari is one of important carpet wool producing sheep breed of North Western arid and semi- arid region of India. The breed is hardy and well adapted to harsh and erratic climatic conditions of hot arid region. This breed is considered to be largest in number and distributed widely in Rajasthan and some parts of Gujarat. The animals of Marwari breed are distributed in Jodhpur, Jalore, Nagaur, Pali, Barmer districts of Rajasthan and border area of Gujarat. The All India Coordinated Research Project on Sheep Breeding was initiated in 1971. From 1991 the AICRP on sheep breeding has been converted in to Network Project on Sheep Improvement to undertake survey, evaluation and improvement of indigenous sheep breeds. Marwari breed was added in this project in 1992. Since then, Marwari breed is being improved for carpet wool production through selection and an elite flock of Marwari has been established with more than 350 breedable ewes at ARC (CSWRI), Bikaner. The main objective of the project is to increase the body weight and greasy fleece yield (GFY). The breeding rams are selected on the basis of selection index incorporating six-month body weight and first six-monthly greasy fleece yields.

The improvement in the body weights at all stages was recorded. The body weights at six months improved from 17.09 kg to 24.57 kg (43.76%) over the periods. Similarly, improvement (56.22%) in body weight at 12 month was also recorded (from 20.81 kg to 32.51 kg). The pre weaning ADG improved from 131 g to 152 g. The post weaning gains were improved by 120% and 47.7% during 3-6 M and 6-12 M, respectively. The adult annual GFY was improved from 1209 g to 1484 g (22.8%) since inception of Network Project. Due to improvement in the body weights and proper management of flock the survivability of animals improved a lot over the years. In general, the overall survivability was more than 97% which is very much desirable for better remuneration to the farmers. The tupping percentage improved from 73.6 to 99.5%. The improvement in tupping percentage showed the good supervision and management conditions at the center. Similarly, lambing rate on ewe's available basis was also improved from 52.0% in 1992 to 100.3% in 2019-20. Due to good health of the animals and improved body weights, the twinning percentage was also improved and 22% twinning was recorded in 2005-06.

Performance of Marwari sheep

Trait		Average
Body weight (kg)	Birth	3.00
	3 month	17.00
	6 month	25.00
	9 month	29.00
	12 month	32.00
Reproduction (%)	Tupping	>97.00
	Lambing	95-100
	Twinning	5-10
Wool	Annual GFY (g)	1400
	Fibre diameter (μ)	35.00
	Staple length (cm)	5-6
	Medullation (%)	45-50
Annual survivability (%)		98.00

The genetic trends were positive for the traits under selection. The genetic gain for six-month body weight per year and per generation was 62 and 147 g, respectively. However, the genetic gain for first six monthly GFY per year and per generation was 1.45 and 3.46 g, respectively. The positive phenotypic trends indicated about general improvement of flock whereas positive genetic trends indicated genetic improvement of the flock over the years. The superior breeding rams were produced every year for the supply to the farmers or Government Organizations for genetic improvement in the animals of farmers. Due to superiority of breeding rams over the rams in field, there is great demand of superior breeding rams in the field. More than 2000 rams/ram lambs were sold to Government Organizations/ Farmers for improvement of the animals in field since inception of Network Project.

Improvement of Magra sheep

Magra is an important carpet wool breed of Rajasthan and is found in its purest form in Bikaner and adjoining areas of Nagaur, Churu and Jhunjhunu districts. The sheep produces extremely white and lustrous fleece. The wool

produced by Magra is most suitable for carpet production and is in great demand due to its lustre. The Magra sheep is being improved through selection under research project since 1996-97. A total of 185 ewes were purchased. The project was further strengthened by having external funded project from Central Wool Development Board, Ministry of Textile, on strengthening of ram rearing centre of Magra sheep at ARC to produce more number of superior breeding rams to fulfil the need of the farmers for genetic improvement of their animals. In 2013, Magra field unit from RAJUVAS, Bikaner was shifted to ARC, CSWRI, Bikaner with the additional responsibility to monitor scientific improvement in adopted flocks in field conditions. In year 2015-16, Farm unit of Magra sheep at ARC, Bikaner was merged in Magra field unit of NWPSI for better coordination in farm and field conditions. Magra breed is being improved for carpet wool production through selection. The rams were selected on the basis of selection index incorporating six month body weight and 1st six monthly greasy fleece yield. The salient findings are:

Farm Unit : There was significant improvement in all growth traits when compared with the performance at inception of the project. The body weight at six months improved by 27.09% (from 19.45 kg to 24.72 kg) over the period. There was an improvement in average daily gain at all stages. The pre weaning ADG ranged between 128.16 and 156.22 g. The post weaning gain improved from 71.25 to 80.94 g and from 26.17 to 43.18 g during 3-6 M and 6-12 M, respectively. The adult annual GFY ranged between 1713 and 2022 g during different periods. The adult annual GFY was improved by 18% in comparison to initiation of the project. Due to improvement in the body weights and proper management of flock the survivability of animals improved a lot over the years. In general, the overall survivability was >97% which is very much desirable for better remuneration to the farmers. The improvement in tupping and lambing rates were recorded over the years. The tupping was improved from 77.1% in 1999-2000 to 97.21% in 2018-19. The lambing percentage was also improved over the years (from 65.8% to 100.0% in 2019-20). Individuals predicted breeding values were calculated for body weight at six months and first six-monthly greasy fleece yields. The genetic trends were positive for the traits under selection. The genetic gain for six-month body weight per year and per generation was 82.6 and 191.7 g, respectively. However, the genetic gain for first six monthly GFY per year and per generation was 1.86 and 3.68 g, respectively. The superior breeding rams produced in the project were supplied to the State Animal Husbandry Departments /Govt. Agency/ Farmers/ NGO/Developmental agency for the genetic improvement of the animals in the farmer's flock. About 1500 superior breeding rams/ram lambs were supplied to the Govt. Agency/Farmers/NGO/ Developmental agency since inception of project.

Performance of Magra sheep

Trait		Average
Body weight (kg)	Birth	3.00
	3 month	16.00
	6 month	24.00
	9 month	28.00
	12 month	31.00
Reproduction (%)	Tupping	>97.00
	Lambing	90-95
	Twinning	3.50
Wool	First 6 monthly GFY (g)	950
	Second 6 monthly GFY (g)	1050
	Annual GFY (kg)	2- 2.2
	Fibre diameter (µ)	32.00
	Staple length (cm)	5-6
	Medullation (%)	35-40
	Annual survivability (%)	98.00

Field unit : Magra field unit was shifted from RAJUVAS, Bikaner to CSWRI, Bikaner in 2013. At present, the project is running at three centres namely Kotda, Goleri and Darbari to bring improvement in farmers flock. A total of 64 sheep breeders are registered under Magra field unit and covered >4200 breedable ewes. Every year superior breeding

rams are being produced and sold/distributed to government agency/farmers/adopted farmers and rams are being used by the farmers for the genetic improvement of their animals. There is improvement in the body weight and greasy fleece yield of the animals in the field by using the superior breeding rams. The overall least square means for birth, 3, 6 and 12 month weight in all the centers were 2.71, 15.46, 21.93 and 28.42kg, respectively. Sex, year and center significantly affected all the growth traits. An improvement was also recorded in each flock by comparing the progeny born from CSWRI rams vs Field rams. In every year the body weight at all stages is 8-10% higher in progenies of CSWRI rams. The overall 6-monthly adult GFY and first clip GFY in field condition over the period was 625.82 and 640.14g, respectively. There was significant effect of villages, year of production and shearing season on wool production traits. The wool production was higher in progenies received from CSWRI supplied rams when compared with progenies of field rams. About 400 rams were distributed to the adopted sheep farmers to bring not only genetic improvement in field flock but also to produce homogeneity in flock appearances. A comprehensive health coverage was provided to sheep flocks through proper deworming, vaccinations and need based treatment which restricted mortality around 7-8%.

Improvement of Chokla sheep

Chokla is an important sheep breed of Rajasthan. The breed is well known for its carpet quality wool production and survivability on scarce feed and fodder resources. Chokla wool is used generally mixed with coarse wool of other breed of Rajasthan to improve the overall quality of wool. Nowadays there is decrease in true to breed Chokla animals in the field which makes obligatory to conserve this breed at institute farm near to its breeding tract for future use. Chokla can be used as improver breed where farmers' preference is to improve the wool quality parameters. The All India coordinated Research project on sheep breeding was initiated in 1971. Since then, Chokla was the one of the native breeds used for cross breeding with exotic animals. From 1991 AICRP on sheep breeding has been converted into Network Project on Sheep Improvement to undertake survey, evaluation and improvement of indigenous sheep breeds.

The body weight at three months improved by 76.39% (from 9.53 kg to 16.81 kg) over the period after start. The body weight at six months improved by 89.31% (from 13.10 kg to 24.80 kg) over the period. The improvement (68.90%) in body weight at 12 month was also recorded as body weight improved from 18.82 kg to 31.79 kg. Growth performance at ARC, Bikaner in 2013-16 is very significantly higher than the performance at Avikanagar setting a new insight in the growth potential of Chokla sheep and possibility of its use as a dual-purpose sheep. Due to improvement in the body weights and proper management of flock the survivability of animals improved a lot over the years. In general, the overall survivability was more than 96%. The tupping percentage was improved from 87.42% in 1992 to 98% in 2019. The lambing percentage was also improved over the years i.e. from 73% to >100 %. In 2013, flock was shifted to ARC, Bikaner comparatively nearer to breeding tract of Chokla animals which resulted in increasing trend in sale of Chokla rams at ARC, Bikaner from 2013 to 2020. In this period a total about 450 rams/ram lambs were distributed among farmers.

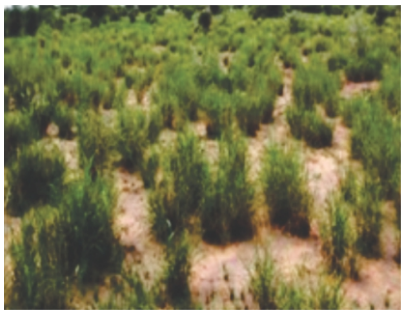
Characterization of Pugal sheep

Pugal is a medium carpet wool producing sheep breed of Rajasthan. The animals of this breed are found in Bikaner district only. Raika, Muslim, Rajput, Jat and Meghwal are the main communities maintaining this breed. Pugal sheep animals are known as "Rataanaa" in the field. The animals of this breed are generally found mixed with Magra, Nali and Jaisalmeri sheep in the flocks and percentage of pure Pugal breed animals in farmers flock ranges from 5-70%. The population of Pugal sheep is declining very fast because of farmers' choice to use Magra breed rams in their flocks reason being Magra breed is superior in wool production and wool quality which fetch more price as compared to Pugal breed. A National Agricultural Technology Project (NATP) entitled "Characterization and Conservation of Pugal Sheep" was initiated at CSWRI, ARC, Bikaner in May, 2000. The major achievements of the project were

identification of Pugal sheep breeding tract, generation of scientific information on managemental practices, breed characters and body measurements, production traits, reproduction traits, wool quality and carcass traits, development of breed descriptors of Pugal sheep and conservation of breed in the form of autosomes.

Feed and fodder evaluation

Sewan (*Lasiurus sindicus*) and Dhaman (*Cenchrus cilliaris*) are the major pasture grasses available during rainy season; Sewan and Dhaman hay contained 5.2 and 5.0% DCP and 41.7 and 50.2% TDN, respectively. On sole feeding both the hays need to be supplemented with protein and energy supplements to support maintenance requirements of sheep. Higher supplementation would be required with *Lasiurus sindicus* compared to *Cenchrus cilliaris* hay. Even with stocking rate of 2.5 animals/ ha under hot arid condition it is desirable to provide rest to the grazing area after two years of continuous grazing else it would deplete vegetation and virtually cause desertification. Ewes could be maintained throughout the year on rangeland pasture of arid zone on sole grazing when not bred. For better lamb production ewes should be supplemented during advance pregnancy and lactation due to increase in nutrient requirements. Plant population and DM availability from pasture improved with advent of monsoon up to October but decreased later and was least during June. CP content also increased up to 9.0% during August and September (during monsoon) due to new sprouts but decreases later on to 4.7% during winter reflecting need to provide concentrate supplement.



Sorghum sudanensis (Sorghum sudan) grass is a multi-cut forage crop which can be advocated in the arid region for summer season. The forage in hay form contains 7.0% DCP and 54.8% TDN and on sole feeding, the hay is adequate to support maintenance during scarcity periods. *Vigina aconitifolia* (Moth) chara - an agro by-product is available after harvest and can be used up to 25% in the diet for pre-weaning growth. Groundnut fodder can be used in the ration up to 70% for post-weaning growth. Supplementation of Cow pea hay should also be accompanied with an energy source for its proper utilization. *Prosopis cineraria* leaves (Khejri) can be incorporated in the dietary of sheep up to 25% for post-weaning growth. *Zizyphus nummularia* (Pala) is found in the habitat of arid region, the leaves can be harvested and fed to sheep up to 60% in the diet for post-weaning growth. Mature *Albizzia lebbeck* (Sirus) pods are potential forest resource with medium protein and energy and could be incorporated up to 40% in concentrate supplements. *Prosopis juliflora* (Vilayati babul) pods could be used in the diet of sheep up to 10%. *Colophospermum mopen* (Mopane), used as wind breaker and soil binder in arid region, green leaves could be fed along with sewan hay for maintenance of body weight during drought periods.

Barley could be replaced by jowar grain as a cheaper energy resource for concentrate supplement in the arid region. Groundnut cake can be replaced by cottonseed cake which is a cheaper protein supplement for use in lamb ration. Guar korma is a cheaper locally available by product of guar gum industry; it can be used as a protein supplement in the ration of adult sheep along with an energy source. Urea: starch ratio of 1.5:13 was found adequate and safe for maintenance of adult sheep, the mixture could be fed as concentrate supplement for maintenance along with low quality roughage, proper mixing of urea should be ensured.

The water requirement for fodder crops of Kharif season viz., Bundel Guar-, Cowpea, Bajra Chari (AVK- 19) and Guar-1 were estimated. Bajra Chari had significantly higher fresh as well as dry weight among all tested fodders while Cowpea had lower dry matter yield. Water productivity of Bajra Chari (1.78kg/m3) was highest followed by Guar -1 (1.07kg/m3), Bundel Guar (1.05kg/m3) and Cowpea (0.99kg/m3). Least virtual water for per unit of meat production was reported with feeding of 2.7kg Bajra Chari dry fodder with 4.0kg Cowpea dry fodder and therefore are more water productive than other fodder crops of Kharif season.

Nutrition and rumen metabolism

The arid plants contain plant secondary metabolites. The concentration of condensed tannins and total phenols in Phog (*Calligonum polygonoides*), Bawali (*Acacia jacqumontii*), Khejri (*Prosopis cineraria*), Beri (*Zizyphus nummularia*) ranged between 4-6% in leaves and 6-23% in twigs. Inclusion of Jal (*Salvodora persica*), and Gundi (*Cardia gharaf*) at 10% in roughage based complete feed, decreased methane production (ml/kg DM) by 28%. A 34% decrease in methane production (ml/kg DDM) was also possible by increasing protein and energy content of roughage based complete feed. At 5% level of inclusion in high roughage diet, saponin rich plant parts - Lucerne (*Medicago sativa*) roots, Reetha (*Sapindus rarak*) pulp and Shikakai (*Acacia concina*) pods decreased rumen protozoa by 45-75%. The herbal mixture developed in our laboratory at 1.0% level in complete feed decreased protozoa count by 19%.

Principal component present in Ajowin (*Trachyspermum ammi*), Dill (*Anethum sowa*), Cumin (*Cuminum cyminum*) and Fennel (*Foeniculum vulgare*) were thymol (72.28%), 2-cyclohexen-1-one 2-methyl-5-(1-methylethenyl)-(CAS) 2-methyl-5-isopropenyl-2-cyclohexenone (56.03%), Cumaldehyde / cuminal (39.15%) and P-Allylanisole (63.44%), respectively. The methane production (ml/g DOM) decreased with increasing levels of Cumin, Fennel, Ajowin and Dill, but at 10% inclusion levels rumen fermentation characters improved. Garlic (*Allium sativum*) powder inclusion at 3% level in complete feed increased digestibility of dry matter (DM) by 7.5%, crude protein (CP) by 11% and ligno-cellulose (ADF) by 28%, as a result sheep gained 17% higher body weight. There was 14.6% improvement in daily gain of Marwari kids by inclusion of Bhringraj (*Eclipta alba*) in complete feed.

Complete feed for Sheep : Multi-nutrient feed block have been developed for sheep by incorporating concentrate and roughage in ratio of 70:30. Local area specific roughage and concentrate ingredients like Guar/Groundnut/Sewan straws/ Khejri leave and Khejri pod, maize, barley, Guar/Mung churi, wheat bran, guar dust along with salt and mineral mixture in molasses/jiggery (2:1) were used. Feed conversion efficiency was 3.10 with dry matter consumption of 357g/h/d. Cost of feeding per day was Rs.5.00 /sheep and average weight gain of growing lambs was 132g/d.

Multi nutrient mixture : Grazing alone could hardly produce satisfactory growth in lambs. Supplementary feeding is needed for better growth and remuneration of farmers. Multi nutrient mixture was prepared by use of molasses 45.4, wheat bran37.5, Urea 1, guar churi 6, salt 5, vitamins and mineral mixture 5% to provide nutrients which are not available to lambs by grazing. The formulation was cost effective and feeding of 200g to weaner lambs over grazing resulted 15-20% more gain in body weights than traditional feeding. Cost of feeding per lambs was Rs. 3.35/d/sheep. Feeding of 200g multi nutrient mixture consisted 4.5% urea and 19.6% CP in addition to grazing resulted significantly higher gain in body weight compare to pellet fed group. The cost of feed per kg additional weight gain was lower in MNM fed group. During lean period of December to May, 90 days feeding of 150 g MNM to 156 lambs of 3 months of age, resulted 50 % higher body weight (4.67 vs 2.45kg) than control group at village level. While in months of July to November, similar feeding of 150g MNM, resulted in 32.50% higher body weight (3.75 vs 2.83kg) compared to lambs on traditional feeding. Pre-partum supplementary feeding of MNM to pregnant ewes 40 days before parturition resulted in significantly higher birth weight (3.2kg) compared to control group. The feeding of 150g MNM in addition to concentrate 200g resulted higher body weights (2.51kg) than feeding of 300 g concentrate only (2.32kg) and control group with no concentrate (1.40kg). On incorporation of DDG (5%, 10% and 15%) in TMR, 15% was found economical and optimum as a replacement of groundnut cake as it reduced feed cost per kg gain up to 37.74%.

Effect of Housing System : Two housing and feeding regimes were evaluated, under closed shed and open shed with 100g herbal supplement and without supplementation in addition to 300g Ground nut straw and 400g of Saras Gold concentrate pellets (20 %CP and 2500Kcal/kg ME) in addition to grazing. Supplementation of herbal pellet to protect the lambs against winter found helpful in maintaining body weight gain. Decrease in body weight was reported due to winter stress in control group. The average body weight gain of herbal supplemented group with shed and open shed was higher (76 and 81g) compared to open shed without herb and ARC fed group (11 and 67g), respectively.

Animal Health

During the last 60 years, protection and promotion of flock health was ensured following research based scientific managemental practices. Initially the mortality at ARC was high (~ 10%) which reduced gradually to 1-2% after applying scientific health technologies, based on a systematic annual health calendar. Initially, mortality among neonates were reported in the range of 15-20%. *E. coli*, Salmonella, Rota virus were identified as a significant cause of mortality among neonatal lambs. The neonatal mortality was reduced to 2-3% through proper management at sector, feeding of colostrum, vaccination of dam, etc. The incidence of different infectious disease such as sheep pox and PPR was reduced by introduction of cell culture attenuated vaccine. Johne's disease was reduced through early identification and isolation of the infected animals. Initially, enterotoxaemia was reported as one of the significant causes of sudden mortality among sheep flock during lush pasture season, which could be controlled following proper vaccination schedule. Blue tongue disease could be controlled after studying detailed epidemiological investigation and vector biology. Since last few years, no outbreak of blue tongue was reported at ARC farm and nearby area in the arid region. Brucellosis has been reported as a significant cause of abortion in small ruminants. For prevention and control of brucellosis, the breedable ewes and rams are screened using RBPT and ELISA. So far, the sheep flock at ARC farm was found to be free from brucellosis.

Animal Physiology and Reproduction

Artificial insemination and enhancement of self-life of semen : Storage life of liquid semen was enhanced at 4ºC, up to 96h using different antioxidants like melatonin, canthaxanthin, ascorbic acid, vitamin E as semen extender additive in Magra ram semen. Conception rate using liquid semen was more than 60%.

Use of herbal extender : Herbal extender was prepared using different concentration of Moringa oleifera and Giloy (*Tinospora cordifolia*) in TRIS based semen extender and obtained encouraging results in enhancing semen storage time period up to 96 h at 4ºC.

Induction of estrus synchronization : Estrus was induced in anestrus Chokla, Magra and Marwari ewes using intravaginal progesterone sponge followed by PMSG on day of sponge withdrawl (12th day) and obtained estrus induction rate of more than 70%. Estrus was also induced in anestrus ewes by physiological intervention using single subcutaneous melatonin hormone @18mg/Sheep with overall more than 85% of estrus induction rate and more than 95% lambing rate.

Grassland and fodder production

The varieties CAZRI-M 305 of *Lasiurus sindicus* and CAZRI-75 of *Cenchrus ciliaris* were found promising and produced higher dry matter yields over other varieties. Half yearly grass cutting schedule was found better than annual cutting schedule. *L. sindicus* produced higher dry matter yield than cenchrus. In case of soil ameliorants combined application of sheep manure and gypsum @ 10t/ha in mine degraded soils was found best followed by sheep manure alone @ 10 t/ha. Sorghum Sudan grass (*Sorghum sudanensis*) and Cow pea (*Vigna unguiculata*) intercropping produced higher and economical green fodder and dry matter yields as compared to sole Sorghum Sudan grass and Cow pea. Application of 40+40 kg N/ha (at sowing + after each cut) recorded greater and economic fodder production than lower levels.

Post emergence application of metsulfuron methyl @0.008 kg/ha effectively controlled the broad leaved weeds in oats (*Avena sativa*) and recorded highest B: C ratio. However, weed free treatment produced maximum fodder yields. Application of 2, 4-D showed phyto-toxic effects in oats crop. Pre-plant incorporation of fluchloralin 0.75 kg/ha effectively controlled the weeds in lucerne (*Medicago sativa*) and recorded maximum B: C ratio. However, maximum green fodder and dry matter yields were provided by weed free treatments. In case of lucerne, chemical weed control in recommended in the conditions of human labour shortage. A pre-emergence application of pendimethalin showed its phyto-toxic effect and badly affected seedlings emergence and growth. Among rejuvenation techniques of old sewan pasture, stubbles burning (light burning) treatment produced maximum dry

matter yields. In case of fertility schedules, 50% each organic and inorganic source of application produced higher dry matter yields than other treatments.

Pelt and wool technology

Technologies were developed to preserve the original characters of a pelt and to produce these with good feel, high lustre, softness, suppleness and strength. A curing method for preserving the freshly slaughtered lamb pelts for a few months without any serious damage was perfected at ARC. An alum-chrome tanning process useful for small scale cottage industry for tanning sheep skins and lamb pelt has been developed. The conventional methods of dyeing the pelts/fur with skin are to dye the fur/pelt and leather separately or both are dyed in same shade. A method has been developed to dye the two parts in two different shades simultaneously by taking advantage of difference in nature of protein of the two.

The alkaline solution (0.1% Na_2CO_3) was found to be most efficient medium for colour extraction as it yielded maximum colouring matter for all materials (Turmeric-rhizomes, Henna-leaves, Jatropha-root, Ratanjot-root, Pomegranate-peels, Babool-bark). Duration of 60 minute was found to be optimum for extraction of colorant from all the materials. Pomegranate peels yielded maximum colouring matter for all mediums and durations (120 minute) which was maximum for alkaline medium (83.37%).

To obtain an even, bright and fast shade from the colour extracts of different vegetable materials on woolen yarn the concentration, duration and temperature of mordanting process were optimized. The optimum quantities of five different mordents viz. Alum (10%), Copper sulphate (5%), Tin chloride (3%), Potassium dichromate (2%) and Hararh (10%) were used for pre-mordanting of woolen yarn dyed with colour extract from Heena leaves, Pomegranate peels, Turmeric rhizomes, Babool bark and Jaropha roots, respectively. The light fastness test of dyed samples revealed that mordanting prior to dyeing improved the fastness to light the obtained fastness to light is fairly good to good (3, 3-4 and 4) on scale of 1-8. The results of washing fastness test were observed very good fastness to wash (grade 4) for both mordanted and un-mordanted yarn samples on scale of 1-5. Thus the fastness standards prescribed for woolen carpet yarn can be easily attained by these natural dyes in addition to protection of environment and pollution control. The results of quality attributes of wool vis a vis visual grades indicate that visual grading of wool samples was very close to the quality appraisal of attributes; this could be used as a tool for grading of wool in the industry. Prolonged storage causes deterioration/ loss in fibre strength which results in higher weight loss.

Transfer of Technology

The extension programme is going on in adopted villages under Network Project on Magra field and Mera Gaon Mera Gourav programme. The technologies developed at institute are being demonstrated to the farmers in about 10-12 villages and the farmers of the different villages are being trained for adopting scientific sheep rearing practices. The transfer of health technologies was applied among the field flocks. Prophylactic programme like vaccination against Sheep pox, enterotoxaemia and PPR were applied and suitable anthelmintics were used periodically. Application of health technology and awareness in the field brought down the mortality in sheep flocks from 10-15% during early phases to 5%.

So far more than 40 M.V.Sc. and Ph.D. students of RAJUVAS completed their research work in field of Animal Genetics & Breeding, Animal Nutrition, Animal Reproduction and Animal Health under the guidance of scientists of ARC Bikaner. Every year 5-6 on Campus/off campus trainings of 2-7 days were conducted at ARC Bikaner under Network Project, ATMA, Watershed, SCSP and TSP. The farmers were acquainted with the latest technologies developed in the field of Sheep husbandry to improve the body weight and wool yield in farmers' flock. Number of superior breeding rams were distributed to the farmers to bring genetic improvement in their flock. The linkages were developed with many government departments and NGO viz. BAIF, Barmer, ATMA, RSETI, Bikaner, Water Shed Department, Parmarth Seva Sansthan Udaipur, KVK Badgaon, Udaipur, Seva Sansthan Udaipur and Jharole, RAJUVAS, Bikaner and SKRAU, Bikaner.

North Temperate Regional Station, Garsa

The North Temperate Regional Station of Central Sheep and Wool Research Institute at Garsa, Kullu valley of Himachal Pradesh was started in 1963 with the mutual collaboration of Ministry of Food and Agriculture, Government of India and erstwhile Punjab Government (subsequently Himachal Pradesh) as a sheep breeding farm. The main objective of the station was to evolve a fine wool sheep producing 2.5 kg greasy fleece per annum with an adult body weight of 30 kg by crossing local Gaddi ewes with exotic Rambouillet / Soviet Merino rams and to carry out research on different aspects of fodder productions, farming system and to study health problems of sheep in temperate Himalayan region. Later on, the station was transferred to the Indian Council of Agricultural Research (ICAR) and functioned as the Regional Station of Central Sheep and Wool Research Institute (CSWRI) for North Temperate Region of the country. In April 1976, this station was upgraded as a full-fledged division and renamed as Division of Fur Animal Breeding. During 1978, studies were extended to rabbit breeding for wool and meat purpose. This station is located at global position of latitude 31.58°N and longitude as 77.20°E with average annual rainfall of about 840mm. In Himalayan Kullu valley it is connected by Delhi-Manali highway (NH-21) lying 14 Km from Bhuntar on Bhuntar-Garsa road. This station has a typical temperate climate with maximum temperature between 30-34°C to lowest temperature in winter going down to -2 to 4°C with occasional snow fall. The farm area comprises of a flat irrigated valley land of 29 hectares and 861 acres of steep hill grazing land on lease from Government of Himachal Pradesh that provide natural grazing to sheep. This station is located at 1400-2100 meters above mean sea level on the right bank of Garsa stream from Bhosa area ridge to Hurla bridge ridge.

The pioneer research and development started at NTRS, Garsa with the import of Russian Angora from erstwhile USSR in the year 1979. Subsequently, this station introduced locally purchased German Angora in 1986 and then in 1992. Later on, a fresh lot of improved German Angora was imported during the year 1997 at this station. At the same time, four breeds of broiler rabbit viz. Soviet Chinchilla, Grey Giant, White Giant and New Zealand White were introduced in 1979 at Garsa and later Black Brown was obtained by crossing Soviet Chinchilla and Grey Giant. The initial attempts were made through breeding of imported Angora on scientific principles, popularized them among the farmers and finally transferred the derived technology to the farmers of hill region in the country. At present the station is having superior germplasm of German Angora, British Angora and Russian Angora for research, development and propagation in the region. The selection criteria in Angora rabbit are wool yield at 2nd and 3rd clip and litter size at weaning, while in broiler rabbit the body weight at 12 weeks and litter size at weaning.

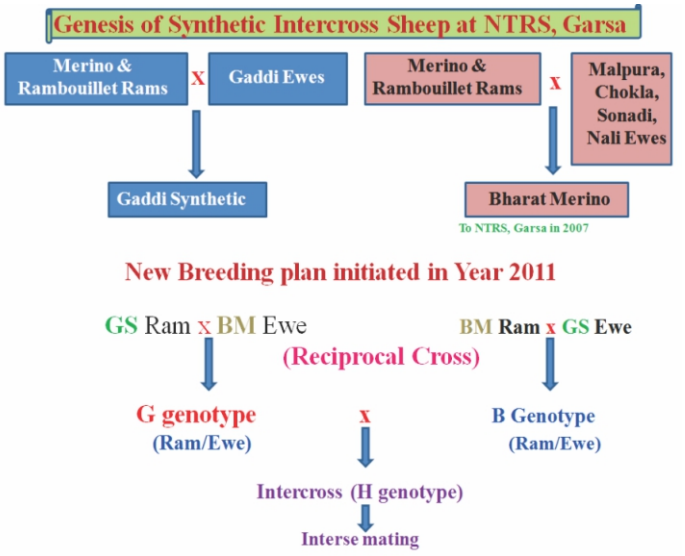
To achieve the targets of sheep improvement programme, the local Gaddi ewes were crossed with Rambouillet and Soviet Merino rams. In this attempt several grades of crosses were produced and evaluated. The 50 and 75% crossbreds produced 26.0 and 40.8% higher wool yield than the indigenous Gaddi sheep, respectively. The improvement in adult body weight was 23.2 and 47.7% respectively. The wool quality improved to fine apparel type in the crossbreds from the carpet quality wool of Gaddi. The 75% exotic inheritance was designated as Gaddi Synthetic strain. Gaddi synthetic strain was further improved by selective breeding, multiplied and propagated among the farmers for improving the wool quality of native sheep. Subsequently, Bharat Merino (BM) developed at CSWRI was also introduced at NTRS Garsa during year 2002 to test its performance under temperate conditions. The selection criteria include body weight and wool production at six months of age and along with reproductive performance. In addition, efforts were also made to improve pastures.

Angora/broiler rabbit

Basic and applied research in all disciplines relating to Angora /broiler rabbit production was carried out. Genetic stabilization of wool and meat breeds of rabbits was made. The housing system with locally available material for better management of rabbits/broilers under field conditions was developed. Locally available feeds, fodders, top

feed and agro by-products for wool/meat production in the rabbits were evaluated. Epidemiological for rabbit/broiler diseases was studied and disease data base was developed to reduce morbidity and mortality in rabbits. Fibre and pelt technology was developed, updated and standardized. Training on rabbit and sheep farming to the farmers was imparted and superior germplasm was supplied to the farmers. Utilization and processing of wool and rabbit fur for garment preparation and development was standardized. The age of weaning with the aim to achieve the maximum body weight at 84 days of age was standardised. The eco-friendly technology for processing of rabbit pelt/fur/skin for value added garment preparation was developed.

Through scientific interventions along with selection and breeding plans, a German Angora strain with adaptability to the Indian cold conditions has been developed. It has a potential to produce 850-950g of wool per annum and average litter size of 6 kits per kindling. Attempts have been made to decrease the age at first mating and to improve the prolificacy of Angora rabbits through nutritional, hormonal and therapeutic interventions. Effect of level of protein contents in concentrate diet of adult and young rabbits on growth, wool yield, wool quality and digestibility was evaluated and found that 14% CP in adults and 16.1% CP in young weaners/growing rabbits gave best results. Influence of different seasonal fodders such as kudzuvine, oat, biul leaves, tall fescue, rye grass white clover, mulberry leaves, robinia leaves, willow forage, kachnar and hay from locally available grasses and also the feeding of different levels of concentrates on Angora rabbit wool production were evaluated. Research results suggested that Soviet Chinchilla (SC), Grey Giant (GG), White Giant (WG) and New Zealand White (NW) are adaptable to Himalayan conditions. By adopting scientific procedure, strains of broiler rabbits were improved which can produce 5-6 kits per quarter beyond six months of age and attain 1.8kg weight at 84days of age. Weaning at 28days of age gives better pre- and post-weaning performance in Soviet chinchilla. Concentrate feeding of kits from 21days of age increased pre and post weaning broiler traits. Pre-weaning kit mortality is affected by litter size at birth, season of birth and mothering ability of females. Mothering ability was found to be highest in Soviet Chinchilla among all broiler breeds. Weight at slaughter had a highly significant phenotypic correlation with carcass weight, pelt weight and dressing percentage. Influence of season, parity, age and weight of doe on reproductive efficiency of rabbits was evaluated and concluded that all these factors affect the same. The spring season appeared to be most favourable season for efficient reproduction in rabbits. Technology for fur processing and its utilization was developed for making valuable garments such as caps, bags, muffler, cushions, gloves and jackets. Eco-friendly technology involving chemical treatment of rabbit skin through various steps such as soaking, scouring, pickling, tanning, tallowing and dyeing was developed to prepare value added garments, which are in much demand at tourist places of temperate region. Complete package of practices of rabbit and broiler feeding were developed by incorporating different local available feed and fodder sources including non-conventional and agro-industrial by-products to make rabbit feeding economical with feed conversion ratio between 3 and 4. With objective of economizing the ration for rabbits several proteins, mineral, additives and roughages were tried and their effect on growth and wool production were evaluated.



Sheep

Fine wool Gaddi Synthetic sheep to produce greasy fleece yield of 2.0 kg with a fibre diameter around 20µ, medullation less than 5% and staple length of 6cm in annual clip was developed. The performance (growth, reproduction and production) of Bharat Merino sheep under temperate conditions was evaluated. Body weights and fine wool production was improved through selection and inter-se breeding of Gaddi Synthetic and Bharat Merino sheep. The growth, reproduction and production performance under migration to highland alpine pasture was recorded and compared with non-migratory flocks. Bharat Merino strain was introduced at the NTRS, Garsa and growth, reproduction and production performance was assessed and improved in the temperate region by adopting scientific measures. Gaddi Synthetic strain developed at the station was further improved and popularized and propagated among farmers for improving the wool quality of native sheep. Gaddi Synthetic, Bharat Merino and their inter-crosses were developed through scientific selection and inter-se breeding which have the capabilities to produce 1.0kg of fine wool (around 20µ diameter) and 28kg of body weight at 6 months of age. Two cross-bred strains viz Gaddi synthetic and Bharat Merino with 75% exotic inheritance was maintained separately at NTRS, Garsa before 2009. Gaddi synthetic (GS) was developed by crossing pure Gaddi ewes with rams of exotic breeds (Merion x Rambouillet) at NTRS Garsa and stabilized 75% exotic blood inheritance. Bharat Merino (BM) was evolved at Avikanagar through crossing Rambouillet and Russian Merino (rams) with Malpura Chokla, Nali and Sonadi ewes with stabilization of 75% exotic blood for fine wool production. As per the revised breeding policy in 2008-09, GS and BM were reciprocally crossed with the aim to mix both synthetic sheep. The BM ewes are mated with GS rams and vice versa to developed B and G genotypes. Both the genotypes are then crossed with each other to developed H genotypes. The H genotypes are stabilized by inter-se mating in next generation.

The performance of inter-cross synthetic sheep at NTRS, Garsa are as below :

	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
Body weight (kg)										
Birth	3.55 ±0.05	3.48 ±0.05	3.41 ±0.04	3.62 ±0.12	3.40 ±0.06	3.40 ±0.04	3.64 ±0.04	3.69 ±0.04	3.88 ±0.04	3.68 ±0.05
3 month	15.85 ±0.23	17.34 ±0.22	18.40 ±0.23	10.87 ±0.29	14.00 ±0.26	14.71 ±0.19	15.13 ±0.22	16.57 ±0.24	15.68 ±0.22	15.30 ±0.17
6 month	23.31 ±0.57	26.23 ±0.40	22.17 ±0.35	18.43 ±0.19	19.02 ±0.32	19.36 ±0.31	18.10 ±0.29	21.75 ±0.39	22.49 ±0.34	22.39 ±0.26
9 month	-	-	29.01 ±0.49	20.78 ±0.16	22.05 ±0.42	24.33 ±0.34	21.95 ±0.37	25.19 ±0.45	25.39 ±0.40	24.97 ±0.31
12 month	29.51 ±0.45	27.81 ±0.39	33.54 ±0.57	22.06 ±0.20	26.11 ±0.55	27.52 ±0.51	24.79 ±0.45	27.32 ±0.54	27.87 ±0.41	26.79 ±0.41
Reproduction										
Tupping (%)	93.37	96.64	99.14	73.07	80.45	91.14	92.50	98.80	96.26	95.48
Lambing (%)	89.27	90.48	92.59	79.60	75.71	79.43	81.30	81.55	87.22	90.00
Wool										
6M GFY (kg)	0.92 ±0.03	1.14 ±0.02	1.06 ±0.02	0.81 ±0.03	0.84 ±0.02	0.79 ±0.02	0.63 ±0.03	0.83 ±0.01	0.99 ±0.03	1.00 ±0.02
Annual GFY (kg)	1.71 ±0.03	1.85 ±0.07	1.96 ±0.03	1.95 ±0.02	1.80 ±0.04	2.09 ±0.04	2.37 ±0.05	1.48 ±0.03	1.36 ±0.02	1.15 ±0.03
Staple length (cm)	3.92 ±0.05	3.58 ±0.02	3.53 ±0.02	3.53 ±0.06	3.20 ±0.04	3.35 ±0.04	3.48 ±0.05	3.89 ±0.06	4.12 ±0.03	3.79 ±0.05
Fibre diameter (µ)	19.90 ±0.12	19.68 ±0.04	19.81 ±0.15	19.61 ±0.16	19.36 ±0.18	19.78 ±0.17	19.02 ±0.12	19.77 ±0.14	20.45 ±0.21	19.60 ±0.15
Medulation (%)	0.59	0.38	0.73	0.54	0.60	0.43	0.70	0.68	0.66	0.60
Distribution (No.)										
Male	36	33	74	55	53	50	46	64	48	68
Female	13	48	58	61	35	59	49	49	23	36

The superior germplasm developed is one of the best available in the north temperate region with a higher fine wool production potential. This germplasm is being used regularly by the farmers to upgrade or improve their existing sheep flocks with an aim to increase the wool production. The “Kullu shawl” based on sheep fine wool as major component had already been awarded “Geographical Indication” tag for its uniqueness and designing and has a huge National and International potential. The major and famous handloom Industry of Kullu Valley is earning several hundred crores of revenue from the sale / export of the shawls and other woollen garments prepared with sheep fine wool. This germplasm will be evolved for economical and sustainable sheep farming for fine wool production in sub-temperate climatic conditions of India.

Research over the years revealed that autumn is the best tupping season and spring is the best lambing season for sheep reproduction in the temperate region, which brings best results in terms of growth and production of newborns and adults. Study on sheep migration to highland alpine pasture during summer was conducted where growth and production performance of young ones and adults were found to be highly appreciable with least cost input as compare to non-migratory flock. In addition, migratory routes were defined and acclimatization at lower hills before high altitude migration resulted in better performance without any health problem. In sheep, creep ration containing 11.2% CP were found to be optimum for economic raising of lambs during pre-weaning stage. Provision of ad libitum concentrate and forage during 3-6 months of age under intensive rearing programme resulted in appreciable growth performance as compared to lambs reared under routine semi-intensive system.

Disease data base regarding sheep and rabbit disease was developed and to reduce the mortality and morbidity, appropriate therapeutic measures were adopted under temperate conditions. However, in migratory flock some problem due to natural calamities like untimely snow, heavy rains, hailstorms, etc. could lead to mortality. Contagious ovine digital dermatitis in inter-cross sheep was also reported. Hair ball in Angora rabbit was a major problem under poor management conditions. The problem of hair ball gets accentuated in absence of proper fibrous diet or fodders. Diseases of respiratory system and alimentary system are predominantly observed clinically in rabbits. Death in rabbits is mainly due to pneumonia, rhinitis along with pulmonary abscesses, enteritis, hepatitis, etc. Aflatoxicosis outbreaks are not uncommon in rabbits and could results in heavy mortality. Enterotoxaemia in rabbits with explosive deaths could occur with feed or diets containing high concentration of soluble carbohydrate or molasses. Kits born during spring season had better survivability.

Southern Regional Research Centre, Mannavanur

Southern Regional Research Centre (SRRC) is one of the regional stations of ICAR-Central Sheep and Wool Research Institute, Avikanagar, located at Mannavanur (35 kms away from Kodaikanal town, Tamil Nadu) in the Poombaarai-Berijam-Kodaikanal circuitous route. It was established on 16.11.1965 in the total area of 1346.88 acres, where in revenue land and forest land covered 545.38 acres and 801.50 acres, respectively. SRRC is located at the height of 2030 meters above the mean sea level and its coordinates are 10°-11° N latitude & 77°-78°E longitude. On an average, the level of rainfall is 1055 mm per annum. From April to June, the mean monthly ambient temperature is 25°C. The range of maximum and minimum temperature is 26°C to 30°C and -3°C to 5°C, respectively. Relative humidity ranges between 15 and 90%. The predominant monocotyledon grass species in the farm are Kikuyu (*Pennisetum clandestinum*) and spear grass (*Heteropogan contortus*). Setaria (*Setaria splandida*), Irrithrina, Desmodium, *Phalaris tuberose,* cocks toot (*Dactalis glomarata*), Congosignal, *Lolium perene,* white clover, *Eschemum indicum*, Paragrass, Themada (*Themada tripogan*), love grass (*Eragrostis currula*), Napier (Pusa and Coimbatore varieties) are the minor grass species. Apart from this, Wattle and Eucalyptus trees are also grown in the farm. About 400 acres of revenue land was withdrawn by Government of Tamil Nadu and 801.5 acres of forest land was handed over to the forest department of State Government during the year 1997. Since then, the centre is functioning in the remaining 145.38 acres of revenue land.

Development of pasture: During the year 1966, improved varieties of legumes and cereal grasses such as Cocks foot, Festuca, *Phlaris tubrosa*, Love grass, Red clover, Kikuyu, White clover, Lolium, Crimson clover, Rye grass and Pusa giant napier, ideal for the local climatic conditions, were cultivated. Further, steps were taken to afford good drainage system by means of reclamation of the marsh land between the hill slopes.

Performance of newly introduced forages to Kodai hills (1973-1975): Under Indo-Swiss project, seeds, saplings and runners of various grasses and legumes were obtained from Mattupatty, Kerala and cultivated in small plots under rainfed conditions. The complete details of the same and their performances under sub-temperate climate of Mannavanur are furnished below:

Forages	Performance
Pongola grass	A runner, attained good growth, leafy but frost affected
Paspalum dilatatum	Leafy growth, leaves are broad, frost resistant, remains green in winter
Guinea grass	Grass is coarse, frost affected
Stylosanthesis gracilis	Growth is stunted
Setaria species	Broad leafy growth, soft and tender, long stem bearing lot of seeds, frost resistant
Desmodium silver leaf	Good kharif legume with profuse leafs, spreads well in native pasture, well relished by sheep, but heavily susceptible to frost
Dolichos axillaries	Good legume with profuse broad and tender leaves, but susceptible to frost

Development of livestock farming system: During the period 1979-85, a study on comparative performance of small ruminants under free range grazing without any supplementary feeding revealed that there was two- and three-fold increase in strength among sheep and goat, respectively with little change in the growth of lambs and kids at different age groups.

Performance of Romney Marsh and South Down sheep: In 1966, from NTRS, Garsa, both South Down (2 rams and 9 ewes) and Romney Marsh (5 rams with 10 ewes) sheep were transferred to SRRC, Mannavanur for the purpose of analysing their performance in the Southern sub-temperate climate of Kodai hills. South Down sheep was able to produce three lambs only during the period between 1966 and 1973. On the other hand, two lambs only were obtained from Romney Marsh sheep during 1966 to 1971.

Cross breeding of Coimbatore sheep with Corriedale: In order to develop a dual-purpose sheep breed by cross breeding programme, a total number of 136 Corriedale were imported from Australia. In addition, 100 Coimbatore sheep were purchased from the local market in the year 1967. It was observed that at all stages, body weight of crossbreds was higher when compared to native Coimbatore sheep, gaining of maximum body weight at 5/8th crosses in feedlot trial, higher greasy fleece yield in crossbreds than in natives, higher mortality in crossbreds having >50% of exotic inheritance, castration in native Coimbatore lambs increased gain in body weights, 42.0 dressing percentage both in Coimbatore and half-breds. In Coimbatore, half-breds and 3/4th crosses, bone:meat ratio was 1:2.6, 1:3.3, 1:4.0, respectively.

Cross breeding Nilgiri and Coimbatore ewes with Corriedale and Merino rams: For the sub-temperate climatic conditions of Kodaikanal, a project was undertaken to evolve a dual purpose fine wool sheep breed through cross breeding programme involving Coimbatore and Nilgiri ewes with Corriedale and Merino rams in the year 1977. Better growth was observed in Merino x (Corriedale x Coimbatore F-1) as compared to Corriedale x Nilgiri, Merino x Coimbatore, Nilgiri and Merino x Nilgiri. As far as, the GFY among crosses, it was highest in Merino x (Corriedale x Coimbatore F-1), followed by Merino x Coimbatore, Corriedale x Nilgiri and Merino x Nilgiri.

Performance of Karakul rams: The performance of the said breed was poor and negligible in the sub-temperate climate.

Cross breeding of Coimbatore (C) ewes with Rambouillet (R) rams: Experimental trials conducted over a period of 3years (1984-86) revealed that in Coimbatore ewes during autumn season, the tupping on the basis of ewes available was 78.31 to 90.54% with lambing between 84.32 to 85.04%, whereas during spring season, the tupping was 86.57% with lambing of 86.21%. During the autumn season, the tupping was 53.57% in R x C crosses. Further, in R x C crosses, the average birth weight was 2.53kg (7.66% higher than in Coimbatore sheep); the average weights at 6 and 9 month of age were 15.12 and 20.04kg, respectively with 18.5 and 29.37% higher than Coimbatore sheep; average annual GFY - 1.126kg (118.6% higher than Coimbatore sheep). The clean fleece yield in Coimbatore sheep was higher (75.8%) as compared to that of cross breeds (58.85%). Staple length in Coimbatore sheep and cross breeds was 5.22 and 4.92cm, respectively. Survivability in Coimbatore sheep was 89.92, 97.41, 94.49 and 93.98% between 0-3, 3-6, 6-12 and adults, respectively, whereas in crossbreeds in order was 93.63, 98.2, 95.28 and 100%, respectively.

Performance of Avivastra sheep: In order to study GFY under the Southern sub-temperate climate of Kodai hills, Avivastra sheep were shifted from CSWRI, Avikanagar to SRRC, Mannavanur in the year 1991. On 6 monthly shearing, it was found that the average GFY varied from 1.32 (female) to 1.85 kg (male) with staple length of 5.54 to 6.29 cm, fibre diameter of 21.58 to 23.23 µ and medullation of 4.63-11.24% in female and 8.0-12.0% in male. On the other hand, on annual shearing, average GFY varied from 1.78 (female) to 3.0 kg (male) with staple length of 8.61 to 11.03 cm, fibre diameter of 19.63 to 22.40 µ and medullation of 2.36-7.15% in female and 0.0-8.0% in male.

Performance of Bharat Merino (BM) sheep: To studying adaptability and obtaining annual shearing of wool with longer staple length, Bharat Merino sheep were transferred from semi-arid climate of Avikanagar to sub-temperate climate of Mannavanur in August 1987. Observations over the years from 1987 to 1992 indicated that BM sheep exhibited good performance in the southern sub-temperate climate of Kodai hills. The annual GFY, fibre diameter, staple length and medullation were 2.8 kg, 20.24 µ, 9.4cm and 1%, respectively. The average weights at birth, weaning, 6 and 12 months were 4.26, 20.11, 25.36 and 34.46kg, respectively. The average annual lambing was 88.26%. Age at first lambing was 657 days and lambing interval was 358 days. The survivability among lambs, weaners (3-6 month), hoggets (6-12 month), rams and ewes were 99.03, 99.15, 99.47 99.23 and 98.56%, respectively. Some of the rams were weighing around 83.0kg at the age of 2.5 year.

Over the period from 1992-97, the least-square means of body weights at birth, weaning, 6 and 12 months was 3.87, 17.67, 23.07 and 32.00kg, respectively. The year and season had significant influence on birth weight of the lambs. The weight of lambs born in autumn was higher when compared to that of lambs born in spring. Compared to twinning (3.37kg), the body weight of lambs born as singles was higher (4.37kg). The highest body weight at birth was observed in lambs born to ewes belonging to fourth parity. The regression on ewe weight was highly significant. It was found that for every kg increase in the ewe weight at lambing, both the birth weight and 6 months body weight of lambs had been increased by 46 and 205g, respectively. The least square means of first annual GFY was 2.304kg. The least square means of staple length and fibre diameter were 8.59 cm and 19.19μ, respectively. After a decade of selection and multiplication, BM sheep was able to produce 3.0kg of fine wool per annum with average staple length of 8.0cm, fibre diameter 19.0μ and modulation of less than 1.0%. It was concluded that if the environmental conditions are favourable for this animal and genetic potential could be exploited to its maximum. During the period from 2017 to 2020, growth performance and GFY of BM sheep were maintained with better survivability and reproduction performance. In the year 2020-21, the overall body weights of BM sheep at birth, 3, 6 and 12 months were 3.94, 20.14, 27.06 and 35.16kg. The survivability during 0-3, 3-6, 6-12 months and adults was 100, 98.03, 100 and 99.48% respectively. The annual tupping was 97.65% with an average weight of 38.84kg at mating. The lambing on ewes tupped basis was 93.60% with an average weight of 42.13kg at lambing. The average GFY was 0.91 and 0.81kg in male and female hogget. Average fiber diameter, medullation and staple length was 19.19μ, 0.20% and 4.57cm.

The emphasis on multiplication of BM sheep according to the grazing land availability and their supply to the progressive farmers of southern states was actively given during the period from 1997-98 to 2009-10. During this period, the average weights at birth, 3, 6 and 12 months of age were 3.81, 18.22, 25.16 and 34.99 kg, respectively. The overall average annual tupping was 88.56%. The average lambing on ewe bred and available basis was 82.25 and 73.01%, respectively. The annual survivability at 0-3, 3-6, 6-12 months, adult and overall was 92.63, 97.89, 99.16, 97.36 and 96.62%, respectively. The adult annual GFY in male and female was 3.65 and 2.15kg, respectively. During this period, a total of 1577 BM elite germplasm were distributed to 110 farmers.

Genetic trend for growth and wool performance in a closed flock of Bharat Merino Sheep at SRRC (Data on 1652 BM progenies of 144 sires, 2000 to 2014) exhibited that least square means were 3.28, 19.08, 25.00 and 2.13kg for BWT, 3WT, 6WT and GFY, respectively. Genetic trends were positive and highly significant for BWT, while the values for 3WT, 6WT and GFY though positive but non-significant. The estimates of genetic trends in BWT, 3WT, 6WT and GFY were 5g, 0.8g, 7g and 0.3g/year gain and the fit of the regression shows 55, 22, 42 and 12% coefficient of determination with the regressed value, respectively. The estimated mean predicted breeding value (kg) in BWT and 3WT, 6WT and GFY were 0.067, 0.008, 0.036 and -0.003, respectively. Non genetic factors such as year, sex, type of birth and dam's age had significant influence on BWT and 3MWT. Season influenced the BWT while it had no significant effect on 3MWT. Six-month weight was also significantly influenced by all non-genetic factors. Twelve-month weight was significantly affected by year, sex and season. Lambs born single had higher values of BWT and 3MWT than that of the lambs born as twins. The trend of the increase in BWT and 3MWT of the lambs is being observed up to the period when the age of their corresponding dams is 4-5 years. The genetic parameters estimated of 6BWT indicate that it is most suitable for use as selection criterion.

The average genetic gain for BWT, 3WT, 6WT, 12WT and GFY (in kg) were 0.067, 0.008, 0.036, -0.106 and (-0.003) over the year respectively. However, for the year 2013 and 2014 the BWT, 3WT, 6WT were positive and (0.116 and 0.116) kg, (0.014 and 0.013) kg and (0.090 and 0.091) kg, respectively. However, 12WT and GFY for the year

2012 and 2013 were (-0.057 and 0.043) kg and (-0.02 and 0.00) kg respectively. The heritability estimates with standard error of the traits namely BWT, WWT and 6WT were 0.52±0.05, 0.16±0.05 and 0.17±0.06 respectively. The average inbreeding co-efficient with standard error for the truncated pedigree data over the years from 2000 to 2014 is 0.0018±0.015 which is very minimal. The inbreeding did not affect the body weight traits significantly.

The average inbreeding coefficient for whole analyzed pedigree from 1975 to 2015 was 2.36%. Initially (1975 to 1986) average inbreeding coefficient at Avikanagar was 0.85% after that (1987 to 2015) at Mannavanur was 2.49%. The inbreeding coefficient increased with the addition of each generation to the pedigree. Although the levels of inbreeding in the flock were under control, looking in to the closed structure of the flock, accumulation of higher inbreeding in some individuals was inevitable. At SRRC Mannavanur inbreeding level was highly significant for birth weight (4.4%), 3-month weight (4.0%) and 6-month weight (3.5%) while, non-significant for 12-month weight and GFY (2.9%).

The study on the influence of season of birth on productive and reproductive performance of BM female sheep at SRRC (involving 100 female lambs born in different seasons (Mar-Jun, Jul-Oct, Nov-Feb) during 2006-13) exhibited that the overall age at first mating, weight at first mating, age at first lambing, gestation length and weight at first lambing were 596days, 37.59kg, 745.25days, 149.25days and 40.15kg, respectively. The results showed that the season of birth had significant influence on weight at first lambing only. In major lambing season (Jul to Oct), there was 9.28% increase in weight at first lambing as compared to other two season of birth. The effects of season on body weight at birth, 3, 6 and 12 months of age exhibited lambs born during July to October had significantly higher body weight at 3 (20.58kg) and 12 months of age (34.31kg) while season of birth showed non-significant influence on birth weight and 6-month body weight. The average daily gains (ADG) in different age groups were significantly influenced by season of birth. Lambs born during July to October showed higher ADG during 0-3 M (185.97g) and 6-12 M (43.92g) as well as overall ADG (83.46g). On the other hand, lambs born during March to June showed better ADG (83.84g) during 3–6 M. The lambs born during July to October season had 18.23% higher first clean fleece yield (1.88kg) as compared to those born in March to June (1.59kg) and in November to February (1.62kg). It was concluded that growth and reproductive performance of BM sheep born during the month from July-October were exposed to better nutritional and favourable environmental factors at the farm.

Performance of Avikalin sheep: During the year 2003, the carpet wool breed, Avikalin sheep were shifted to SRRC, Mannavanur. During the period from 2003 to 2008, it was observed that the average weights at birth, 3, 6 and 12 months of age were 3.15, 17.03, 25.26 and 38.29kg, respectively. The overall average annual tupping was 73.91%. The average lambing on ewe bred and available basis was 88.24 and 65.22%, respectively. The annual survivability at 0-3, 3-6, 6-12 months, adult and overall was 93.70, 98.48, 100.00, 93.41 and 95.07%, respectively. The adult annual GFY in male and female was 2.88 and 1.86kg, respectively. Further, Avikalin sheep were transferred from ICAR-CSWRI, Avikanagar to SRRC, Mannavanur in August, 2015 and September, 2016. Based on data from 2015-18, the heritability estimates of birth weight due to maternal effect and direct additive effect were 0.367 and 0.445, respectively. Similarly, the heritability estimates of weaning weight due to maternal effect and direct additive effect were 0.554 and 0.000, respectively. In the year 2020-2021, the pooled body weights at birth, 3, 6 and 12 months were 3.41, 17.57, 25.00 and 36.00kg, respectively. The survivability between 0-3 months, 3-6 months, 6-12 months and adults pooled over sexes was 97.9, 97.9, 100 and 99.23% respectively. The annual tupping was 96.51% with an average weight of 33.47kg at mating. The lambing on the basis of ewes tupped was 95.18% with an average weight of 37.70kg at lambing. The average GFY was 0.970 and 0.925kg in male and female hogget, respectively. Average fiber diameter, medullation and staple length was 34.39µ, 51.35% and 6.87cm, respectively.

Epidemiological studies on sheep and rabbit diseases: Upon the investigation on the causes of debility and anaemia in sheep at sub-temperate climatic conditions of Tamil Nadu, it was found that gastrointestinal parasites were identified as the principal causes of anaemia. Further, it was also observed that survival and migration of pre parasitic

stages of nematodes had been highly noticed during rainy and autumn seasons (June-November). During the rainy season, the survivability of infective larva was higher (>11 weeks). *Haemonchus contortus* and *Trichostrongylus colubriformis* were the predominant nematode larvae in the pasture area of sheep. During the rainy and autumn seasons, *H. contortus* was highly active, playing a major role whereas during winter and spring, their availability was very poor. However, *T. colubriformis* larvae were seen throughout the year including winter season. The worm remained in inhibitory stages as early 4th stage larva in winter season contaminated pasture followed by autumn season. The least inhibition was observed in rainy and spring season contaminated pasture. The factor responsible for hypobiosis of *H. contortus* was the exposure of the infective larvae to low temperature. Based on the behaviour of the said nematode larvae in such agroclimatic conditions, it was noticed that not only tactical anthelmintics dosing but also rotational grazing in one form or the other along with strategic drenching schedule could also be the control measures in intensive management of sheep. Sheep flocks were found to be free from brucellosis.

A pilot study involving the combination of rotational and clean grazing along with anthelmintic dosing at strategic points based on etho-biology of the parasites revealed that the clean pasture, provided after winter drenching in January, could be grazed for more than three months. On the other hand, clean pasture provided after rainy season drenching in June showed high pasture contamination in the second month of grazing. Monthly rotation of pasture was practiced as pasture larval burden reached above critical level within a month of grazing. Similar findings were also observed in EPG values and worm counts. This improved grazing management with strategic anthelmintic dosing was proved to be beneficial in controlling ovine parasitic gastroenteritis in south Indian sub-temperate climate. Studies on pasture infectivity index suggested that the conventional 'W' pattern pasture sampling could be convenient and effective measures to monitor pasture larval burden. The index of pasture infectivity can be used as a reliable guide to assess the periods of risk in intensively managed sheep farms provided total worm count and randomly collected pasture samples are analysed.

The Johne's disease (JD) vaccine developed using sheep strain of Mycobacterium avium subsp. paratuberculosis by Vaccine Research Centre-Bacterial Vaccine unit of TANUVAS, Chennai in 2009 was tested among sheep maintained at SRRC and found that good amount of gamma interferon is being maintained till the study period of 4 months as compared to unvaccinated control group. Out of 120 samples from SRRC, only 18 were found positive for JD.

The species of Moniezia infecting sheep at SRRC, Mannavanur was identified as *M. expansa* by using Cox I gene-based PCR and eventual gene sequencing protocols. M. expansa from SRRC, Mannavanur is having 99% identity at nucleotide level with that from sheep of Senegal, 87% with *M. benedeni* from buffalo of China and 84% with *Echinococcus canadensis* from sheep of China.

The cDNA of type I interferon viz., Interferon-ε from the liver of Avishaan sheep was amplified by PCR using published sheep sequences and subsequently cloned for sequence analysis. Sequence analysis revealed that Avishaan sheep shared 100% both at nucleotide and amino acid levels with that of Rambouillet sheep. With other artiodactyls, the range of identity of Avishaan sheep was 85- 99 and 78-98% at nucleotide and amino acid levels, respectively. Perissodactyls shared 84-85% and 77-78% identity at nucleotide and amino acid levels, respectively with that of Avishaan sheep from India. Phylogenetic analysis based on amino acid sequences indicated the close relationship in Interferon-ε gene between sheep and other artiodactyls.

At SRRC, two different kinds of flies caught from the pasture area during April, 2020 were identified as Haematopota nathani (Cleg fly) and Stenopogon ambryon (Robber fly) causing annoyance and painful bite in sheep and graziers. H. nathani is the holotype found in Kodaikanal, Tamil Nadu while, S. ambryon at SRRC is the first report. The snails and slugs specimens from grazing area at SRRC were collected in September 2018 and July 2020 from the pasture area and identified as Mariaella beddomei, Pseudaustenia atra and Ariophanta basileus.

Broiler rabbit production

In order to study the performance of broiler rabbits at Southern sub-temperate climatic conditions, four breeds of rabbits (White Giant (WG), New Zealand White (NZW), Grey Giant (GG) and Soviet Chinchilla (SC)) were introduced to SRRC, Mannavanur in January 1983. Further, Black Brown, Dutch, Grey Giant and New Zealand White were transferred from ICAR-CSWRI, Avikanagar to SRRC, Mannavanur in August 2018. The average body weight varied from 0.570 (WG) to 0.619kg (NZW), from 1.386 (GG) to 1.439Kg (NZW) and from 2.819 (NZW) to 3.207kg (WG) at 6, 12 and 24 weeks of age. The reproductive performance exhibited that average kindling was 73.63, 70.00, 62.79 and 59.61%, average litter size at birth was 7.47, 6.63, 6.51 and 6.63 and litter size at weaning was 6.22, 6.48, 5.83 and 6.05 among WG, GG, NZW and SC, respectively. The survivability ranged from 78.71 (WG) to 88.31% (GG) in kits, from 94.38 (GG) to 98.09% (WG) in weaners, from 92.85 (GG) to 98.55% (SC) in grower and from 78.58 (WG) to 78.95% (SC) in adult.

The heritability (h^2) from full-sib component of variance for body weight at 16, 20 and 24weeks were quite high. As the age advanced, the estimate showed a tendency to decline. The h^2 for body weights at 6, 7, 8, 9, 10, 11 and 12weeks were more than one. The full-sib and dam component contains in addition to additive genetic variance, the variance due to dominance and maternal effects (variants due to common environment). It was possible that during the early stages of weaning the maternal effects were so large and seemed to be very high, thereby making the estimation of additive genetic effects difficult. The h^2 from sire component of variants could not be obtained due to the reason that the sire variances tended to be negative (partly due to few numbers of sires). The litter weight at birth had h^2 of 0.34±0.26. The phenotypic correlations between body weights at different ages were positive and high. The estimates tended to decrease in value as the differences between the two ages increased. The estimates of genetic correlation from dam component among body weights were positive, high and significant. The genetic correlations from full-sib component were also positive, moderate to large and significant. It could be inferred from the values of genetic correlations that rabbit body weights at earlier ages would be used for selection and improvement of body weight at later ages. As far as the body weight was concerned, the individual's own performance could be taken as the criterion for selection. Selection studies in White Giant rabbits with the aim to evolve a broiler rabbit which could attain 2.0 kg body weight at 12 weeks of age with a litter size of at least 5.0 at weaning exhibited that 12-week body weight is a function of litter size at weaning. Since, it is now clear that kits belonging to smaller litter sizes would achieve higher 12-week body weight, selection for body weight alone may not result in increased body weights. The litter size at weaning of about 5.0 would be appropriate for attaining heavier body weights at 12 weeks of age.

Based on data from 1992 to 1995 in SC, it was found that the average litter size at birth was 7.12 with litter weight of 401g. The litter size at weaning was 5.85. The body weights at 4 and 12week of age were 383.0g and 1.53kg, respectively. The number of kindling/doe/ year was 4.11 (28.07kits born /doe). Number of kits weaned /doe/year was 17.62 and kg weaned was 2.29. The kit mortality was 46.2%. The per cent survivability in weaners, growers and adults was 77.95, 98.17 and 92.59, respectively. Since the revenue obtained was only 33.76% of the recurring expenditure, it was felt that rearing broiler rabbits on concentrate feeding is not commercially viable. Further, the revenue obtained is only 85.62% of the amount spent on concentrate feeding which also indicated that the project is commercially viable only upon the development of some cheaper feeding system for broiler rabbit. Like-wise, based on data from 1994 to 1996 in WG, it was observed that the average litter size at birth was 6.74 with litter weight of 385.3g. The litter size and weight at weaning was 5.60 and 2.298kg, respectively. The body weights at 4 and 12week of age were 410.0g and 1.46kg, respectively. The number of kindling was 58%. The number of kindling/doe/yr was 5.60, the number of kits born/doe/yr was 37.72, the number of kits weaned/doe/yr was 25.76 and kg weaned/doe/litter was 2.298 and kg weaned/doe/yr was 12.87. The survivability in kits, weaner, growers and adults was 68.30, 74.24, 76.54 and 68.75, respectively. The cost of producing rabbit meat works out to be Rs. 33.37/kg. In recent year (2020-21), the performance of different traits in WG and SC rabbits at SRRC is as below:

Trait	Finding	Trait	Finding
Litter trait		Reproduction	
Size at birth (no.)	5.848 (SC) to 7.403 (WG)	Weight at mating (kg)	4.101 (SC) to 4.382 (WG)
Weight at birth (g)	0.294 (SC) to 0.370 (WG)	Weight at kindling	4.166 (SC) to 4.440 (WG)
Size at birth (no.)	5.141 (SC) to 6.842 (WG)	Kindling (%)	72.47 (SC) to 79.50 (WG)
Weight at birth (kg)	4.842 (SC) to 6.282 (WG)		
Body weight (kg)		Survivability including kits (%)	91.85
6 week	0.918 (WG) to 0.929 (SC)		
12 week	1.953 (WG) to 1.966 (SC)		

Economic feeding systems for commercial rabbit production exhibited that each grower in Gr-I consumed about 6.72kg of pellet feed in 84 days and gained 1171g weight with a cost of Rs. 85.68/grower. The average daily gain was 13.98g and pellet feed cost/g gain was Rs.0.72. In Gr-II, grower consumed about 3.26kg of pellet feed and gained 748g weight with a cost of Rs.42.84. The daily gain in this group was 8.9 g/day/grower and the cost /g gain was Rs.0.57. The growers in Gr-III gained 894g in 84 days without consuming the pellet feed with a daily gain of 10.6g and the cost/g gain was nil. In Gr-I and III, the growth was steady and increasing, while in Gr-II, it was decreased after 4 weeks and again increased after 8weeks due to non-nutritional factors which could be the reason for the low performance of the growers in Gr-II. The per day gain in body weight was 13.9, 8.9 and 10.6g in growers fed with pellet feed at the rate of 80, 40g and on sole feeding with mixed greens, respectively.

Provision of steaming up ration to pregnant rabbits during last six days of pregnancy (2014-15) exhibited that supplementation of additional 50g of concentrate (in addition to maintenance diet -200g pellets) resulted in birth of kits with around 9% higher birth weight (56.63 to 56.79g) than the control group (51.34 to 52.03g). Better birth weights were found to play a significant role in better survival of kits, higher litter weight gain at market age (10.71 vs. 10.08kg). The increase in rate of return from each litter was Rs.63.00 while additional cost incurred for feeding of extra ration was Rs.7.50. Feeding of prebiotics (Xylo-oligosaccharide @0.5 and 1.0%) to the broiler weaner rabbits resulted in better coat texture as compared to the control group.

A feed trial was conducted, wherein the male kits were fed 80g of pelleted feed/day with sufficient water without any green fodder supplementation. The average weaning weights were 0.695 and 0.665kg for WG and SC rabbits, respectively. The final weights on 84th day were 1.930 and 1.975kg in WG and SC rabbits, respectively. There was no significant difference between the two breeds with respect to their carcass traits such as slaughter weight, carcass weight without offal, offal weight, inedible offal and skin weight. The carcass yield (without edible offal) in WG and SC was 50.27 and 51.08%, respectively. It was concluded that there could be sufficient scope for improving the carcass yield in both the breeds through selection.

In order to study effect of THI on performance of rabbits, the period was classified as comfort period (THI: 60 to 65, May to Oct), cold period (THI: 50 to 55, Dec to Feb) and transitional period (THI: 55 to 60, Nov, Mar and Apr). The period had significant influence on LSB, LSW and LWW. LSB was lowest (6.994) in cold period as compared to transitional (7.052) and comfort (7.419) period. LSW and LWW were 5.933 and 5.085kg, respectively in cold period while corresponding values for comfort period were 6.440 and 5.508 kg, respectively. Kindling was lower in cold (72.72%) and transitional (69.51%) period than comfort period (76.66%).

Studies on *Eimeria stiedae* revealed that its sporulated oocysts at the concentration of 105 were lethal where most of the rabbits died between 2nd and 3rd week post infection. The body weight and carcass characteristics of rabbits were not affected by varying grades of *E. stiedae* infection. However, livers from the infected animals were significantly heavier (up to 10-fold) when compared to that of control. Histopathologically, hepatic cells showed extensive necrosis in the periportal area and increase in fibrous tissue with leucocytic infiltration. There was also biliary hyperplasia and hypertrophy of bile duct epithelium with enlargement of biliary canal. Bile duct epithelium showed various developmental stages of coccidia. Biliary epithelium revealed desquamation and cellular debris along with oocysts were seen in the biliary lumina with thickening of biliary wall.

In southern India, during 2003 an upsurge was observed in the establishment of rabbitries by many clients and since than SRRC is continuously imparting training on regularly almost every month.

Adoption level of sheep and rabbit rearing farmers in Coimbatore district and status of sheep in Tamil Nadu: Most of the marketing by the farmers (80%) was being carried out at their houses itself. The major constraints were the frequent outbreak of diseases and scarcity of quality sheep to the markets. Mutton production in Tamil Nadu witnessed a sharp decline during 1997-98 (11,457,398kg) as against 13,600,298kg during 1996-97. Most of the non-vegetarians were showing interest in consuming chicken whereas mutton was preferred by the city dwellers. The red hair sheep skins of Tamil Nadu were fetching good market value. Sheep skins were preferred for leather garments and shoe uppers.

During the year 2012 to 2017, a survey was conducted to document management practices followed by sheep herders in traditional sheep husbandry in 16 villages (88 flocks) of Tirunelveli, Tuticorin and Dindigul district. Majority of sheep are reared in extensive system of rearing involving seasonal migration in search of pasture and a distance of 60 to 70 km was covered in migration in surveyed flocks of Tirunelveli and Tuticorin. Sheep herders starts their migration in the month of April/ May from their homestead to foothills of Western Ghats wherein by the time South West Monsoon sets in and good pasture are available for grazing. The farmers return to their native villages by October/ November by the time North East Monsoon sets in and there will be availability of adequate grasses. Provision of proper housing to sheep during night hours was seen only in 23.86% of the flocks surveyed. The shelter consists of wall in one side with three sides covered with half wall made of bamboo. The floor is invariably katcha and roof is either of thatch or tiles. In the sheep flocks during seasonal migration (71.59%), no provision of shelter is being followed, during night hours, the flocks are housed in simple enclosures made of bamboo/ wire netting in barren lands or harvested agricultural fields and kept under open sky. When the herders halt the sheep during night at agricultural field, herders are paid by land owners an amount of Rs.150–250 per night per flock as charge to manure the farm lands. Grazing is the only source of feed for the sheep reared under extensive system. Even though farmers are aware of importance of feeding concentrate to the animals, the farmers are not following feeding concentrate to sheep flock. Similarly, they are not following any other improved feeding practices like mineral supplementation or cut and carry system of feeding fodders, feeding hay/ silage during lean season.

New born lambs are housed separately in dome shaped baskets and were sent for grazing along with the ewes only after 15 to 20days of birth. Lambs are allowed to suckle the ewes twice a day during morning and evening when the flocks were sent for/ return from grazing. Bunches of neem leaves and sesbania leaves were tied inside the baskets which the lambs nibble. From fourth week onwards, the lambs were allowed for grazing and housed along with other animals. The lambs were weaned and sold at two and a half month to three months of age. The flock strength varied from 80 to 120 adult female and its followers, the sex ratio varied from 1:30 to 1:40. Usually three to four herders used to graze the animal together and both male and female animal are penned together, random mating is being followed and the majority of sheep are of mixed breed. Breeding rams were selected usually from within the flock and rarely bought from fair or market. The farmers are not giving any special importance for maintaining pure breed and only very few pure breed flocks of Chevvadu, Kilakaraisal and Vembur sheep flocks are noticed in the surveyed area. In Nilakotai taluk of Dindigul, the sheep maintained were of admixture of Ramnad White and Mecheri sheep which the farmers locally calling it as Mailampadi and very few Ramnad White sheep are available which locally called as Naatu Adu. Age at first mating in field condition ranged from 15 to 18 months.

The 72% of the respondents are practicing regular deworming and only 40% farmers vaccinate the animals. Remaining farmers interviewed have responded that whenever disease outbreak occurs in their locality, then only

they are opting for vaccinating their stocks which again hampers the health status of the flock. Major disease problems in the region include Foot and Mouth Disease, Blue Tongue, Sheep Pox, PPR and Enterotoxaemia. Farmers are unable to avail the veterinary facility due to shortage of manpower for rearing the sheep.

Survey of livestock market and sheep marketing channels in Tirunelveli district: Marketing of sheep is almost fully controlled by middlemen. The traders visit various sheep flocks and buys the animals ready for sale. They pay the herders based on visual appraisal of body condition of sheep. The traders bring the animals to weekly livestock market from where they sell the animal to butchers or to other farmer who are in need of replacement stock/ raises the lamb for fattening. Sheep herders usually avoids selling the animals directly in the markets because many a times, they use to take advance payment from traders for sale of animals and also due to manpower shortage as they have to graze the sheep daily and no one is there to take the animals to market for sale. However, farmers visit the market to know the prevailing market rates. Approximate prize of sheep traded in these markets were Rs. 6000–7000 for Ram, Rs. 4000-5000 for Ewe, Rs. 2500 for lamb and Rs. 3500 for culled animals depending on age, weight, expected meat yield. Physical infrastructure facilities in livestock markets of Tirunelveli district are very poor and almost all markets are functioning in open ground without any logistics. The major constraints faced by farmers in sheep marketing were dominance of livestock traders, unorganized pricing mechanism, cost of transporting animals from village to markets, high entry and exit fees for animals in markets, lack of animal shelter, loading facilities etc, threats of disease outbreak and lack of veterinary care and lack of parking space for vehicles.

Survey to document sheep production system in Karnataka: Survey was conducted in 12 villages of Kolar and Chikballapura districts of Karnataka. Sheep rearing forms an integral part of mixed farming system involving agriculture, dairying, horticulture and sericulture. Almost all household maintains 5 to 10 sheep heads. Unlike in Tamil Nadu where sheep rearing is sole livelihood activity for majority of traditional sheep rearing community, in Kolar district, sheep rearing forms part of their livelihood activity. Around 10 to 15% of the sheep flock surveyed were Bharat merino crosses and rest 85% were local non descriptive and Bannur sheep. 50% of farmers were having flock size of 5 to 20 sheep while 25% farmers had flocks of 30 to 70 sheep. Large commercial sheep farms were maintaining up to 800 heads were also common. Sheep were housed in good shelters and large farms are having elaborate housing system with provision of feed and water troughs. Sheep are raised through grazing; in addition, feeding of silage, chopped green and dry fodders are common phenomenon. Large farms are following complete stall-feeding system. Sheep were regularly vaccinated against enterotoxaemia, foot & mouth disease and peste-des-petits ruminants and around 92% of farmers were following vaccination and 90% are regularly deworming their stock. Technology adoption level by sheep farmers is higher in these districts as compared to Tirunelveli district of Tamil Nadu. KSSWDB has introduced machine shearing in large commercial farms and greasy fleece yield in Bharat merino crosses ranged from 2.0 to 2.5kg. Bharat merino crossbred males reached body weight of 3.82, 19.54, 29.28 and 46.40kg at birth, 3, 6 and 12 months of age, respectively while the values were 2.68, 11.84, 19.40 and 27.08kg in non-descriptive male sheep. The values for female Bharat merino crosses were 3.16, 16.15, 24.94 and 36.00kg at birth, 3, 6 and 12 month of age and non-descriptive female sheep achieved body weight of 2.36, 11.08, 16.50 and 22.34kg, respectively. Bharat merino supplied by SRRC, Mannavanur is judiciously used by farmers of Kolar region and BM crosses are seen in the field condition. Due to better body weight, they are fetching more returns to the farmers.

Sporadic epidemiological surveys indicated prevalence of brucellosis and Blue tongue in Kamudhi taluk (Ramnad Dist), brucellosis, leptospirosis and PPR (83.00%) in Nilakotai (Dindigul Dist), PPR and Blue tongue in Aranthangi (Pudukotai Dist), brucellosis in Seevalaperi (Tirunelveli Dist), Orf in Kodai hills (Dindigul Dist) and leptospirosis in Maniyatchi (Thoothukudi Dist).

MAJOR OUTCOMES

Memorandum of Understanding (MoU)

Institute has developed MoU with different universities and institutions for extending research facilities to students for undertaking their research work of Post graduate and Ph.D programmes under guidance of scientists of the institute. The list of universities and institutions entered into MoU with the institute is given below:

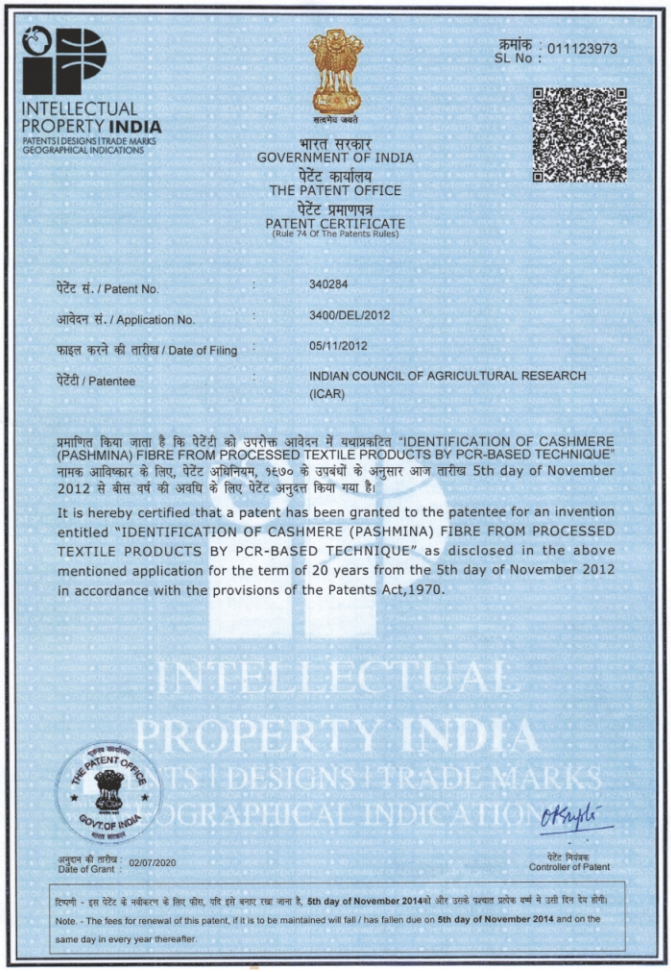
S.No.	Name of the Institution / Organization with whom MoU signed	Date of signing
1.	Rajasthan University of Veterinary and Animal Sciences, Bikaner, Rajasthan	13.12.2013
2.	Maharashtra Animal and Fishery Sciences University, Nagpur, Maharashtra	21.02.2014
3.	Chhattisgarh Kamdhenu Vishwavidhalaya, Durg, Chattisgarh	03.08.2015
4.	Uttar Pradesh Textile Technology Institute, Kanpur, UP	22.08.2015
5.	Indian Institute of Carpet Technology, Bhadohi, UP	29.09.2015
6.	Banda University of Agriculture and Technology, Banda UP	28.01.2016
7.	San Higginbottom Institute of Agriculture Tech and Sci., Allahabad, UP	16.02.2016
8.	Bihar Animal Sciences University, Patna, Bihar	14.02.2019
9.	GLA, Mathura, UP	16.04.2019
10.	CCS Haryana Agriculture University, Hissar, Haryana	03.12.2019
11.	Indian Institute of Crafts and Design, Jaipur, Rajasthan	13.12.2019
12.	Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan	16.07.2020
13.	Mother Teresa Women's University, Attuvampatti, Kodaikanal, Tamil Nadu	19.09.2020
14.	ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, West Bengal	21.11.2020
15.	ICAR-National Research centre on Camel, Bikaner, Rajasthan	19.01.2021
16.	ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh (for ARC, Bikaner)	04.01.2021
	ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh (for NTRS, Garsa)	02.08.2021
17.	ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, West Bengal and ICAR-National Research centre on Camel, Bikaner, Rajasthan	28.03.2021
18.	Govind Ballabh Pant University of agriculture and Technology, Pantnagar, Uttarakhand	12.08.2021
19.	Swami Keshwanand Rajasthan Agricultural Unoversity, Bikaner, Rajasthan	30.08.2021

Patent applications filed

SN	Application No.	Date of filing	Title	Inventors
1	2020111011700	19.03.2021	Woven cotton cloth covered coarse wool needle punched eco friendly quilt comforter for cold weather protection	DB Shakyawar, N Shanmugam, Ajay Kumar, VV Kadam, S Jose, Arun Kumar and A Sahoo
2	202111010071	10.03.2021	Method of lustre evaluation of textile fibre	Ajay Kumar, DB Shakyawar, Rajiv Kumar, AS Meena, NL Meena, Ashish Chopra and Mahendra Uttam
3	202011057021	29.12.2020	A complete feed block (Avi - Batika) and a method for preparing the same	RS. Bhatt and A Sahoo
4	202011049589	13.11.2020	Coarse wool fabric reinforced high strength composite and its preparation	VV Kadam, DB Shakyawar, N Shanmugam, S Jose and Ajay Kumar
5	201911009676A	13.03. 2019	Liquid milk formula Published on 18.09.2020	RS Bhatt, A Sahoo and SK Sankhyan
6	2114/DEL/2010	06.09.2010	Low cost, indigenous vaginal sponges for estrus control in buffaloes	SMK Naqvi, Sajjan Singh and Davendra Kumar
7	2486/DEL/2009	03.12.2009	Fermentation vessel for conducting gas production studies (*in vitro*): Fabrication, protocol and uses	RC Jakhmola, SKS Raghuvansi, Narendra Singh and MK Tripathi
8	2108/DEL/2009	12.10.2009	Method for manufacturing an economic fermented animal feed for probiotic applications	MK Tripathi and SA Karim
9	240/DEL/2009	06.02.2009	Area specific mineral mixture-A pellets for augmenting reproduction and production in sheep	AK Shinde, SK Sankhyan and SA Karim

Patents granted

S. No.	Patent No.	Title	Inventors	Date of grant
1	340284	Identification of cashmere (Pashmina) fibre from processed textile products by PCR-based techniques	Rajiv Kumar, DB Shakyawar, PK Pareek, LLL Prince, AS Meena, Satish Kumar, ASM Raja, SA Wani and SA Karim	07.02.2020
2	344857	Low cost, indigenous cradle for safe restraining of sheep for pregnancy diagnosis	VP Maurya, V Sejian, SMK Naqvi and SA Karim	24.06.2020



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GEOGRAPHICAL INDICATIONS

क्रमांक : 011123973
SL No :

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE
पेटेंट प्रमाणपत्र
PATENT CERTIFICATE
(Rule 74 Of The Patents Rules)

पेटेंट सं. / Patent No. : 340284
आवेदन सं. / Application No. : 3400/DEL/2012
फाइल करने की तारीख / Date of Filing : 05/11/2012
पेटेंटी / Patentee : INDIAN COUNCIL OF AGRICULTURAL RESEARCH (ICAR)

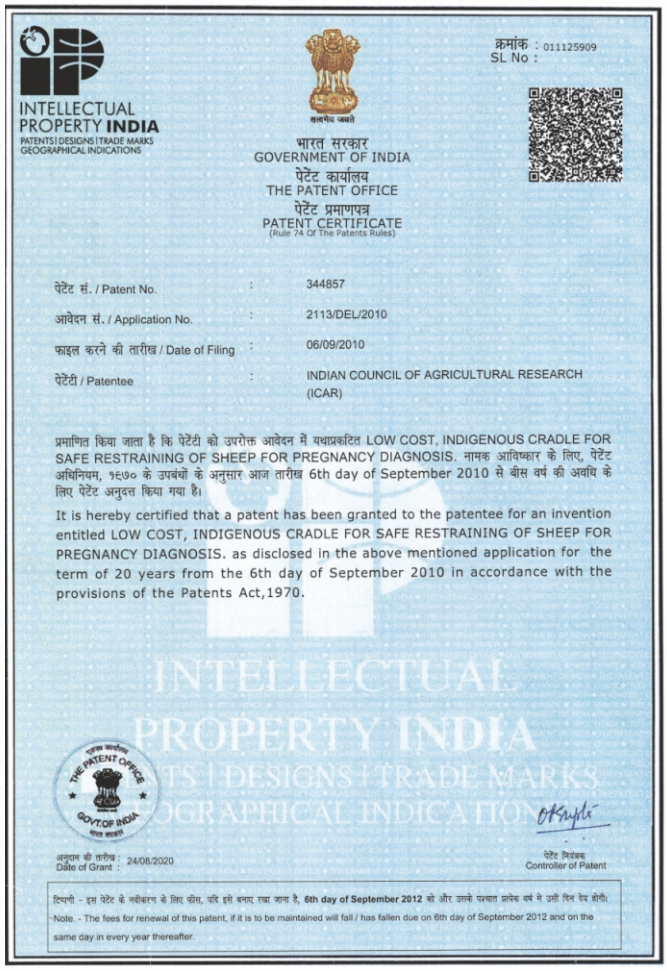
प्रमाणित किया जाता है कि पेटेंटी को उपरोक्त आवेदन में यथाप्रकटित "IDENTIFICATION OF CASHMERE (PASHMINA) FIBRE FROM PROCESSED TEXTILE PRODUCTS BY PCR-BASED TECHNIQUE" नामक आविष्कार के लिए, पेटेंट अधिनियम, १९७० के उपबंधों के अनुसार आज तारीख 5th day of November 2012 से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled "IDENTIFICATION OF CASHMERE (PASHMINA) FIBRE FROM PROCESSED TEXTILE PRODUCTS BY PCR-BASED TECHNIQUE" as disclosed in the above mentioned application for the term of 20 years from the 5th day of November 2012 in accordance with the provisions of the Patents Act,1970.

अनुदान की तारीख : 02/07/2020
Date of Grant :

पेटेंट नियंत्रक
Controller of Patent

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, 5th day of November 2014 को और उसके पश्चात प्रत्येक वर्ष में उसी दिन देय होगी।
Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 5th day of November 2014 and on the same day in every year thereafter.



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क्रमांक : 011125909
SL No :

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THE PATENT OFFICE
पेटेंट प्रमाणपत्र
PATENT CERTIFICATE
(Rule 74 Of The Patents Rules)

पेटेंट सं. / Patent No. : 344857
आवेदन सं. / Application No. : 2113/DEL/2010
फाइल करने की तारीख / Date of Filing : 06/09/2010
पेटेंटी / Patentee : INDIAN COUNCIL OF AGRICULTURAL RESEARCH (ICAR)

प्रमाणित किया जाता है कि पेटेंटी को उपरोक्त आवेदन में यथाप्रकटित LOW COST, INDIGENOUS CRADLE FOR SAFE RESTRAINING OF SHEEP FOR PREGNANCY DIAGNOSIS. नामक आविष्कार के लिए, पेटेंट अधिनियम, १९७० के उपबंधों के अनुसार आज तारीख 6th day of September 2010 से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled LOW COST, INDIGENOUS CRADLE FOR SAFE RESTRAINING OF SHEEP FOR PREGNANCY DIAGNOSIS. as disclosed in the above mentioned application for the term of 20 years from the 6th day of September 2010 in accordance with the provisions of the Patents Act,1970.

अनुदान की तारीख : 24/08/2020
Date of Grant :

पेटेंट नियंत्रक
Controller of Patent

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, 6th day of September 2012 को और उसके पश्चात प्रत्येक वर्ष में उसी दिन देय होगी।
Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 6th day of September 2012 and on the same day in every year thereafter.

Copyrights registered

S. No.	Registration No.	Title	Inventors
1	CF-4449/2019	Cinematographic film on methane estimation by sulfur hexachloride tracer technique	RS Bhatt
2	CF-4501/2019	Cinematographic film on memnaprash	RS Bhatt
3	SW-8118/2014	Computer Software Work -FROGIN (Forecasting for Rajasthan on Ovine Gastrointestinal Nematodiasis)	CP Swarnkar, Dhirendra Singh, FA Khan and VK Singh
4	CF-3786/2014	Cinematograph Film Work - Semen Collection and Artificial Insemination (AI) in Sheep	SMK Naqvi


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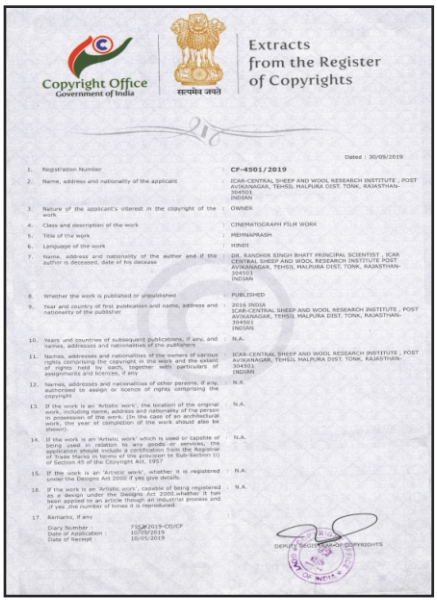
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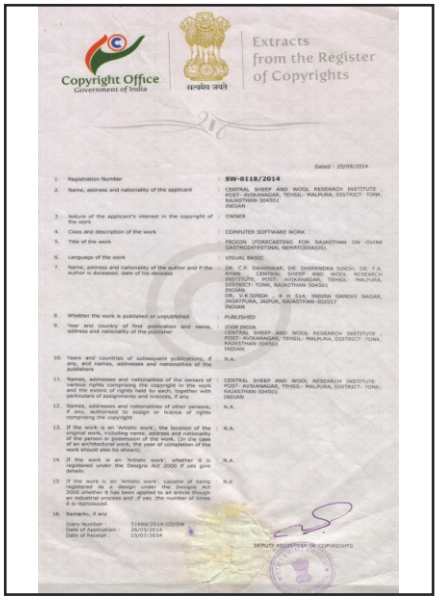
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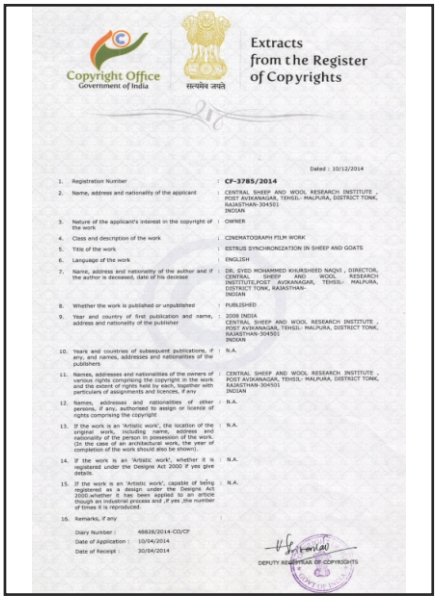
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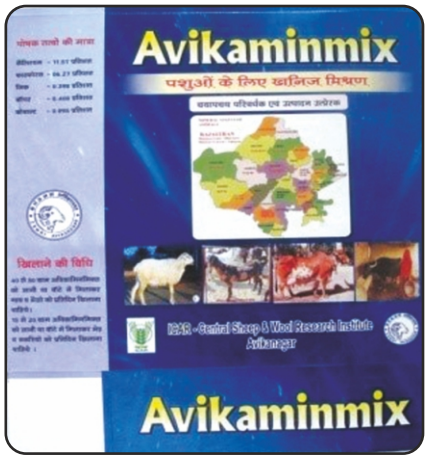
Trademarks filed and registered

S. No.	Application / Registration No. and date	Title	Status
1	4910021 / 18.03.2021	Avi-Cookies	Filed
2	4794154 / 24.12.2020	Avi-Cripa	Filed
3	4794155 / 24.12.2020	Avi-Rakshak	Filed
4	4794156 / 24.12.2020	Avi-sep	Filed
5	3513446 / 24.03.2017	Memnaprash	Registered
6	3513447 / 24.03.2017	Avikhad	Registered
7	3513442 / 24.03.2017	Avikaminmix	Registered
8	3513445 / 24.03.2017	Avikesil-S	Registered



Eentrepreneurs / firms joined to ABIC, ICAR-CSWRI, Avikanagar

S. No.	Name and address of incubates
1.	Gourav Parmar, Orgo fiber LLP, Vadodara, Gujarat
2.	Mukesh Kumar, Ashirwad Live-Stock, Jhunjhunu, Rajasthan
3.	Mr. Ghanshyam Mundra, Kekari, Rajasthan
4.	Siya formulations, Jaipur, Rajasthan
5.	Manish Kumar Meena, Star Skill Consultancy Pvt. Ltd. Jaipur, Rajasthan
6.	Avinash Maurya and Kriti Gupta, Wabisabi Jaipur
7.	Kamlesh Kumar Kushwaha, Bhumika Animal Breeder Farm, Sheopur Bhopal
8.	Sahjeevan Society, Kutch, Gujarat
9.	Mohd. Umarshad, S/o Peer Mohammad, Village Mahrauda, Sahson, Allahabad
10.	Sachin Chourasiya S/o Dinesh Chourasiya, Bada Takhta, Tonk , Rajasthan
11.	Dr. Avinash Anand, Uttarakhand State Sheep, Goat Rabbit Farmers Co-Operative Federation Ltd., Dehradun

Details of MOUs signed under ABIC

S. No.	Agency	Activities
1.	Orgo fiber LLP, Vadodara, Gujarat	Sapling bag from wool nonwoven
2.	Aashirwad Livestock, Jhunjhunu, Rajasthan	Setting up of rabbit farm
3.	Mundra Woolen Mill, Kekari, Rajasthan	Pashmina shawl manufacturing
4.	Bhumika Animal Breeder Farm, Bhopal, MP	Technical mentoring in sheep husbandry practises
5.	Sachin Chourasiya, Tonk, Rajasthan	Wool felt, namda and handicraft manufacturing

Technologies at a glance

1. Avishaan: A prolific sheep
2. Fat tail/rump sheep (Dumba): Extra ordinary growth and demand
3. Malpura: A promising mutton sheep of semi-arid region of Rajasthan
4. Avikalin: A dual type cross-bred sheep for carpet wool and mutton
5. Chokla: Best carpet wool breed of Rajasthan
6. Magra: A lustrous carpet quality wool sheep
7. Marwari: A robust sheep breed of arid zone
8. Gaddi Synthetic: Fine wool sheep for temperate region
9. Bharat Merino: Fine wool producing sheep of India
10. Sirohi: Dual purpose hardy goat breed of Rajasthan
11. Molecular technique for identification of adulteration of meat of sheep and goats
12. Application of FecB genotyping test in MAS programme in sheep

13. DNA test for identification of the benzimidazole resistance in *Haemonchus contortus* parasite in sheep
14. Artificial insemination in sheep with liquid chilled semen
15. Indigenous intra-vaginal sponges for estrus induction and synchronization
16. Embryo transfer technique in sheep
17. Ram semen freezing technique
18. Accelerated lambing system: Three lambs in two years
19. Lamb feeding for mutton production
20. Milk replacer/supplements in lambs
21. Area specific mineral mixture for sheep and goats
22. Multi nutrient blocks
23. Complete feed block technology for animal
24. Prickly pear cactus: A promising feed resource during scarcity
25. Herbal feed supplements: Nutritional and therapeutic intervention to ameliorate stress
26. Conservation of monsoon herbage for scarcity period
27. Pasture establishment
28. Organic sheep manure from wool waste
29. Avikhad Organic manure from waste wool
30. Sheep flock health technology
31. Worm management programme for sheep flocks of Rajasthan
32. Targeted selective treatment (TST) approach for management of Haemonchosis in sheep
33. FROGIN: Software for forecasting gastrointestinal nematodiasis in sheep of Rajasthan
34. Diagnosis of paratuberculosis (Johne's Disease)
35. Diagnosis of caseous lymphadenitis
36. Molecular technique for identification of wool and specialty hairs
37. Aesthetic and durable carpet from indigenous wool and its blends
38. Angora rabbit hair - Bharat Merino wool blended shawls
39. Development of pure pashmina yarn using PVA as carrier fibre
40. Natural dyes with antimicrobial and antimoth properties for wool and speciality hairs
41. High quality blankets from indigenous wool
42. Development of woolen handicrafts from coarse wool
43. Anti-microbial and anti-moth properties of natural dyes for wool and specialty hairs
44. Handmade felt and its products
45. Development of fabric from fine wool of Dumba sheep
46. Development of lustre wash process for carpet yarn
47. Ornamental home furnishing from coarse wool braided yarn
48. Development of reinforced composite from coarse wool
49. Development of sapling begs from coarse wool
50. Value added sheep meat products
51. Development of mutton cookies
52. Value added sheep milk products

CONTRIBUTORS

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