Sheep Wool & Mutton: Production and Value Addition

Editors

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ICAR- CSWRI, Avikanagar & MANAGE, Hyderabad

Sheep Wool & Mutton: Production and Value Addition

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This e-book is a compilation of resource text obtained from various subject experts for Collaborative Online Training Programme of ICAR-CSWRI, Avikanagar, Rajasthan & MANAGE, Hyderabad on Value Addition to Sheep Products with Special Reference to Wool & Mutton from 12-16 April, 2021. This e-book is designed to educate extension workers, students, research scholars, academicians related to veterinary and textile science about sheep produce and its value addition.

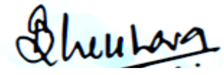
MESSAGE

National Institute of Agricultural Extension Management (MANAGE), Hyderabad is an autonomous organization under the Ministry of Agriculture & Farmers Welfare, Government of India. The policies of liberalization and globalization of the economy and the level of agricultural technology becoming more sophisticated and complex, called for major initiatives towards reorientation and modernization of the agricultural extension system. Effective ways of managing the extension system needed to be evolved and extension organizations enabled to transform the existing set up through professional guidance and training of critical manpower. MANAGE is the response to this imperative need. Agricultural extension to be effective, demands sound technological knowledge to the extension functionaries and therefore MANAGE has focused on training program on technological aspect in collaboration with ICAR institutions and state agriculture/veterinary universities, who having expertise and facilities to organize technical training program for extension functionaries of state department.

In India, Sheep are mainly reared for the production of Meat and Wool and making contribution to the livelihood of the economically weaker sections of the society. The export earnings from different woolen products and mutton is also noticeably contributing to the National income. Amongst the livestock owners the shepherd's community used to rear the sheep, which is highly unorganised in nature with poor marketing facilities. These raised the issue of sustainability of sheep farming in spite of high demand of meat and wool. In this context the value addition in Meat and Wool may be ensure profitability and sustainability.

It is a pleasure to note that, Central Sheep and Wool Research Institute, Avikanagar, Rajasthan and MANAGE, Hyderabad is organizing a collaborative training program on **"Value Addition to Sheep Products with Special Reference to Wool & Mutton"** during 12-16 April, 2021 and coming up a joint publication as e-book on **"Sheep wool and mutton: Production and value addition"** as immediate outcome of the training program.

I wish the program be very purposeful and meaningful to the participants and also the e-book will be useful for stakeholders across the country. I extend my best wishes for success of the program and also I wish Central Sheep and Wool Research Institute, Avikanagar, Rajasthan many more glorious years in service of Indian agriculture and allied sector ultimately benefitting the farmers. I would like compliment the efforts of Dr. Shahaji Phand, Center Head-EAAS, MANAGE and Director, CSWRI, Avikanagar for this valuable publication.



(P. Chandra Shekara)
Director General, MANAGE

FOREWORD

Although sheep rearing is known to us since early civilization, sheep is considered as a future animal for rural prosperity under the current scenario of climatic conditions and limited grazing resources. Sheep can adapt to wide range of climate conditions and requires minimum inputs. Sheep rearing is especially beneficial to small and marginal landholders and farmers. Post-harvest products of sheep such as wool and mutton play an important role in the socioeconomic life of India. They are an industrial commodity. There are ample opportunities of value addition to wool and mutton. ICAR-CSWRI has developed various diversified wool and mutton products. These products and their associated technologies should be communicated to a larger audience.

In this context, ICAR-CSWRI is conducting a free online training program on "**Value addition to sheep products with special reference to wool and mutton**" sponsored by the National Institute of Agricultural Extension Management (MANAGE), Hyderabad for the Extension officials of state/central animal husbandry departments, veterinarians, faculty of SAUs/KVKs/ICAR institutes, etc. during 12-16th April 2021 through Cisco Webex Online Platform. The lectures of this online course are exactly designed to expose the participants to various aspects of wool and mutton production, quality evaluation and value addition. I hope that the participants from different parts of the country would be immensely benefitted from this online course by interactions with expert resource persons selected for the training. I have no doubt that the course will be intellectually rewarding to the participants.

I would like to take this opportunity to congratulate MANAGE and ICAR-CSWRI for their fruitful collaboration towards benefits to farmer community. I also congratulated course directors and course coordinators for their untiring work and high level of enthusiasm.

(Arun Kumar)

Director, ICAR-CSWRI

PREFACE

This e-book is an outcome of collaborative online training program on "**Value addition to sheep products with special reference to wool and mutton**" from 12-16 April, 2021. The editors' main aim is to provide insights to all extension workers, faculties, researchers and students about wool and mutton science right from production to value addition. The extension people should know the entire value chain of wool as well as mutton. They can be benefitted from getting knowledge of various wool products and mutton products. The current information in product development will help them to do well in the extension field.

The editors felt that all the experience of resource persons of this training should be clubbed together to form a unique proposition on wool and mutton. Wool and mutton science are subjects which have different magnitudes. Coordinating both subjects from a common point was indeed a challenging job. The experts and resource persons in wool and mutton science contributed immensely and tirelessly to develop various chapters of this e-book in very short span of time. They all deserve applaud. The editors extend their sincere thanks to all the experts who have contributed valuable time and put sincere efforts to produce this e-book.

The editors also thank MANAGE, Hyderabad for the financial support to the training program. The editors express gratitude towards the director, ICAR-CSWRI for the constant encouragement for this training and e-book creation for the participants. The editors hope that this e-book will help participants as well as other extension people across the country to gain valuable information on sheep wool and mutton.

Editors

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Chapter 1

Sheep Production in India: an Overview

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1.1 Introduction

Livestock, an integral component of the agriculture and allied sector, contributes 28.4% Gross Value Added (GVA) to agriculture and allied sector which is equivalent to 4.9% of total GVA (BAHS, 2019). Though the contribution of agriculture and allied sector, as a whole, to total GVA is declining over the years, the share of the livestock sector to agricultural GVA and total GVA is showing an increasing trend. It infers that the role of the livestock sector is gradually becoming much more important in the national economy.

Sheep is one of the most important livestock species providing food and nutritional security to a large resource-scarce section of the human population of India belonging to the small, marginal farmers and landless labourers. Sheep farming, which needs less initial investment, is suitable for a low input system, and adapted to adverse climatic conditions. Thus, it is an important tool of poverty alleviation. Sheep are contributing to the livestock sector through the production of mutton, wool, milk, skin, manure, etc. Besides domestic consumption mutton is being exported to foreign countries.

1.2 Sheep population

As per the 2019 livestock census, India recorded a sheep population of 74.26 million ranking 3rd in the world (Table 1.1). The sheep population in India generally showed an overall increasing trend across livestock censuses since 1951.

Table 1.1 Composition of sheep population (million) in major states in 2019

Rank	State/UTs	Exotic/Crossbred	Indigenous	Total sheep
1	Telangana	0.49	18.58	19.06
2	Andhra Pradesh	1.18	16.45	17.63
3	Karnataka	0.10	10.95	11.05
4	Rajasthan	0.05	7.86	7.90
5	Tamil Nadu	0.28	4.22	4.50
6	Jammu & Kashmir	1.58	1.66	3.25
7	Maharashtra	0.12	2.56	2.68
8	Gujarat	0.00	1.78	1.79
9	Odisha	0.01	1.27	1.28
10	Uttar Pradesh	0.05	0.93	0.98
11	Other states/UTs	0.22	3.91	4.14
	India Total	**4.09**	**70.17**	**74.26**

1.3 Mutton production

Sheep contributed 8.36% of India's overall meat production of 8.11 million tonnes in 2018-19 (BAHFS, 2019). Telangana, Andhra Pradesh, and Tamil Nadu were the top three mutton-producing states, with 34.90, 23.83, and 8.94% share, respectively (Table 1.2). In 2018-19, an estimated 50.86 million sheep were slaughtered, yielding an average of 13.33 kg of mutton per animal. The slaughter rate was 68.49% of the present population of 74.26 million sheep. The share of mutton to total meat production in the country has remained around 7.5% for the last several years.

Table 1.2 Mutton production (2018-19) in different states (BAHS, 2019)

Rank	States/ UTs	Mutton (‘000 tonnes)	% share
1	Telangana	236.59	34.90
2	Andhra Pradesh	161.55	23.83
3	Tamil Nadu	60.64	8.94
4	Rajasthan	51.47	7.59
5	Karnataka	47.42	6.99
6	Jammu & Kashmir	21.37	3.15
7	West Bengal	20.56	3.03
8	Uttar Pradesh	18.78	2.77
9	Odisha	17.55	2.59
10	Maharashtra	12.73	1.88
11	Haryana	12.52	1.85
12	Other states/UTs	16.81	2.48
	India total	**677.99**	**100.00**

1.3.1 Export of sheep and goat meat

During 2019-20, India exported 14128.84 MT of sheep/goat meat earning US $ 90.77 million from different countries, mostly from the Middle East (Table 1.3). More than 85% of this export was to UAE, Qatar, Kuwait, and Saudi Arabia. The total export quantity of sheep/goat meat by India is showing a declining trend in the last three years.

Table 1.3 Export of Indian sheep/goat meat to different countries (APEDA, 2020)

		2017-18		**2018-19**		**2019-20**	
S. No.	**Country**	**Qty (MT)**	**Value (US$ Million)**	**Qty (MT)**	**Value (US$ Million)**	**Qty (MT)**	**Value (US$ Million)**
1	UAE	12,619.70	72.39	11,717.29	72.03	9,884.44	63.78
2	Qatar	2,119.43	12.41	1,896.41	11.64	1,308.36	8.70
3	Kuwait	1,925.70	11.62	1,779.95	11.13	1,303.50	8.66
4	Saudi Arabia	4,239.58	27.55	1,849.24	12.29	596.66	3.87
5	Oman	539.39	3.15	610.38	3.57	443.17	2.58
6	Maldives	143.48	0.63	223.06	0.99	343.93	1.58
7	Baharain	296.69	1.82	297.19	1.85	227.15	1.51
8	Seychelles	17.11	0.08	28.42	0.15	14.72	0.07
9	Nepal	0	0	14	0.06	5.75	0.02
10	Others	5.43	0.02	9.06	0.03	1.16	0
	Total	**21,906.51**	**129.67**	**18,425.00**	**113.74**	**14,128.84**	**90.77**

1.4 Wool production

India's wool production has steadily increased from 1950-51 to 1986-87. After that, it declined till 1992-93, again improved consistently up to 2002-03. It again declined till 2010-11. The latest wool production data (2018-19) recorded a further decline to 40.4 million kg wool. The wool production decreased from 48.1 to 40.4 million kg during 2014-15 to 2018-19 (Table 1.4). In 2018-19, Rajasthan (35.9%) was the leading wool producer followed by Jammu & Kashmir (18.9%) and Telangana (10.5%). Despite the varying trend in wool production across different states during 2013-14 to 2018-19, Rajasthan remained as the top wool-producing state throughout the period.

Table 1.4 Wool production ('000 kg) in different states (BAHS, 2019)

S. No.	States/ UTs	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
1	Andhra Pradesh	5036.83	778.23	788.63	791.62	794.39	797.12
2	Arunachal Pradesh	21.55	24.23	35.70	58.25	60.40	42.63
3	Bihar	270.60	278.42	240.16	280.87	298.10	312.38
4	Chhattisgarh	105.95	115.53	90.15	87.29	81.77	81.95
5	Gujarat	2578.06	2577.41	2282.65	2267.32	2294.96	2270.51
6	Haryana	1390.41	1428.69	702.17	691.22	693.39	718.50
7	Himachal Pradesh	1654.99	1663.07	1408.87	1475.00	1481.87	1503.14
8	Jammu & Kashmir	8709.70	8371.01	6865.65	7265.51	7489.43	7629.28
9	Jharkhand	156.13	160.76	165.82	177.65	186.59	198.59
10	Karnataka	7754.53	8821.44	8191.42	6588.25	4305.00	3057.92
11	Madhya Pradesh	466.34	483.83	442.39	406.22	408.16	410.17
12	Maharashtra	1538.62	1385.78	1389.89	1406.65	1436.77	1456.93
13	Punjab	557.73	460.89	472.69	489.64	514.70	524.85
14	Rajasthan	15026.77	14463.36	13414.61	14321.27	14287.42	14521.84
15	Sikkim	1.00	0.00	0.00	0.00	0.00	0.00
16	Tamil Nadu	1.83	1.20	1.36	2.08	1.96	2.28
17	Telangana	-	4422.97	4562.41	4658.11	4506.02	4263.51
18	Uttar Pradesh	1472.55	1493.71	1264.98	1286.10	1299.62	1315.97
19	Uttarakhand	440.14	468.93	513.33	538.24	564.07	551.98
20	West Bengal	725.17	740.40	748.47	753.07	758.10	760.43
	All India	**47908.88**	**48139.88**	**43581.34**	**43544.37**	**41462.71**	**40420.00**

1.5 Prolificacy

Some of the Indian sheep breeds can produce more than one lamb per lambing due to their unique genetic constitution. They possess some specific Single Nucleotide Polymorphisms (SNPs) in their major prolific gene(s) which enable them to increase ovulation rate leading to the production of multiple births. The indigenous sheep breeds like Garole, Kendrapada, Bonpala, and Nilgiri were found to possess the SNP, popularly known as *FecB* mutation, in the major prolific gene BMPR1B responsible for prolificacy in these breeds.

ICAR-Central Sheep and Wool Research Institute (CSWRI), Avikanagar has developed a three breed prolific sheep 'Avishaan' through introgression of *FecB* mutation from Garole sheep of Sunderban (West Bengal) into the non-prolific mutton sheep Malpura of the semi-arid region of Rajasthan, then backcrossing of carrier half-bred (GM) males with Malpura females and subsequently crossing the carrier backcross (GMM) males with dairy type Patanwadi females from Gujarat. The genetic constitution of Avishaan is having 12.5% Garole, 37.5% Malpura, and 50% Patanwadi inheritance. Avishaan's average growth performance under farm conditions at the time of release was 3.30 kg at birth, 16.80 kg at 3 months, 25.90 kg at 6 months, and 34.70 kg at 12 months of age. In terms of Ewe Productivity Efficiency (EPE), Avishaan outperformed native Malpura sheep by around 30% at six months of age. Avishaan, the product of a '***Make in India***' initiative is capable of achieving the dream goal of '***Doubling the farmers' income***' by producing more lambs, more mutton, more milk in ewes to support the multiple lambs, more wool, and increased survivability.

1.6 Sheep produce other than wool and mutton

Sheep also produce skin, manure, and a small amount of milk in addition to mutton and wool. Sheep skin is exported in the form of leather and leather products, in addition to its domestic use. Agricultural activities use sheep manure. Some sheep breeds that produce a higher amount of milk are milked and sold as whole milk or milk products. Production data of Indian sheep for these traits are not available.

1.7 Major challenges in sheep production

- Rapid shrinkage of natural pasture/grazing land severely impacting the extensive system of rearing followed by sheep rearers
- Stoppage or reduced scope of migratory sheep rearing system over the years
- Climate change effect- shortage in quality feed and fodder availability
- Insufficiency of proper and required nutritional inputs leading to incomplete exploitation of the genetic potential of indigenous breeds
- The fading interest of youth from farming communities for sheep/goat farming
- Low reproductive efficiency of most indigenous breeds
- Losing value of wool – no hue and cry for MSP for animal products
- Over-emphasis on a single trait instead of overall multiple-use efficiency of sheep
- A large proportion of the non-descript population

- Lack of awareness about good germplasm (breed) among farmers
- Unrestricted migration of well-known breeds far away from their original breeding tract
- Multiple players from different Govt. Departments/Institutions, domestic and foreign NGOs in working for short term gain without any coordination among them
- Very high rate of early age slaughter leading to loss of prospective breeding animals
- Insufficient and inaccessible veterinary health care for sheep and goats – very low vaccination and therapeutic coverage leading to high mortality
- Non-availability of properly organized marketing facilities and middleman menace
- Rapid conversion of new sheep breeders into traders for risk-free instant profit
- Insufficient organized financial support for improved sheep farming

1.8 Strategies for enhancing the productivity of sheep

Following are some of the strategies, adoption of which can increase productivity and income from sheep.

- **Ensuring availability of good germplasm:** Though India possesses the 3rd highest number of sheep in the world, per animal productivity, is low and meat production didn't increase much. Also, farmers are not properly aware of the importance and availability of good germplasm. This provides a huge challenge and at the same time a very good opportunity to upgrade the non-descript sheep population with the locally available high-performing breeding rams of recognized breeds in their respective breeding tracts.

- **Adoption of scientific rearing practices:** Adoption of scientific breeding, feeding, and management practices including timely health care by farmers will ensure better production from sheep. There is a need to demonstrate the advantages of streamlining these practices to get good returns from sheep farming.

- **Prolific sheep germplasm:** Some sheep breeds are prolific and can produce more than one lamb per lambing. With little more care provided to these lambs in the initial stages of their life, the per ewe productivity in terms of the litter weight harvested at marketable age will be increased to a large extent if not doubled. It will enable the sheep farmers to produce more lambs from the rearing of smaller number of females resulting in higher and faster economic return to them.

- **Accelerated lambing:** Round the year breeding and lambing practiced by the farmer's cause difficulties in the adoption of different health and other management practices leading to increased mortality in the flock. It can be streamlined by the adoption of breeding practices to produce three lamb crops in two years, thus, providing overall more economic return to the farmers.
- **Use of reproductive tools**: The use of reproductive tools like oestrous synchronization coupled with artificial insemination will lead to the production of extra lambs/kids and additional income to the farmers.
- **Shifting of production system:** Farmers traditionally manage their sheep through a zero-input extensive system. Some sheep farmers follow migratory sheep farming. Gradual shrinkage of pasture due to several reasons forcing farmers to leave sheep husbandry. There is an urgent need to address the issues crippling the life of poor sheep farmers. Shifting from an extensive to an intensive system of management is imminent. Scope of self-sustaining intensive farming system needs to be explored and demonstrated to the farmers. It can be part of an integrated farming system for the production of feed and fodder resources for sheep so that the use of available resources can be optimized. The sheep production in an intensively reared completely controlled management condition will be easy to plan according to the specific seasonal availability of resources and market demand. Further, it can guarantee the sustainability of production and thus income.

1.9 Other strategies

- Implementation of National Level Animal Identification System (NAIS) by tagging of all sheep in all states/UTs for real-time traceability, data recording and increase accuracy in policy planning
- An integrated, non-conflicting, and coordinated approach to improve sheep production by all players from Govt., NGO, etc.
- Expanding the breed coverage of existing indigenous breed improvement programmes, integration of genomic selection into the traditional breed improvement programmes which needs to be converted into community based breeding programmes.
- Ensuring proper and consistent nutritional inputs to the animals covered under genetic improvement programmes

- Emphasis on dedicated new pasture development – replenishing the nutrient-deficient pastures
- Climate-resilient sheep production
- Encouraging involvement of private sector for input sharing, implementation of schemes, etc.
- Entrepreneurship development
- Insurance for social security of sheep farmers
- Demonstration and large-scale implementation of a profit-oriented tested model for commercial sheep production under an intensive and accelerated lambing system
- Free, adequate, and accessible veterinary healthcare coverage for all sheep in the country
- Processing and value addition of sheep products
- Market chain development for live animal and animal produces
- Minimum Support Price for wool
- Exploring alternative uses of wool; development of associated technology for this purpose.

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Chapter 2

Climate Change Impact on Small Ruminant Practice

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Summary

Global demand for livestock products is expected to double by 2050, mainly due to progress in the standard of living. Meanwhile, climate change is a threat to livestock production because of the impact on biodiversity, availability of water and quality feed crop and forage resources, animal and productivity, livestock diseases, and ultimately, socio-economic livelihood based on small ruminant rearing. Interactions between climate change and livestock production are still not well understood and there is a gap in knowledge related to the nutritional and metabolic processes of livestock, which needs to be addressed to improve the management practices that increase sustainability, welfare, and performance of livestock in ensuing climate-change scenario. High temperature, low feed, and water scarcity of this region continue to endure stressful conditions in small ruminant population and they most often exposed to one or the other or a combination of the stress of water scarcity, nutritional insufficiency, migration, or long-distance walking that referred to multiple stress leading to production as well as population decline. Further, it is important to identify breeds with inherent genetic capabilities that can adapt to climate change and evaluate the dynamics of disease prevalence, epidemiology of newer diseases, and timely disease forecasting and prophylactic measures so that a sudden drop in production can be averted. In this transition to sustainable small ruminant production, there is a need to propagate and routinely promote the use of adaptation and mitigation measures tailored to the location and the production system and frame and implement policies that support and facilitate strategic climate change adaptation and mitigation measures.

2.1 Introduction

While climate change is a global occurrence, its negative impacts are more severely felt by poor people in developing countries who rely greatly on the natural resource base for their livelihoods. Rural poor communities rely greatly for their survival on agriculture and livestock keeping that are amongst the most climate-sensitive economic sectors. Among the livestock species, small ruminants are more vulnerable to climate change as they are reared by poor, unprivileged landless/ marginal farmers under an extensive system of production. The local native animals of arid-climatic regions of India have their adaptive mechanism of altering physiological, neuroendocrine, biochemical, cellular, and molecular processes to encounter the stress (Naqvi et al., 2017). The impact of climate change on small ruminant production is apparent in breed composition, population, and distribution, feed and fodder scarcity, shrinkage of grazing land, reproductive and productive disorders, the spread of diseases, poor performances, consumer demand, and market trend for meat, milk, and fibre, etc. (Sahoo et al., 2013). The shift in population trend of sheep and goats in India is also a reflection of a climate-change impact besides other socio-economic and demand-driven policy and/or marketing issues. Telangana state showed maximum increase in sheep population (19.1%) followed by Andhra Pradesh (17.6%) and Karnataka (15.31%), but Rajasthan, a hot-arid climatic region once ranked first (1997) had a negative trend (-12.95%) when compared between the 19th and 20th livestock census. The goat population also showed a negative trend (-3.81%). The frequent drought and famine situations and continuous decline of grazing resources, both in terms of quality and quantity are the persistent factors for this change. In the present climate-change scenario, migration becomes hard and harsh for the farmers and thus, the migratory sheep flock size is declining sharply over the period (average flock size reduced to 35–40 as against 80–100 in two decades) in the semiarid region of Rajasthan (Shinde and Sejian 2013).

The arid and semi-arid regions of India are characterized by water scarcity and fluctuating precipitation. Rainfall is becoming even more irregular under the effect of global warming and unpredictable weather and thus limiting water availability. This has a calamitous effect on food/feed and other resources including metabolic functioning and the health status of animals (Jaber et al., 2013). Although small ruminants in hot arid and semi-arid regions may survive up to one week with little or even no water, water deficiency is proved to affect animals' physiological homeostasis leading to loss of body weight, low reproductive rates, and a decreased resistance to diseases.

2.2 Adaptation and sustenance

Sheep and goats are the only domestic animals that can utilize wastelands, stubbles of cultivated corps, tree topping, farm wastes, or weeds from the field to convert them into meat, milk, fibre, skin, and manure. Animals which are hardy and more adapted to harsh climate condition may thrive well while others may either shift to the more suitable region or suffer stressful environment. Adverse climate condition is known to influence more severely to non-adapted and high producing sheep and goats. For example, the production performance and survivability of Bharat Merino sheep i.e., Crossbred (75% exotic inheritance), was unsatisfactory at Avikanagar (semi-arid tropical area) but their shifting to Mannavanur (sub-temperate location) resulted in a marked increase in production and health performance (growth, reproduction, and survivability) (Naqvi and Sejian, 2011). The IPCC summarized research on the potential impacts of climate change for livestock and listed four possible effects: (1) changes in livestock feed grain availability and price; (2) direct effects of climate on animal health, growth, and reproduction; (3) impacts on pasture and forage crops; and (4) changes in the distribution of disease and parasites (Sahoo and De, 2018).

Extreme ambient temperatures may hamper the homeothermy of these most adaptive sheep and goat breeds of India, although they are well adapted to extreme climatic variables of arid and semi-arid regions. Many strategies including feeding and nutrition, strategic micronutrient supplementation, shelter management practices are delineated to counter thermal stress and production decline in small ruminants (Sahoo et al., 2013). Climate change is leading to shrinkage of grazing lands and feed and fodder scarcity, which directly hamper animal's production performance. It is observed that farmers are being forced to sell their lambs early at 3-4 months of age weighing only 12–14 kg as against 9-12 months of age that usually fetch them 20–22 kg marketing weight (Shinde and Sankhyan 2010). Further, climate change has induced poor health and increased susceptibility to diseases which are adding to the cost of production (Shinde and Sejian, 2013).

2.3 Backing resilience in native animals

Exposure of sheep and goats to high ambient temperature in the existing rearing practice (mostly extensive type) cannot be avoided and this leads to disturbance of the animal's normal physiological functioning and behaviour, viz. reduced feed and water intake, alteration in blood metabolites, plasma hormonal and enzyme levels and a negative impact on production, immunity, and welfare (Sahoo et al., 2013). Therefore, it is essential to explore new initiatives that could be simple, affordable, or at least allow reducing the heat stress of animals in this region. Catalytic supplementation of mineral mixture and antioxidants is reported to protect

Malpura ewes against the adverse effect of heat stress on productive and reproductive efficiency (Sejian et al., 2014). Similarly, selenium-enriched yeast can be fed to improve resilience against heat stress during extreme summer and improve the reproductive performance of ewes (De et al. (2017). Moreover, seasonal variation has a severe impact on physiological responses to maintain thermo-regulations as evident from significant variation in physiological responses (De et al., 2014). Although the native breed is well adapted to the semi-arid tropical climate, they need protection during peak environment temperature (14:00 h) in summer and autumn, and shelter at night during the winter season to maintain their body temperature and hence production.

2.4 Climate-smart production system

It is an approach for transforming and reorienting the small ruminant production under the new realities of climate change. The main objective of climate-smart small ruminant production is to make the production sustainable for national food security, enhancement of resilience, and reduction of greenhouse gasses emission. Climate-smart agriculture is that, which increases sustainable productivity, enhances resilience, reduces greenhouse gasses (GHG), and boosts the achievements of national food security and development goals (FAO, 2013). In India, most of the rural communities earn their livelihood on smallholder livestock production systems and they are very much vulnerable to climate change. Therefore, the need of the hour is to address the impact of climate change both in terms of adaptation as well as mitigation perspective (Vemeulen et al., 2013). The increase in population, the higher income, urbanization, and change in dietary preference leading to increased demand for animal products that pressurizing for higher productivity of livestock (Delgado et al., 1999; Thronton et al., 2007).

The mutton production in our country was 399 million Kg in 2012 which will be around 537 million Kg by 2020, and 840 million Kg in 2030, and 1317 million Kg in 2050. However, the requirement for mutton would be 813 million Kg by 2020, 986 million Kg by 2030, and 1408 million Kg by 2050. Similarly, the wool production in the country is 44.7 million Kg at present time (2011-2012), which have to be increased 150, 180, and 200 million Kg in 2020, 2030, and 2050, respectively. But the harsh climatic condition, shrinkage of grazing resources, increase in cultivation and industrialization, and decline interest of new generation for small ruminant rearing put a question mark to meet the future demand in the current production trend. Livestock production is likely to be adversely affected by climate change, competition for land and water, and food security at a time when it is most needed to address the future demand (Thornton and

Gerber, 2010). The scarcity of resources, the impact of climate change, and increase demand for mutton have made the traditional coping mechanism less effective. Therefore, we need climate-smart sheep and goat production options that can achieve the triple win scenario of increasing productivity, adapting, and building resilience to climate change through a reduction of greenhouse gas (GHG) emission (FAO, 2013; Shikuku et al., 2016).

The impact of climate change in small ruminant production is worldwide because of their dependence on grazing in an extensive system of production. The impact is more severe in countries like India, where climatic variability throughout the country is enormous. In an intensive system of production, the impact is less severe and indirect like the impact of lower crop yield, feed scarcity, and higher energy price will increase the production cost. In general, other impacts are the emergence of livestock diseases, higher temperature and changing rainfall pattern, alter the abundance, and distribution, and transmission of pathogens (Baylis and Litheko, 2006).

The 3 pillars of climate-smart small ruminant production

a. **Productivity**: Sustainably increasing productivity without any negative impact on the environment will provide better food and nutritional security. Productivity enhancement refers to sustainable intensification.
b. **Adaptation**: For maintaining productivity, adaptation to the changing climate is essential. It strengthens resilience by building the capacity to adapt to short-term or long-term stresses. Different adaptation options are available which include technological options, behavioral modifications, and managerial choice and policy alternatives.
c. **Mitigation**: Mitigation indicates reducing the GHG emission for each kilo of mutton, a fibre that we produce. The production system should manage soil and tree in such a way that maximizes their potential to act as carbon sinks and absorb CO_2 from the atmosphere.

2.5 Focus on production-efficient animals

Genomic selection of breeds that are high producing and tolerant to the adverse effects can be an option to counter shuttle changes in population trend, a sequel to the uncertain or fragile socio-economic livelihood of a large chunk of dependent farmers. Selection of efficient animals based on residual feed intake (RFI) can also be a possible approach for selection and animals with low RFI are desirable as their maintenance requirement is low (Sahoo et al., 2019). Residual feed intake (RFI) is a measure of feed efficiency defined as the difference between an individual's actual feed intake and the predicted feed intake. The predicted feed intake is estimated based on the individual's requirements for maintenance of body weight (BW) and growth (average daily gain-ADG). Animals attaining high production performance with lower intake should therefore be screened from a farm flock and selected for the next breeding cycle for enhancing efficiency (Sahoo, 2016).

Prolificacy is another important trait that can be used to establish a 'Multiplier Flock' to meet the demand of finisher lambs or kids for marketing (Sahoo et al., 2019). Many goat breeds are prolific to give multiple births, e.g., Black Bengal, Beetal, Barbari, Malabari, Sikkim, and Jakhrana, etc. But few native sheep breeds like Garole, Kendrapara have the FecB gene, which is responsible for multiple births. Garole is a native and local sheep of Bengal in extended costal Sundarban area having distinct and separate phenotypic characters, productive performances and is the latest sensations in the world of domestic species by virtue of its prolificacy, lambing frequency, disease resistance, and other extraordinary merits rarely or not even observed in other sheep breeds of the world (Banerjee et al., 2010). It is very popular for its bi-annual lambing, multiple births, grazing on aquatic weeds and grass in knee-deep water, and disease resistance characters. A new strain of sheep is developed vide introduction of FecB gene in other native sheep, viz. 'Avishan' developed by ICAR-Central Sheep and Wool Research Institute (CSWRI), Avikanagar (Rajasthan), and 'Suwarna' by Nimbkar Agricultural Research Institute (NARI) in Phaltan (Maharashtra) and have shown promise to give multiple births. De et al (2019) studied the oscillatory thermo-regulatory behavior of fecundity-gene-introgressed sheep, 'Avishaan' in the hot semi-arid region, and observed a similar adaptive strategy to cope with environmental extremes similar to well-adapted sheep. The higher productivity (in terms of weight of lamb weaned) of twin-bearing ewes compared with those bearing singles is evident even in all rearing conditions.

India has promising native sheep and goat breeds with average adult weight ranging from 30-40 kg, which holds promise for extensive selection to achieve improved birth weight that can yield better finishing weight at marketing. Some of the heavy breeds of sheep and goats that promise maximum weaning weight are:

Sheep: Muzafarnagari, Patanwadi, Malpura, Marwari, Nellore, Decani, Madras red, Mecheri

Goat: Jamunapari, Jakhrana, Sirohi, Beetal, Boer, Osmanabadi, Malabari, Mehsana

Furthermore, another type of sheep, commonly referred to as 'Dumba', is a fat-tail/fatrump sheep that can also serve as a promising genotype to yield maximum weight. Maximum weight of 135 kg is recorded in this sheep with an encouraging birth weight of ≥4.0 kg. The tail fat serves as a reserve energy store for scarcity periods. These heavy breeds of sheep and goats can be reared selectively for maximum finishing weight or can be introduced in planned breeding programmes for increasing birth weight of ‘Maximizing Flock’.

2.6 Augmenting adaptation to climate change

2.6.1 Grazing management

Rotational grazing can be a useful strategy for grazing management in climate-smart sheep and goat production (Sharma and Sahoo, 2017). Rotational grazing gives the option to adjust the frequency and timing to livestock grazing needs and it allows the maintenance of forage at an earlier growth stage, which provides better quality digestibility as well as better productivity and reduces city emission per unit of live weight gain (Eagle et al., 2017). Migration is a traditional strategy of nomadic farmers in the arid and semi-arid regions. This system increases the resilience of the production system under changing climate. In the intensive system, cultivation of improved varieties of pasture by replacing some native grasses with high-yielding and more digestible forages, perennial fodders, pastures, and legumes may be an effective pasture management option in climate-smart sheep and goat production (Bentley et al., 2008).

2.6.2 Animal breeding

Selecting higher productive animals to enhance productivity and thereby reduction of CH_4 emission intensity may be a breeding strategy (Waghorn and Hegarty, 2011). Cross-breeding can provide adaptation, food security, and mitigation benefits. Preferably cross-breeding with locally available adapted breeds, which are tolerant to heat stress, nutritional stress, parasites, and diseases are going to be an important component of the climate-smart sheep production system. The North-Western arid and semi-arid regions of India have 14 well-defined sheep breeds/strains and therefore, breed improvement policy for sheep needs to be looked upon as a bottom-up instead of the traditional top-down approach. ICAR-CSWRI has developed new strains and improved native sheep such as Malpura, Magra, Marwari, Chokla, Patanwadi, Sonadi, Muzaffarnagari, Avikalin, prolific Avishaan, Dumba, and sheep strains resistance to *Haemonchus contortus* in the arid and semi-arid regions (Kumar et al., 2021). Thus, breeding of sheep under climate change should emphasize region-wise and location-specific identification of adaptive sheep and goat breeds, use of information technology for data collection and linkage to market, genomic selection for thermo-resistant straits. Gowane et al (2020) advocated farmer's participatory approach for breed improvement in Malpura sheep and proposed a community-based breeding programme (CBBP) model, which is self-sustainable and it has a breeder's organization to lead the way for establishing a ram-rearing centre (RRC), teams of experts for ram selection, data collection and market linkage. The early selection of 5% male lambs at weaning and rearing them at RRC until final selection at 12-month will provide an unbiased selection of rams under CBBP. Several key measures such as micro-finance, coordination between stakeholders, market linkage, and technical input for data collection and selection have been suggested to make the CBBP self-sustainable.

2.6.3 Feed and water resource

The sheep and goats generally graze on pastures, wastelands, fallow lands. However, during the lean period, feed and fodder scarcity occurs. To meet the demand during those period top feed resources can be fed to the small ruminants. The trees and shrubs of different agro climatic zones have significance in small ruminant feeding. The country tree leaves are harvested and sun-dried at the appropriate stage and stored, for use as supplements in addition to grazing during the lean period of the region. As looping is prohibited, the dry fallen leaves from the surface, which is almost estimated that 300 to 350 million MT and the grass is available from the forest with good nutrient content can be used to fed during scarcity period. Furthermore, and most importantly, the unconventional feed e. g. Monsoon Herbage, grasses, and fodder may be a good source of feed during the scarcity period (Sharma and Sahoo, 2017). The unconventional feed can be stored as a fodder bank by making good quality silage, feed pellet, feed blocks. The silage can very well constitute part or whole of the daily diet of the animal during the scarcity of water and food (Sahoo, 2018). The concept of mixed-silage can further be effective in improving feed quality and providing adequate nutrition in regions exposed to extreme climatic events. Similarly, complete feed block (CFB) technology ensures feed banking and the authors (Chaturvedi et al., 2014) observed maintenance of body weight by grazing ewes supplemented with CFB compared to control, which lost body weight during the scarcity period of summer in semi-arid Rajasthan.

2.6.4 Agro-forestry:

Agroforestry is important to climate change mitigation by contributing to carbon sequestration, improved feed, and consequently reduces enteric methane. Tree shades protect against heat stress during extreme summer (De et al., 2020). Trees also provide quantity forage that reduces overgrazing and land degradation (Thornton and Herrero, 2010) and a '3-Tier' agro-forestry system is the most efficient in providing double the forage biomass compared to mono-pasture (Sharma and Sahoo, 2017). Prickly-pear cactus (Opuntia sps) can also constitute one of the tiers in this agro-forestry system (Sahoo et al., 2017), and it provides both feed and water to small ruminants in this water-scarce arid region.

2.6.5 Water management:

The arid and semi-arid regions of the country are prone to water scarcity and it will further worsen due to a downward trend in the water table. The small ruminant species of this region have to walk kilometers due to the limited availability of drinking water in grazing areas, particularly during the summer months. Eventually, the animals undergo stressful conditions due to wandering for the scarce feed and water resources alongside high ambient temperature and no shade to rest in the barren desert area. Therefore, water management is going to be a critical factor for any type of production system and the practice of increasing the output per unit of water use will be considered as an adaptive and climate-resilient production system. The native Malpura sheep demonstrated good adaptability to water stress as evident from negating live weight decline with limited (60%) water supply and quick rejuvenation after reversal to ad libitum water (De et al., 2015). Several adaptive techniques and approaches are available to increase the water use efficiency for crop production that indirectly influences the water management of livestock production.

2.6.6 Feed conversion

A higher feed conversion ratio reduces the amount of feed requires per unit of animal product. Feed efficiency can be increased by selecting breeds of faster growth rate, handier, feed efficiency can also be improved by improving herd health through better veterinary services, preventive health programs, and improved water quality. Selecting feed with a low carbon footprint is another way to reduce emissions.

2.6.7 Building resilience along the supply chain:

Climate change increases the price volatility of inputs, feed, and energy that increases the financial risk for stakeholders involved in the livestock supply chain. The changing disease pattern due to changing climate further added to the risk. Probably greater coordination among the different stakeholders involved in the supply chain, insurance schemes, buffers, and stocks may contribute to greater resilience of the supply chain that relies on the landless livestock system.

2.6.8 Reproductive function

Although breeding takes place throughout the year, most breeding is linked with the highly seasonal availability of grazing resources. The rams and bucks stay with the flock throughout the year, but sheep flock owners, especially in Rajasthan and Gujarat tie the prepuce with cotton tape to avoid matings during undesirable seasons. Most sheep breeding takes place in July–August i.e. immediately after the onset of the monsoon and some of it in March–April, when stubble grazing and Acacia and *Prosopis* pods are available to the animals. The age at first mating in sheep is nearly 1 year. Sheep generally lamb only once a year (Acharya, 1985). Research at ARC, Bikaner, revealed that 80 to 100% of animals exhibit oestrus throughout the year. However, considering lambing percentages and lamb survival and growth, breeding in March-April and August-September is preferable (Acharya, 1982). Furthermore, to increase the sustainability of production, it's time to get 3 crops in two years. For this, artificial reproductive techniques like estrus synchronization and artificial insemination may be done in the flocks avoiding the lean period for lambing can improve the production of the flock.

2.6.9 Health and welfare

Global climate change shifts the efficiency and transmission pattern of hosts. With the change of atmospheric humidity and temperature the proliferation of the pathogen and vector is evident. Altogether, the climate alters the occurrence, pathogenicity, spread, transmission, timing, and intensity of outbreaks. The exotic diseases, the main effect of climate change may be an increase in the geographic range and an increase in competence of the non-vertebrate vector. Consideration on the rights of indigenous, migratory, and pastoral people in the formulation of strategies, needs to develop a comprehensive plan (e.g. health, disaster reduction) to deal with the migration of disease due to climate change. A positive animal welfare contingency plan to control zoonoses caused by climate change has to be developed. There should be use of vaccinations as a preventive measure, where appropriate, in regions where the disease is endemic. The transportation of live animals has been limited. Finally, by combining improved empirical data and refined models with a broad view of the small ruminant production system, robust projections of disease risk can be developed.

2.6.10 Weather forecasting and insurance

The proper information on the weather forecast for the rural communities will help to manage the risk as well as taking adaptive measures to prevent climatic variability. In such situations, livestock insurance schemes which are weather-indexed (i.e., policyholders are paid in response to trigger events such as abnormal rainfall or high local animal mortality rates) may be effective where preventive measure fails (Skees and Enkh-Amagala, 2012).

2.7 Conclusion

Sheep and goat husbandry is a sustainable livelihood option for landless marginal farmers, especially in arid and semi-arid regions since ancient times. Although livestock husbandry especially the small ruminant practice is climate-smart agriculture, there is ample scope to make it better under the pressure of changing climatic aberrations because of its increasing demand, socio-economic link, low-input production system, easy to start ensuring quick return, avenues for a start-up providing job opportunity and ever-ready crisis management 'ATM'. Alternative strategies have to be implemented in sheep husbandry practices especially during the scarcity period of feed and water. To make the production system more sustainable it is essential to provide resilience through nutritional intervention, water management strategies, and climate-friendly rearing practice and to augment adaptive mechanism by addressing thematic issues related to climatic adaptation, identifying and propagating adaptive breeds of sheep and goats, development of suitable genetic lines, dissemination of new understanding in rangeland ecology, and holistic understanding of pastoral resource management. Climate change adaptation, mitigation practices, and policy frameworks are thus critical to protect livestock production. Diversification of small ruminants (within species), use of different crop varieties, and shifting to mixed crop-livestock systems seem to be the most promising adaptation measures. All these efforts should be directed towards sustainable climate-smart agriculture to provide a better livelihood to the poor farmers and protecting the climate.

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Chapter 3

Sheep Genetic Resources of India

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3.1 Introduction

India is rich with a vast diversity of animal genetic resources. Among them, sheep is an important 'five-star' livestock species contributing significantly to the rural economy. Sheep farming acts as a major tool of poverty alleviation in rural areas through the production of mutton, wool, manure, skin, and milk. It is largely reared by marginal and small farmers, and landless laborers, particularly in the dry land areas of the country. As per the latest livestock census (2019), India is home to 74.26 million sheep fetching world ranking 3rd after China and Australia. This population comprises three types of sheep categorized as per their genetic makeup, namely, indigenous established breeds, indigenous non-descript (desi/local) sheep, and exotic/crossbred. To date, there are 44 registered well-defined breeds of indigenous sheep, distributed in four agro-climatic zones of the country. They are known mainly for their mutton and wool production.

3.2 Population status

The current (2019) sheep population of India is increased by 14.13% over the 2012 census. The top five states with leading sheep populations together contribute more than 81% of the total sheep population of the country (Table 3.1). They are Telangana (25.72%), Andhra Pradesh (23.70%), Karnataka (14.95%), Rajasthan (10.64%), and Tamil Nadu (6.06%) (Fig. 3.1). The majority (94.49%) of the total sheep population comprised of indigenous including non-descript sheep only. While the female sheep population of both indigenous (21.67%) and exotic/crossbred (26.62%) increased over the previous census, the population of males in both categories decreased by 9.93 and 31.32%, respectively (Table 3.2).

Table 3.1 States with leading sheep population (Livestock Census 2019)

S. No.	States/UTs	2019 Census (million)
1	Telangana	19.1
2	Andhra Pradesh	17.6
3	Karnataka	11.1
4	Rajasthan	7.9
5	Tamil Nadu	4.5
6	Jammu & Kashmir	3.2
7	Maharashtra	2.7
8	Gujarat	1.8
9	Odisha	1.3
10	Uttar Pradesh	1.0
	All India	**74.26**

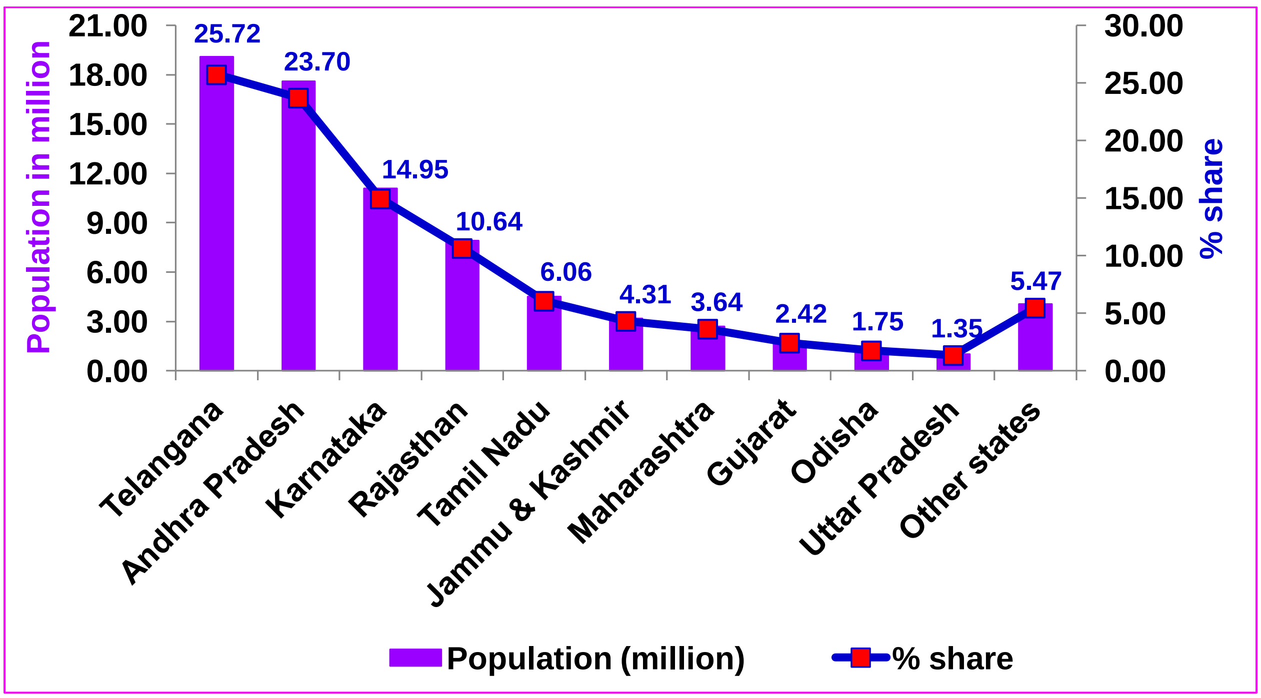

Fig. 3.1 Contribution (% share) of sheep population of different states (Livestock Census, 2019)

Table 3.2 Change in different categories of sheep population (Livestock census 2012, 2019)

Category	2012 Census (million)			2019 Census (million)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Sheep - Total	**63.78**	**1.29**	**65.07**	**72.23**	**2.03**	**74.26**	**13.25**	**57.28**	**14.13**
Exotic/Crossbred	3.63	0.15	3.78	3.93	0.16	4.09	8.21	6.06	8.12
Exotic/Crossbred Male	1.15	0.06	1.21	0.78	0.05	0.83	-31.99	-18.5	-31.32
Exotic/Crossbred Female	2.48	0.09	2.57	3.15	0.11	3.26	26.79	22.11	26.62
Indigenous/Non-Descript	60.15	1.14	61.29	68.3	1.87	70.17	13.55	64.07	14.50
Indigenous/Non-Descript Male	13.58	0.34	13.92	12.13	0.4	12.53	-10.66	18.99	-9.93
Indigenous/Non-Descript Female	46.57	0.8	47.37	56.17	1.47	57.64	20.61	83.07	21.67

Change in state-wise sheep population: There was a remarkable increase in sheep population in the three leading sheep-producing states Telangana (48.93%), Andhra Pradesh (29.61%), and Karnataka (15.31%), which together possess more than 64% of the total sheep of the country. The other two states Maharashtra and Gujarat with more than 2% share in sheep population also registered an increase in the sheep population. Rajasthan and Jammu & Kashmir, the two traditional sheep-producing states as well as Tamil Nadu recorded a decline of 12.95, 4.19, and 5.98% in the 2019 sheep population. The other important states with more than 1% share of sheep population but showed a decline in sheep population were Uttar Pradesh (27.25%), Odisha (19.10%), West Bengal (11.45%), and Himachal Pradesh (1.68%).

Table 3.3 State-wise change in sheep population during 2012-2019

		Exotic/Crossbred			Indigenous			Total sheep		
S. No.	**State/UTs**	**2012**	**2019**	**% change**	**2012**	**2019**	**% change**	**2012**	**2019**	**% change**
1	A&N Islands	0	0		0	5		0	5	
2	Andhra	-	1180626	-	-	16446345	-	13600000	17626971	29.61
3	Arunachal	1340	260	-80.60	12210	7085	-41.97	13550	7345	-45.79
4	Assam	9490	6809	-28.25	508580	325291	-36.04	518070	332100	-35.90
5	Bihar	9150	9129	-0.23	223320	204248	-8.54	232470	213377	-8.21
6	Chandigarh	10	0	-100.00	60	0	-	70	0	-100.00
7	Chhattisgarh	1800	581	-67.72	166420	179648	7.95	168220	180229	7.14
8	D&N Haveli	40	1	-97.50	90	83	-7.78	120	84	-30.00
9	Daman &	0	0		0	68		0	68	
10	Delhi	650	0	-100.00	280	278	-0.71	930	278	-70.11
11	Goa	20	654	3170.00	0	8	-	20	662	3210.00
12	Gujarat	26080	4863	-81.35	1681670	1782400	5.99	1707750	1787263	4.66
13	Haryana	51700	20053	-61.21	310920	268317	-13.70	362620	288370	-20.48
14	Himachal	305190	72821	-76.14	499680	718524	43.80	804870	791345	-1.68
15	Jammu &	2315460	1584035	-31.59	1074020	1663468	54.88	3389490	3247503	-4.19
16	Jharkhand	8380	1331	-84.12	574550	639852	11.37	582930	641183	9.99
17	Karnataka	40280	100263	148.92	9543480	10950465	14.74	9583760	11050728	15.31
18	Kerala	450	497	10.44	1000	985	-1.50	1450	1482	2.21
19	Lakshadweep	0	0	-	0	0	-	0	0	-
20	Madhya	13900	4603	-66.88	295050	319982	8.45	308950	324585	5.06
21	Maharashtra	71620	124817	74.28	2508760	2555512	1.86	2580380	2680329	3.87
22	Manipur	3950	31	-99.22	7510	5890	-21.57	11460	5921	-48.33
23	Meghalaya	600	99	-83.50	19500	15580	-20.10	20100	15679	-22.00
24	Mizoram	580	442	-23.79	70	43	-38.57	650	485	-25.38
25	Nagaland	930	161	-82.69	2910	200	-93.13	3840	361	-90.60
26	Odisha	10610	6489	-38.84	1570520	1272660	-18.97	1581130	1279149	-19.10
27	Puducherry	840	976	16.19	760	1469	93.29	1600	2445	52.81
28	Punjab	29610	11887	-59.85	98930	73673	-25.53	128530	85560	-33.43
29	Rajasthan	91060	48306	-46.95	8988640	7855551	-12.61	9079700	7903857	-12.95
30	Sikkim	1090	45	-95.87	1550	1971	27.16	2630	2016	-23.35
31	Tamil Nadu	498280	277650	-44.28	4288400	4222841	-1.53	4786680	4500491	-5.98
32	Telangana	-	486951	-	-	18576107	-	12800000	19063058	48.93
33	Tripura	280	220	-21.43	2830	5240	85.16	3110	5460	75.56
34	Uttar Pradesh	82080	51086	-37.76	1271570	933639	-26.58	1353650	984725	-27.25
35	Uttarakhand	127510	76359	-40.12	241250	208256	-13.68	368760	284615	-22.82
36	West Bengal	24780	16088	-35.08	1051340	936798	-10.89	1076120	952886	-11.45
	Total	**3781090**	**4088133**	**8.12**	**61288100**	**70172482**	**14.50**	**65069190**	**74260615**	**14.13**

The trend of sheep population: The available sheep population data from 1951 to 2019 (Fig. 3.2) showed an increasing trend over the years, but there was a decline in 1972, 1987, and 2012. The sheep population of the country was increased by almost 90% in the last 70 years and is expected to be more than double by the next census provided the population growth rate is maintained.

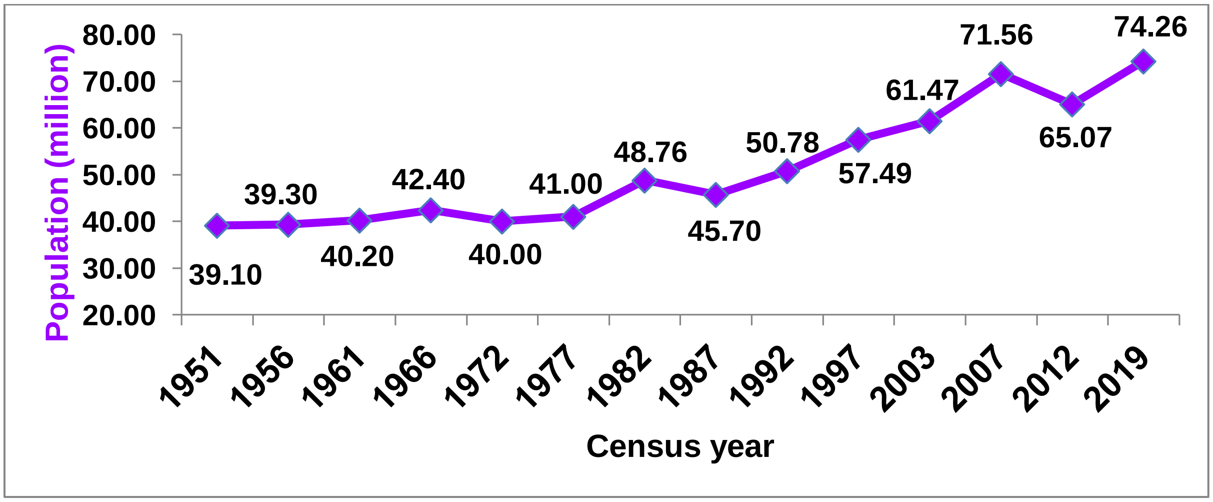

Fig. 3.2 Trend of sheep population (million) in India from 1951 to 2019

3.3 Breed status

The 18th livestock census (2007) for the 1st time recorded a breed-wise population of sheep. At that time, the population of all well-established breeds (31.98 million) constituted only 47.15% of indigenous sheep and 44.69% of the total sheep population of 71.55 million. The top three populations were of Nellore, Marwari, and Deccani breed contributing 19.44, 16.28, and 13.54%, respectively, of the total population of all the recorded breeds. However, as per the breed survey, 2013, the estimated population of 37 recognized/registered sheep breeds (pure + graded) was 36.11 million which was about 58.92% of the total population of all indigenous including non-descript sheep (61.29 million). The latest livestock census (2019) report, though mentioned in its preface that it was '*designed to capture a breed-wise number of animals*' the same has not been published. Till date, the National Bureau of Animal Genetic Resources (NBAGR), Karnal has registered 44 sheep breeds (Table 3.4).

Table 3.4 Registered sheep breeds of India (NBAGR, 2020)

S.No.	Breed	Home Tract	Accession number
1	Balangir	Odisha	INDIA_SHEEP_1500_BALANGIR_14033
2	Bellary	Karnataka	INDIA_SHEEP_0800_BELLARY_14019
3	Bhakarwal	Jammu and Kashmir	INDIA_SHEEP_0700 _BHAKARWAL_14001
4	Bonpala	Sikkim	INDIA_SHEEP_2200 _BONPALA_14034
5	Changthangi	Jammu and Kashmir	INDIA_SHEEP__0700 _CHANGTHANGI_14002
6	Chokla	Rajasthan	INDIA_SHEEP_1700 _CHOKLA_14008
7	Chhotanagpuri	Jharkhand	INDIA_SHEEP_2500 _CHOTTANAGPURI_14035
8	Coimbatore	Tamil Nadu	INDIA_SHEEP_1800 _COIMBATORE_14020
9	Deccani	Andhra Pradesh and Maharashtra	INDIA_SHEEP_0111 _DECCANI_14021
10	Gaddi	Himachal Pradesh	INDIA_SHEEP__0600 _GADDI_14003
11	Ganjam	Odisha	INDIA_SHEEP_1500 _GANJAM_14036
12	Garole	West Bengal	INDIA_SHEEP_2100 _GAROLE_14039
13	Gurez	Jammu and Kashmir	INDIA_SHEEP__0700 _GUREZ_14004
14	Hassan	Karnataka	INDIA_SHEEP_0800 _HASSAN_14022
15	Jaisalmeri	Rajasthan	INDIA_SHEEP_1700 _JAISALMERI_14009
16	Jalauni	Uttar Pradesh and Madhya Pradesh	INDIA_SHEEP_2010_JALAUNI_14010
17	Karnah	Jammu and Kashmir	INDIA_SHEEP__0700 _KARNAH_14005
18	Kenguri	Karnataka	INDIA_SHEEP_0800 _KENGURI_14023
19	Kilakarsal	Tamil Nadu	INDIA_SHEEP_1800 _KILAKARSAL_14024
20	Madras Red	Tamil Nadu	INDIA_SHEEP_1800 _MADRASRED_14025
21	Magra	Rajasthan	INDIA_SHEEP_1700 _MAGRA_14011
22	Malpura	Rajasthan	INDIA_SHEEP_1700 _MALPURA_14012
23	Mandya	Karnataka	INDIA_SHEEP_0800 _MANDYA_14026
24	Marwari	Rajasthan and Gujarat	INDIA_SHEEP_1704 _MARWARI_14013
25	Mecheri	Tamil Nadu	INDIA_SHEEP_1800 _MECHERI_14027
26	Muzaffarnagari	Uttar Pradesh and Uttarakhand	INDIA_SHEEP_2024 _MUZZAFARNAGRI_14014
27	Nali	Rajasthan	INDIA_SHEEP_170 _NALI_14015
28	Nellore	Andhra Pradesh	INDIA_SHEEP_0100 _NELLORE_14028
29	Nilgiri	Tamil Nadu	INDIA_SHEEP_1800 _NILGIRI_14029
30	Patanwadi	Gujarat	INDIA_SHEEP_0400 _PATANWADI_14016
31	Poonchi	Jammu and Kashmir	INDIA_SHEEP__0700 _POONCHI_14006
32	Pugal	Rajasthan	INDIA_SHEEP_1700 _PUGAL_14017
33	Ramnad White	Tamil Nadu	INDIA_SHEEP_1800_RAMNADWHITE_14030
34	Rampur Bushair	Himachal Pradesh	INDIA_SHEEP_0600 _RAMPURBUSHAIR_14007

35	Shahbadi	Bihar	INDIA_SHEEP_0300 _SHAHBADI_14037
36	Sonadi	Rajasthan	INDIA_SHEEP_1700_SONADI_14018
37	Tibetan	Arunachal Pradesh	INDIA_SHEEP_2300_TIBETAN_14038
38	Tiruchi Black	Tamil Nadu	INDIA_SHEEP_1800 _TIRUCHIBLACK_14031
39	Vembur	Tamil Nadu	INDIA_SHEEP_1800_VEMBUR_14032
40	Katchaikatty Black	Tamil Nadu	INDIA_SHEEP_1800 _KATCHAIKATTYBLACK_ 14040
41	Chevaadu	Tamil Nadu	INDIA_SHEEP_1800_ CHEVAADU _ 14041
42	Kendrapada	Odisha	INDIA_SHEEP_1500_ KENDRAPADA _ 14042
43	Panchali	Gujarat	INDIA_SHEEP_0400_PANCHALI_14043
44	Kajali	Punjab	INDIA_SHEEP_1600_KAJALI_14044

3.4 Other sheep genetic resources

Kheri, Hissardale, Bharat-Merino, Avishaan, Avikalin, Avivastra, Avimaans are some of the sheep genetic resources found/developed in India. Some of these breeds are not available at present.

3.5 Region and utility-wise sheep breeds

The majority of the sheep breeds found in India are of mutton type producing coarse carpet quality wool. Table 3.5 shows the sheep breeds categorization as per their utility and breeding tracts located in different agro-climatic regions of the country.

Table 3.5 Region and utility-wise important sheep breeds

North Temperate	North-Western Arid and Semi-Arid	Southern Peninsular	Eastern region
Carpet wool	**Mutton and Carpet wool**	**Mutton and Carpet wool**	**Mutton and Carpet wool**
Bhakarwal	Hissardale	Bellary	Balangir
Changthangi	Jaisalmeri	Coimbatore	Bonpala
Gaddi	Jalauni		Chhotanagpuri
Gurez	*Kheri*		Ganjam
Poonchi	Malpura		Shahbadi
Rampur - Bushair	Marwari		
	Muzaffarnagari		
	Pugal		
	Sonadi		
Apparel wool	**Carpet wool**	**Apparel wool**	**Carpet wool**
Karnah	Chokla	Nilgiri	Tibetan
Kashmir-Merino	Magra		
	Nali		

Mutton	Mutton	Mutton Prolific
Munjal	Deccani	Garole
Kajali	Hassan	Kendrapara
	Kenguri	
Mutton and Milk	Kilakarsal	
Patanwadi	Madras Red	
Panchali	Mandya	
	Mecheri	
	Nellore	
	Rammand White	
	Tiruchy Black	
	Vembur	

3.6 Population share of important breeds

Fig. 3.3 shows the breed distribution as per the last breed survey (2013), the sheep breeds occupying the top five positions in terms of their share of the total indigenous population were Nellore (19.17%), Deccani (10.15%), Marwari (6.70%), Bellari (3.79%) and Jailsalmeri (2.92%). A large proportion (41.08%) of the indigenous sheep population of the country was of non-descript type.

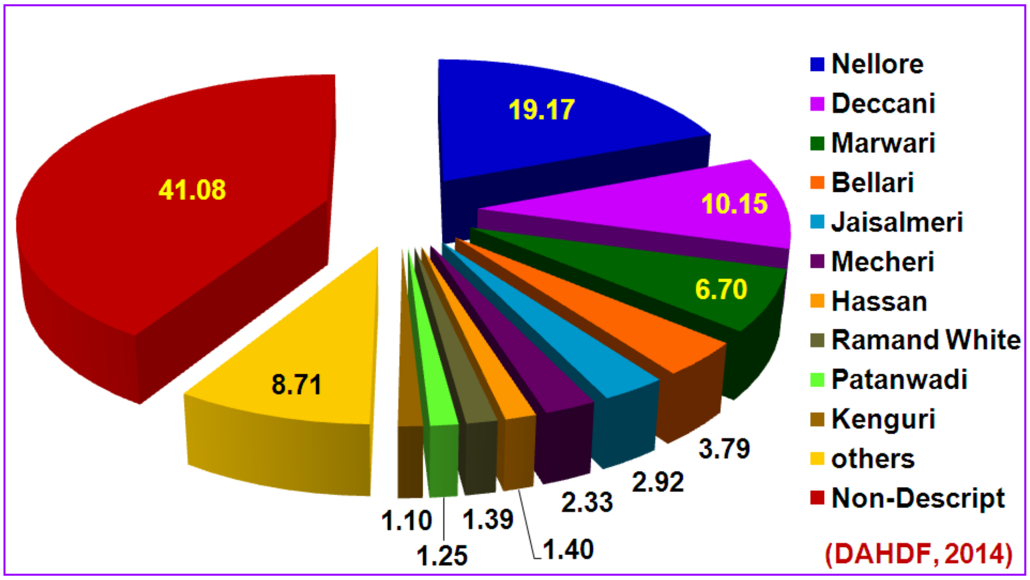

Fig. 3.3 Share (%) of important breeds to indigenous sheep population (Breed Survey, 2013)

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Chapter 4

Nutrition Approach of Sheep for Higher Wool and Mutton Production

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In India, small ruminants are maintained on scrub vegetation available on shrinking wastelands, community grazing lands, crop stubbles, and tree lopping with little or no supplementary feeding resulting in low productivity and high morbidity and mortality. The grazing resources fail to meet energy and protein requirements including that of minerals and vitamins throughout the year affecting flock health growth, production, and reproduction. Small ruminants are considered to be the most efficient transformers of low quality forage into high quality animal products. Despite being a low input production system, yet small ruminant husbandry faces several constraints being always at the receiving end in competition with other animal species and suffers more due to the feed and fodder crisis.

4.1 Nutrition for wool production

Wool is a biodegradable fibrous protein, comprising of < 20 amino acids and a small content of fat, sodium, and calcium. Nutrition bears a significant role in wool production. A balanced diet increases the diameter and length of wool fibre, hence, the requirement for wool should be included in the maintenance requirement of sheep.

4.1.1 Energy requirement

Energy is the largest and most limiting nutrient in sheep's diet. The chief energy sources in diet sheep are grains, browse, pasture, hay, and silage. Deficiency of energy reduces the diameter of wool fibre, slower wool growth, and frail spots in wool. For 100 g of dry matter digested around 2 g of wool is produced, therefore, nearly 11.3 to 13.6 kg quality feed is needed to produce 453.6 g of wool. In case of grazing sheep, 800-1500 g DM per day is adequate to obtain optimum wool production.

4.1.2 Protein requirement

Protein is the most important nutrient for wool production, as it is composed mainly of amino acids i.e. high levels of cysteine and serine. It is the costliest nutrient in sheep's diet. As rumen microbes synthesize microbial crude protein from amino acids, hence, protein quantity is more essential than quality. When an animal is fed rumen bypass there is a significant increase in the growth of wool fibers. If energy, sulfur, and nitrogen supply to the rumen are non-limiting then rumen microbial outflow will provide about 0.2 g sulfur amino acids/MJ of metabolisable energy. Sulphur containing amino acids are most important for wool production. The common protein supplements for sheep are oil cakes/meals like soybean meal, groundnut cake, mustard cake, sesame cake, cottonseed meal, and sunflower meal.

4.1.3 Mineral requirement

Minerals which influence wool production are Ca, Mn, Fe, Na, K, S, P, Mg, Co, I, Se, Cu, and Zn. Matrix of wool contains a large amount of Ca, K, Na, Zn, Cu, Mn, Fe, and Se. However, only Cu, Zn, and I affect wool growth and follicle function directly. Sulphur plays a vital role in wool production as it is present in cysteine and methionine, which are the major amino acids present in wool. Copper is responsible for maintaining the quality of wool fiber and its deficiency causes depigmentation of wool, lack of crimpness, reduced lusture, and low mechanical strength. Depigmentation of wool is due to the lower activity of Cu containing enzyme tyrosinase. The deficiency of Zn causes a distinct decline in wool growth and keratinization of wool fibre.

4.1.4 Vitamin requirement

Vitamin deficiency reduces or completely inhibits the growth of wool fiber by reducing feed intake which impairs nutrient supply to wool follicles. Vitamin B1 (Thiamine), a cofactor for transketolase enzyme is required for HMP shunt during energy metabolism. Vitamin B6 (Pyridoxine) is required for a trans-sulphuration reaction for converting methionine to cysteine. Biotin is involved in wool follicle function. However, in case of adult sheep, B-group vitamins are synthesized by the rumen microbes hence, they are not likely to experience B vitamin deficiencies if rumen functioning remains adequate. In case of fat-soluble vitamins, A and D3 are directly involved with follicle function, due to the presence of specific receptors in the follicles.

4.2 Feeding for optimum mutton production

Proper nutrition of sheep/goats during active growth phase and also in pregnancy and lactation stages are utmost important to achieve desirable production. Grazing of flocks on pasture followed by supplementary feeding is most suitable and economic production in sheep. Lambs for fattening purposes can be maintained on stall feeding on complete ration consisting of roughage and concentrate to attain desirable slaughter weights at early age with desirable meat yield and quality. Table 4.1 shows the feeding schedule to obtain optimum mutton production.

Table 4.1 Feeding schedule for different categories of sheep

Categories	**Colostrum**	**Milk**	**Concentrate feed**	**Roughage**	
				Dry	**Green**
New born (0-5 day)	1/10 of BW thrice in a day	-	-	-	-
Suckling		1/10 of BW during 6-30 days,1/15 during 31-60 days and 1/20 during 61-90days	Creep ration from 15 days	Legume hay or tree leaves or green fodder from 15 day	-
Weaners	-	-	Start with 100-150g conc. mix and gradually increased to 250-300g daily	200-300 g in initial age and increased to 400-500g	
Hogget	-	-	200-300g conc. mix	400-500g good quality	500g green fodder
Adult females	-	-		1.00kg dry fodder (From grazing land)	500g green fodder
Pregnant	-	-	200-300g during last 60 days	500g dry fodder (From grazing land)	500g green fodder
Lactating	-	-	300g during first 90 days	700g dry fodder (From grazing land)	1.0kg green fodder
Adult males	-	-	200-300g conc. mix during breeding season	1.0kg dry fodder (From grazing land)	500g green fodder

4.2.1 Pre weaning

Lambs/kids after birth should be allowed to suckle their dams within 2-3 hours of birth for better absorption of colostrum. It is rich in immunoglobulin and readily absorbed from the intestine 2-3 hours after birth. The lambs should be kept in an enclosure with their dams during the first 3-5 days so that they could suckle colostrum in sufficient quantity. Thereafter the milk should be fed at the rate of 300-400 g daily in two feeds. The creep ration should be prepared by mixing maize (40), wheat bran (10), de-oiled rice bran (13), groundnut cake (30), molasses (5), mineral mixture (2), and common salt (1) in parts. Vitamin A, $B_{2,}$ and D_3 mixture at the rate of 20 g per quintal should also be added to the creep mixture. Creep mixture rich protein-energy (17-18% DCP and 73-75% TDN) and highly palatable should be started feeding on first 2-3 weeks to suckling lambs beside 300-500 g of legume hay and 2-3 hours of grazing on improved pasture. Creep ration should be prepared and supplemented to lambs at the rate of 150-200 g daily for achieving desirable growth.

4.2.2 Post-weaning

Maximum income from sheep rearing is obtained from the sale of lambs for mutton. The primary aim of broiler lamb production is to achieve early slaughter weights in lambs. In general, lambs are sold for meat at an age of 3 to 4 months when they reach 12 to 14 kg of slaughter weight. For medium-sized sheep breeds, a mature weight of 30 kg is attained at 12 months of age. These weights can be increased in 135 to 150 days of age with intensive feeding systems. Lambs are grazed on improved pasture and offered grains or concentrate mixture at the rate of 300 g during evening hours after grazing. In an intensive system, lambs are stall-fed on a complete ration consisting of concentrate mixture and roughage in 50:50 or 60:40 ratios. They attained 30-33 kg body weight at six months of age. The feed should contain dried leaves (50), barley (20), maize (14), mustard cake (14), mineral mixture (1), and common salt (1) parts.

4.2.3 Adult female

Feeding of female hogget is crucial for attaining earlier maturity and body weights for breeding. Hoggets are grazed on improved pasture and offered concentrate mixture at the rate of 300 g daily. The supplementation of concentrate mixture should be adjusted depending upon forage supply from grazing land. Hogget should attain a bodyweight of 28-30 kg at 1 year of age. Male hogget should be raised separately for breeding purposes on grazing with concentrate supplementation at the rate of 300 g daily.

4.2.4 Flushing of breeding stock

Provision of extra ration in form of concentrate mixture at the rate of 250-300 g daily 3-4 weeks before the breeding season brings the animals in estrus at a time and also improves the prolificacy and conception rate. The reproduction of animals is triggered by supplementation of concentrate mixture particularly in flocks maintained on a low plane of nutrition. In field flocks of dry regions, the pods of acacia species and Khejri rich in protein are widely used during the summer months to induce estrus in sheep and goats.

4.2.5 Pregnant ewe

The sheep during the last quarter of pregnancy require extra feed for the rapid growth of the foetus in the womb as well as nourishment of their own body. A concentrate mixture containing maize (30), groundnut cake (20), de-oiled rice bran (23), wheat bran (20), molasses (5), mineral mixture (1), and common salt (1) parts is prepared. Generally, 300 g of concentrate mixture is supplemented in addition to grazing for 8-10 hours on improved pasture.

4.2.6 Lactating ewe

Although the milk yield of indigenous sheep is low and ranges between 500-800 g daily still this yield is not maintained on grazing alone. Some kind of supplementation either in the form of tree leaves or concentrate mixture should be offered for milk yield. In organized farms, a concentrate mixture of 300 g daily after grazing is recommended. The physical composition of the concentrate mixture for lactating sheep remains similar to that of pregnant sheep.

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Chapter 5

Sheep Milk: Production and Value Addition

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5.1 Introduction

Livestock is the fastest growing agricultural subsector in developing countries. This growth is driven by a rapidly growing population, demand for animal products, and an increase in purchasing power of people. Nowadays, people need quality products rather than quantity as they are becoming more and more health cautious with time. Milk is one of the most produced animal products which is valued worldwide. Milk can be obtained primarily from cows, buffalo, sheep, and goats. Sheep milk is much appreciated internationally for its nutritional and health benefits particularly for a special class of people (old age, arthritic patient, and heart disease people). Sheep in Indian society is used for meat and wool. Sheep milk production and utilization in India are mainly limited to shepherds and their family members. The major sheep milk producers are mainly Asia, Europe, and Africa. Sheep breeds available in Asia (except China and Turkey) are mainly low producers. The sheep breeds found near the black sea and medditerian region are dairy type. Well-known milk breeds of sheep are Eastern Friesian of Germany, Lacaune of France, and Awassi of the Middle East. These elite sheep breeds are generally exported from their native tracts for upgrading the productive status of native breeds. Crossbreeding alone cannot bring high productive potential.

Sheep in most of the world are reared mainly in harsh climatic conditions like deserts and mountains. Here they are raised under an extensive system of management with poor quality fodder and grazing under severe environmental stress. Therefore, even after crossbreeding also milk yield of these animals does not improve a lot (Haenlein, 2007). Apart from superior feeding management pedigree and performance record are also essential for upgrading the native breeds for milk production. Table 5.1 shows the milk production potential of world-famous dairy-type sheep breeds. Most of them have a 1.5 kg yield per day. The milk yield of the Indian sheep breed is Patanwadi which has 90 days of lactation period and an average daily milk yield of 800 g. Therefore, the potential of our native breeds can be best judged at an improved feeding condition.

Table 5.1 Milk production potential of world-famous dairy type sheep breeds

Breed	Lactation length (days)	Milk yield (kg)	Avg. daily milk yield (kg)
Eastern Friesian	300	632	2.10
Israeli Awassi	270	495	1.83
Lacaune	165	270	1.63

Source: Park and Haenlein, 2006

5.2 Nutritional facts of sheep milk

Sheep milk is highly nutritious and is considered an excellent source of human nutrition. Its calorie content, fat content and essential vitamin and mineral content are almost double that of a cow. Like goat milk, it is naturally homogenized; so can be appreciated by young children. Adequacy in calcium (about 36% more calcium than cow milk) and magnesium make it an ideal food for elderly people. Sheep milk has the highest casein and whey protein compared to other ruminants. Apart from nutritional advantages, sheep milk has several technological advantages. Sheep milk has a higher total solid which made it a suitable base material for product formulation like yogurt, cheese, and ghee, etc. Reports also say that the yield of cheese and curd is highest in sheep among all ruminants per volume of milk. The dense network of proteins and firmness of milk gel makes it perfect food milk for yogurt formulation. Milk yield is inversely related to milk fat content. Sheep although produces less milk but the milk fat content is double of a cow. Milk fatty acid profiling revealed the abundance of beneficial fatty acids like short and medium-chain fatty acid, unsaturated fatty acid, and CLA in sheep milk. Therefore, sheep milk is worldwide used for skincare product formulations like soap, cream, lotion, etc.

China is excelling these days in sheep milk production. They use sheep milk for organic milk and infant formulations (Pulina et al., 2018). India is the highest producer of milk; therefore, the demand for high yielders is more here. Table 5.2 shows the nutrient denseness of sheep milk over cow milk.

Table 5.2 The richness of sheep milk over cow milk

Milk composition	Cow milk	Sheep milk
Water%	85-87	79-82
Protein%	3.2-3.8	5.6-6.7
Fat %	3.7-4.4	6.9-8.6
Ash %	0.7-0.8	0.9-1.1
Lactose %	4.8-4.9	4.3-4.8
SNF%	8.7-10.6	10.8-12.6
Total Solid %	12.4-15.0	17.4-21.2
Vitamin A(µg /100ml)	34	43.5
Vitamin E(µg /100ml)	30	15
Ascorbic acid (mg/100ml)	1.6	4
Thiamin(µg /100ml)	42	100
Riboflavin (µg /100ml)	157	400
Vitamin B_6(µg /100ml)	48	70
Nicotinic Acid (µg /100ml)	85	500
Pantothenic Acid (µg /100ml)	350	400
Biotin (µg /100ml)	3.5	7
Folic Acid(µg /100ml)	0.23	5
Calcium (mg/ 100 ml)	112-123	159-249
Phosphorous (mg/ 100 ml)	59-119	124-175
Potassium (mg/ 100 ml)	106-163	94-162
Magnesium (mg/ 100 ml)	7-12	16-25
Sodium (mg/ 100 ml)	58	30-75
Chloride (mg/ 100 ml)	100-119	99-160
Iron (mg/ 100 ml)	0.03-0.10	0.08-0.10
Zinc (mg/ 100 ml)	0.30-0.55	0.40-0.90
Copper (mg/ 100 ml)	0.01-0.08	0.03-0.05

(Source: Kula, 2016; Barreto et al., 2019)

5.3 Value addition in sheep milk

Value addition means adding value to the term i.e. in terms of quality, functionality, or shelf life. It also broadens the consumer base. Milk is a highly perishable food, so value addition increases its shelf-life like infant formulas from milk. Value-addition in sheep milk can boost revenue. It can be converted to consumable or non-consumable products. Consumable products from sheep milk include cheese, yogurt, ice-cream, kulfi, paneer, etc. which makes milk more palatable. Non-consumable products include soaps, shampoo, lotions, lip balms, etc. These are mainly skincare products as sheep milk is rich in beneficial fats and essential minerals and vitamins.

Sheep do not have milk production potential similar to cow and buffalo, but sheep milk can be stored without hindering its quality. For maintaining protein stability for more than 12 months sheep milk should be rapidly frozen and stored below -20^0 C. Internationally sheep milk is not popular in its native form but famous for value-added product forms like cheese, yogurt, ice cream, infant formula, etc. Feta, Roquefort, Manchego, Ricotta, and Pecorino Romano are some well-known cheeses developed from sheep milk in different countries. Sheep milk cheese is not only delicious but its appearance, texture, and nutrient-dense quality make it a world-famous value-added product. As sheep milk casein is bound to calcium, so there is no need of adding $CaCl_2$ to milk for cheese preparation. Italy (36%) and France (20%) are leading sheep milk cheese exporters.

Sheep milk ice cream needs no more addition of fat or protein. As sheep milk is naturally homogenized, no more homogenization is needed in ice-cream preparation from sheep milk. Due to higher protein and fat content, several probiotics that can survive in cold temperatures can safely be delivered to gastrointestinal sites by sheep milk ice creams (Rasika et al., 2020). Concentrated form sheep milk fat can be obtained in butter, ghee, paneer and cheese formulations while fat free milk can be obtained in form of skim milk. Sheep milk is also a perfect raw material for sweets preparation.

Value addition not only increases shelf life and quality of milk rather it adds functional quality to milk. Sheep milk bio-peptides are gaining attention these days by most health cautious consumers as it has anti-aging property, anti-microbial property, anti-oxidant nature, anti-hypertensive qualities, etc. Nowadays along with a nutrition interest, medical and therapeutic industries are also interested in sheep milk.

5.4 Conclusion

Sheep milk is getting consumer acceptance and satisfaction and now creating its market. Sheep milk has a positive effect on bone growth, skin moisturizing, blood vascular system, cardiac health, cognitive development, and other special illnesses. The significant impact of sheep milk on human health importance is the major area of focus today. Milk is now not only a source of nutrition but also a vehicle for good health. Over the coming decades, urbanization, disease risks, climate change, income growth will show huge growth. Under that scenario, sheep milk will play a crucial role to meet the nutritional as well as health security of the global population.

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Chapter 6

Sheep Health: Care and Management

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6.1 Introduction

The quality and quantity of sheep produce are not independent of sheep health. Like that of all other domestic animals, in sheep also, health is a priority for sustained production and profit. "Healthy sheep" would be an asset that can multiply. "Sick sheep" turns out to be a liability that too can multiply. "Healthy" sheep implies animals that are reasonably free from illness and perform better in their reproduction. Of course, profit in a sheep farm depends upon the production of marketable lambs with optimal body weight. The average daily gain in body weight should be corresponding to the amount of feed provided to them.

Understanding the behavior of sheep, by and large, simplifies health management. Sheep prefers to move together in flocks. This flocking attitude has been a means of deterrence from predators. Although domesticated in prehistoric times, sheep still retain the flocking tendency. Interestingly, a sick sheep stands alone. This behavioural change is a point of interest to sheep keepers. Even in the intensive system of rearing, lonely and lagging sheep need attention. Sheep suffer from many diseases and disorders which do not have an infectious origin. As far as sheep practice is concerned, these diseases do not attract clinical attention as they are rare and they get noticed only at the end-stage.

Herd medicine is the preventive veterinary medicine that is suitable for sheep. Similar to poultry birds, sheep maintain close contact hence spread of disease is rapid. At the same time, they share similar management and materials. Individual animal treatment is essential in high-value animals and ethical management situations. The occurrence of a case of thiamine deficiency in a flock does not mean an isolated or sporadic individual case but that case could be an indicator of sub-clinically prevailing deficiency in the flock. Hence, sheep diseases are essential to be seen as an issue of flock though they are not always.

For example, a flock that has been taken for grazing and overstayed in a sandy landscape may exhibit signs of cobalt deficiency. It means that epidemiological information on the recent movement of the flock is a matter of diagnostic importance. Proper and complete history taking would help the disease investigator to zero in on the correct cause of illness. Similarly, health management starts at purchase. Mingling different flocks from different locations, and mingling different age groups, are the major determining factors in the transmission of devastating infections like PPR. Hence it is always advisable to avoid mixing flocks. Apart from this, purchases should be made from a known source with proper preventive health protocol.

When the preventive health measures are considered for discussion, it is quite usual to bother only the major infectious diseases. But largely ignored non-infectious / metabolic / deficiency diseases can also detrimentally affect the farm business. Preventive health measures are not limited only to vaccination. Even, timely provision of water to thirsty animals would reduce the incidence of climatic stress, salt poisoning, and sunstroke. Deworming the sheep that are taken for grazing in a pasture contaminated with haemonchus is also a major preventive measure.

However, some of the metabolic diseases or production diseases like ovine pregnancy toxemia are very important as they may emerge as flock problems. Metabolic diseases may arise out of defective nutritional management. Similarly, various toxicities may conspicuously challenge the farm economy. Plant and farm chemical toxicities can play havoc in sheep production systems. Sheep, in an extensive system, is highly susceptible to plant toxins. Although toxic plants are ubiquitous, the incidence of toxicity is determined by the ingested quantity and frequency. Ingestion of large volumes in a short period is the major and consistent determinant for plant toxicities. Periods of drought, newer grasslands, erroneous feed mixing, overzealous supplementation and inappropriate exchange of mineral supplement intended for other species are the common circumstances which predispose sheep for toxicities. For example, sheep are highly susceptible to copper toxicity; the use of the mineral supplement in sheep that are meant for cattle may lead to copper toxicity.

6.2 Microminerals and sheep

Copper, cobalt, selenium, and iodine are the major deficiencies in sheep that have clinical significance. Other deficiencies (Zn, Fe, Mn) are also recorded but rare. Depletion, deficiency, dysfunction, and disorder are the four phases of any deficiency syndrome. Research indicates "responsiveness" to a specific supplementation is the right indicator for diagnosis that deficiency. Many times, laboratory analysis of animal samples and forage samples are not conclusive. Even in pasture samples, seasonal variations, mineral–mineral interaction, intake variation, soil management activities, etc. can heavily influence the mineral composition. Hence it is unreliable.

Similarly, as pregnant and lactating ewes have higher nutritional demand, supplementation of microminerals is very essential. In pregnant ewes, microminerals supplementation would ensure the birth of a healthy lamb and an increased survival rate. This does not mean that ad libitum supplementation of micronutrients. Some of the minerals are too toxic even in small doses. For example, sheep are highly susceptible to copper toxicity. However, copper should be supplemented with utmost care. The birth process severs the dependency of offspring from the dam for thermoregulation. Colostrum is the first fuel for independent thermoregulation in mammals. An elaborate review on ewe nutrition impacting colostrum production is available. A lamb, in its first 18 hours of life, requires 200 ml of colostrum/kg of birth weight. This requirement is variable according to the environmental condition at the time of lambing. The said quantity is optimal in mild weather conditions. But rain and windy conditions increase the requirement by 50% more.

6.3 Preventive health care of pregnant ewes

Pregnant ewe nutrition has now been given due importance in the intensive sheep production system. Feed quality and quantity are modified for pregnant ewes. Nowadays, feeding management is streamlined in such a way that BCS remains at a desirable level. To avoid ovine pregnancy toxaemia and vaginal prolapse associated with undernourishment or overfeeding, BCS-adjusted feeding is now widely practiced. Cobalt supplementation as an intra-ruminal bolus to pregnant ewe is effective. The lambs born were very active in the first three days of life than the lambs born to cobalt deficient ewes.

Lamb loss occurs primarily at the lambing. Dystocia or difficulty in delivery is the most common cause of lamb loss. Lambs of poor body condition, poor glycogen reserve succumbs to inclement weather. Lambs born in the winter season may not have enough energy reserve to fight out the chill. Deprivation of colostrum due to maternal reasons like mismothering, agalactia, mastitis, death of ewe, etc. are other causes of lamb loss. Usually, starvation, mismothering, and exposure to inclement weather conditions contribute altogether to the death of lambs. In the second week of age, respiratory infection and gastrointestinal diseases are prevalent in lambs. Another aspect of lamb survival is maternal behavior. The establishment of ewe-lamb bonding is a function of hormonal, olfactory, nutritional factors working in coordination. Extra colostrum in the gut of lamb is increasing the lamb's activity to recognize its mother and improves ewe-lamb bonding.

Among the neonatal behavior, teat-seeking behavior is solely responsible for lamb survival rate as ewe's udder is the only source of nutrition in the first week of life. A maternal behavior score has been devised and it is the distance a ewe retreats from a shepherd restraining her lambs in the first 24 hours after birth. Lambs born to ewes with high MBS have a higher survival rate. When we consider the ewe nutrition, even a moderate level of under-nutrition can compromise the lamb survival rate. Birth weight has been a vital determinant for lamb's survival. A widely accepted fact is that maternal nutrition influences the offspring's birth weight.

Six weeks before lambing, a multicomponent sheep clostridial vaccine is highly recommended. Enterotoxemias, especially pulpy kidney disease (PKD), caused by *Clostridium perfringens* type D is an economically most important disease in sheep. In an intensive production system, enterotoxemia plays havoc. Lambs that are stall-fed and over-nourished are highly susceptible to PKD. Lambing pen hygiene has been emphasized nowadays because unhygienic lambing pen may predispose the newborn lamb to watery mouth disease, caused by *E.coli.*

Enzootic abortion in ewes (EAE) caused by chlamydia is not at all ignorable. Major sheep rearing nations have started vaccinating their sheep against this infection. Apart from other infectious causes of abortion, selenium deficiency can also cause abortion, stillbirth, and weak lambs. In a free-range system, natural vegetation may also contain few potent abortifacient plants.

6.4 Vaccination

Ideally, vaccines should confer protection against a specific pathogen by providing a lasting and strong immune response. Active immunization sometimes, not only protects the recipient but also its offspring by passive colostral transfer of immunoglobulin. At the same time, vaccines are preferred to be free from any major adverse reactions. Vaccine reactions like swelling at the site of administration are acceptable to a certain extent. Stability and ease of administration are the other qualities expected in a good quality vaccine.

In major sheep rearing nations, multicomponent sheep clostridial vaccines, Orf vaccine, sheep pox vaccine, Bluetongue vaccine, PPR vaccine, FMD vaccine, Chlamydial vaccine are widely in use. In India, BT, FMD, PPR and Pox, ET, HS vaccines are available. Commonly, vaccine failure is associated with improper storage, improper administration, unfit/sick animal, multi-pharmacy (concurrent administration of antibiotics, anti-inflammatory drugs, etc), contamination, wrong selection of vaccine, inherently poor immune response in some animals. All these factors have to be taken into account while assessing any vaccine's efficacy.

6.5 Prevention against external parasites

Dipping has been a part of healthcare in sheep because sheep and goats have always been suitable hosts for seasonal and perennial external parasites. Although there are effective treatment and control measures, sheep farmers often complain that their animals are getting re-infected even after treatment. Severe infestation with Tick, fleas, and mites can cause anemia and production loss. Even if other management measures like feeding, breeding, and nutritional supplementation are practiced as per standard, flock performance is poor in the ectoparasite-infested flock. Besides these direct effects, Ticks can spread diseases like louping ill and tick fever. Apart from these, many hemoprotozoan like babesia, theileria, are also transmitted to sheep by these vectors. Infestation by mites is called scabies/mange. These microscopic insects are capable of damaging the skin and become a common cause of weight loss in sheep. Lush growth of pasture after monsoon is conducive for tick reproduction and questing for the host. Hence dipping is scheduled according to the increase in the tick population.

6.6 Plant poisoning prevention

In all incidences of plant toxicity, a principle can be applied quite commonly i.e. "Too much; Too fast". It implies that even if the toxin content is less, eating too fast and too large a quantity may end in plant toxicity. As a general rule, animals should be removed from the suspected pasture. Marking the toxic pasture and fencing off from further grazing should be the next course of action. In all episodes of plant poisoning, correct identification of the plant and the toxic principle is necessary. If a specific antidote is available (e. g.: methylene blue for nitrates, hypo for cyanide toxicity, di-calcium phosphate for oxalate toxicity), there should not be any delay in administering them. As an emergency measure, drenching 50-60 g of activated charcoal (as slurry) per sheep is sufficient to adsorb and eliminate the toxin. Most of the organic / plant poisonings can be managed with activated charcoal. Providing good quality forage can also dilute the ingested toxin. Based on the symptoms exhibited, palliative therapy is advisable.

In conclusion, the flock health approach with strategic and updated scientific interventions would be the most appropriate way of managing health in sheep. Newer and emerging diseases warrant the adoption of newer prevention and control methods.

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Chapter 7

Ante-Mortem and Post-Mortem Examination of Sheep

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7.1 Introduction

Meat has been a very important source of the human diet. Being nutrient-dense food, it provides suitable conditions for the growth and proliferation of microorganisms. The microbes are detrimental due to the reduction of shelf life of meat and meat products and meat if it is produced in unhygienic conditions from diseased animals, may transmit the diseases. Therefore, hygienic and wholesome meat production and maintenance of high standards of food safety are the need of an hour. Clean meat production begins right from the animal farm and continues till it reaches to consumer. When animals reach from farm/market to slaughterhouse, the animals should be given proper rest to cope up with transportation stress; as stress might harm meat quality.

7.2 Ante-mortem inspection

Ante-mortem inspection (AMI) should be conducted in the lairage or receiving area. It should be conducted within 24 hrs before slaughter preferably in daylight. If the slaughter is postponed, the animals should be subjected to another inspection immediately before slaughter. AMI be carried out by a qualified Veterinarian assisted by an inspector who can assist in collecting the preliminary data from the animal. Simple clinical equipment and some restraining equipment are required during AMI.

As shown in Fig. 7.1, AMI has three main purposes: to safeguard public health, animal health, and animal welfare.

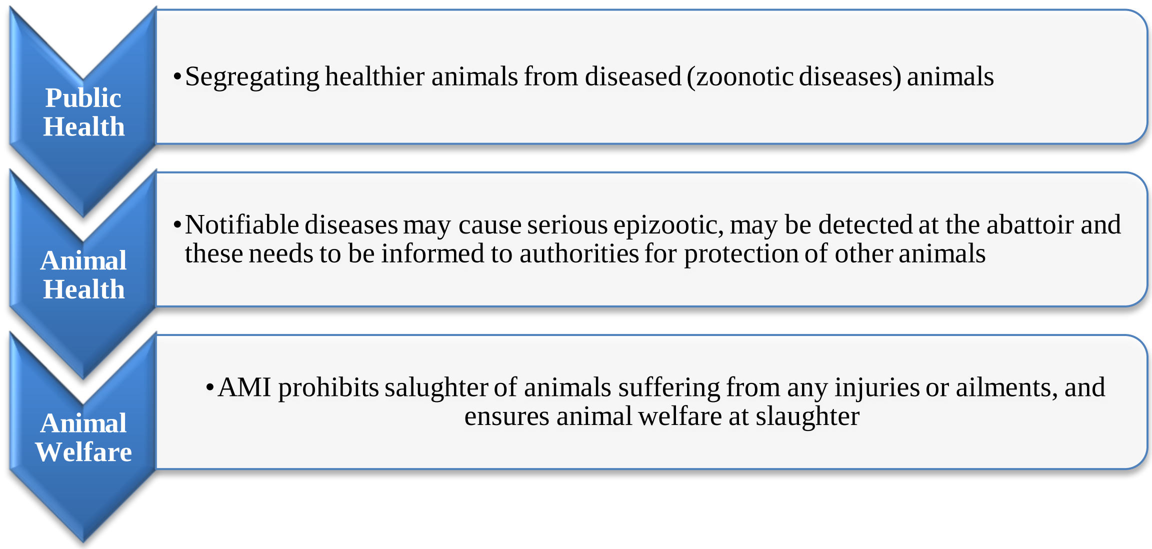

Fig 7.1 Aims of ante-mortem inspection

The main objectives of AMI are

1. Wholesome meat production from normal rested animals.
2. Separate diseased and suspected animals for further detailed inspection.
3. To prevent the spread of communicable diseases, reduce contamination of slaughter premises/cleaning floor by separating dirty animals and condemning the diseased animals
4. To facilitate and provide additional information for post-mortem inspection.
5. Prevent suffering of injured/animals in acute pain by emergency slaughter
6. Animals and food handlers are protected against zoonoses.
7. Protect public health through consumption of unhealthy meat.
8. Certain diseases (Rabies, Listeriosis, heavy metal poisoning) are detected during ante-mortem inspection only

7.3 Procedure of AMI

When the animal reaches abattoir premises, the animal identification should be carried out and the details regarding the source of animals or origin should be documented. The animal should be observed, both while resting and in motion from both sides. The observation should include general behavior of the animal, appearance, posture and gait, nutritional status, cleanliness, signs of diseases, and abnormalities.

Some of the abnormalities, which are to be checked on AMI, include.

1. **Respiration:** Animals with abnormal respiration frequency should be isolated as a suspect. In sheep and goats, abdominal respiration is usual.
2. **Behavior:** It helps to assess the duration and severity of the disease. Normally, healthy animals respond quickly to the stimulus. Diseased/abnormal animals isolate themselves from the rest of the flock. In a few animals either anxiety or depression is observed. Some abnormal behaviours observed in sheep include circular walking, head pushing against walls, aggression, etc.
3. **Gait:** Gait reflects locomotor processes and the pattern of the animal during motion. Abnormal gait is commonly linked with leg, chest, or abdominal pain or is an indication of nervous disease. Slow wobble Gait: *All febrile and Septicaemic diseases;* Walking in circles: *Coenurosis (gid), otitis, Listeriosis;* High stepping movement with the rigidity of limbs: *Tetanus;* Stumbling gait: *Encephalitis; narcotic poisoning;* Stiff gait with brisket edema: *Traumatic Pericarditis*.
4. **Posture:** Posture is an anatomical pattern of an animal in a stationary condition. Abnormality in posture is observed as tucked up abdomen or the animal may stand with an extended head and stretch on the feet. Frog like posture: *Bilateral hip dysplasia & Obturator nerve paralysis*; Shifting of weight on one leg: *Laminitis;* Dog sitting posture and Kicking of Belly: *Acute Gastric disorder;* Animal stiff with four legs abducted with locked jaw and rigid ears: *Tetanus;* Star Gazing posture (Sheep): *Gid/ Poliencephalomalacia;* Frog sitting posture (Sheep/ Goat): *Parturient hypocalcaemia.*
5. **Appearance:** Healthy animals generally have bright eyes, alert and responsive ears, glossy skin, and a moist muzzle. Skin gives a good indication of the general appearance of the animal. In healthy animals, it's glossy with a smooth hair coat. The condition of the skin gives a good indication of the level of hydration. Rough and starring hairs- Endo and Ectoparasite, Mineral deficiencies; Abnormal Skin lesions- Bruising, tear- due to improper handling on-farm and during transit; Emaciation and Cachexia- Chronic wasting diseases (Tuberculosis, heavy parasitism).
6. **Structure:** the animal should be observed from both the front and rear sides. Abnormalities in the structure are swelling (abscesses); enlarged joints; umbilical swelling; enlarged jaw; bloated abdomen.

7. **Discharges or protrusions:** secretions and excretions from natural orifices (ocular, nasal) should be carefully observed. Discharges from the nose, excessive salivation- FMD, mucosal disease; Ocular discharge: Blue tongue; Prolapsed rectum or uterus- Post parturient complications, abortions (brucellosis); Growth on the eye and bloody diarrhea.
8. **Abnormal odor:** It is very difficult to detect on routine Ante-mortem inspection. The foul odor may be due to discharges or due to some abnormality in the animal digestive physiology. Purulent exudates with medicinal odor – abscess; Putrefactive exudates- putrid rhinitis, putrid bronchitis.

Once ante-mortem examination is done, judgments are given regarding the suitability of animals for slaughter.

1. Passed for slaughter: Healthy animals
2. Suspect/detained: Animals suffering from certain conditions/abnormalities.
3. Unfit for slaughter: include immature animals; pregnant animals; recent parturition; animals with symptoms of infectious/contagious diseases.

Diseases/ conditions in which sheep are unfit for slaughter: Foot and Mouth Disease (FMD), Anthrax, Black Quarter, Rabies, Emaciation, Salmonellosis, Tetanus, acute Listeriosis, Selenium poisoning, and Tuberculosis

Diseases/ conditions in which sheep are retained as suspect: Actinomycosis, Actinobacillosis, Localized Caseous, Lymphadenitis, Pneumonia, Sheep scab, Mastitis

7.4 Post-mortem Inspection

Post-mortem inspection (PMI) is a systematic examination of carcasses and their offals immediately after slaughter in the adequate light by a qualified person to provide wholesome meat to the consumers. A routine post mortem inspection should be carried out as soon as possible after carcass dressing is completed since the carcass sets rapidly. If the inspection is delayed the examination of carcass lymph nodes becomes difficult. PMI of the carcass and viscera, head of the corresponding animal should be carried out on a viscera table, offal conveyor, or belt. Each inspection point should have a uniform and sufficient light of 540 lux (50-foot candles) intensity. Continuous supply of hot and cold water should be ensured at the inspection point. In one day (8hrs), 400 sheep can be effectively examined by a meat inspector. Post-mortem inspection should provide necessary information for the scientific evaluation of pathological lesions pertinent to the wholesomeness of the meat.

7.5 Post-mortem inspection procedure

PMI should be carried out systematically and hygienically and care being taken to avoid contamination. The procedure generally includes the following steps:

a. Gross visual examination
b. Palpation of tissues and organs
c. Making incisions
d. Use of inspector's sense of smell and taste.
e. Laboratory test(s).

There are normally three main inspection points in an abattoir:

Head: It includes the examination of the exterior of the tongue, the palate or oral cavity, throat lymph nodes (retropharyngeal, sub-maxillary, and parotid). The cheek muscles are inspected on either side.

Viscera: All offals and associated lymph nodes are examined. In any abnormal condition, the organs are incised carefully to prevent further contamination.

Carcass: Every carcass should be examined for nutritional status, bruises or injuries, oedema (hydrothorax, ascitis, and brisket edema), the efficiency of bleeding, swelling, or deformities of bones or musculature, abnormal odour (abscess). The pleura and peritoneum are inspected. Look for the size, colour, and consistency of the lymph nodes. View, palpate, and if necessary, incise the carcass lymph nodes.

The carcass and offals are retained for veterinary disposition during post-mortem inspection: Caseous lymphadenitis, Nodular worms (Oesophagostomum species), Cysticercusovis, Sarcosporidiosis sp, Neoplasia, tumors, Pneumonia, Nephritis, Abscesses, Arthritis, and Emaciation.

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Chapter 8

Technology and Innovations for Sheep Meat Production and Value Addition

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8.1 Introduction

Sheep husbandry is a source of livelihood and nutritional security for resource-poor, landless, small, and marginal farmers. Sheep's main products are meat, wool, milk, skin, and manure besides moving banks for farmers. Sheep is considered as a future animal for rural prosperity under the scenario of climatic conditions and grazing resources because of their better adaptability to a wide range of climate conditions and better efficiency of poor feed resource utilization. The majority of sheep flocks are maintained on a common property resource by employing family members with little capital, resources, and traditional knowledge (Shinde and Mahanta 2020).

India is a rich depository of sheep genetic resource with 44 well-defined breeds and non-descript animals, well adapted to different agro-climatic conditions of the country. Nowadays demand for mutton in southern states and other parts of the country is increasing rapidly with increasing population and living standards. On the other hand, grazing resources which are major sources of forage to sheep are declining. With the existing production system on natural resources, the demand for meat cannot be met; there is a need to introduce newer technology to accelerate mutton production in areas of nutrition, breed improvement, reproduction, and health cover. Most of the meat is sold in the market as fresh meat; a very little amount of meat (hardly 4%) is being sold as processed meat into different products. Now the demand for functional and diversified meat products is coming up in big cities. Healthy, functional ready to eat, heat, and serve meat products are well in demand in the country. There is a need to organize the sheep and meat production sector to reduce the cost of production and encourage the value addition of meat into diversified meat products for consumers.

As per the recent 20th livestock census, India has 74.26 million sheep, contribute 678 million kg of mutton, 40.26 million kg of wool (BAHS 2019), 31 million kg manure, and 41.6

million pieces of skin. About 100 million kg of wool is imported to meet the demand of woolen industries. Carpets worth 10000 cores are exported from the country. Sheep husbandry employs 6 million people in various sectors of sheep production, wool processing, live animal trading, and meat processing, etc.

The top states with sheep populations are Telangana (19.1 million), Andhra Pradesh (17.6 million), Karnataka (11.1 million), and Rajasthan (7.9 million). As per the National Bureau of Animal Genetic Resources (NBGAR), Karnal, India has diverse sheep germplasm with 44 breeds. In the country, there are 41.08% nondescript sheep. Major sheep breeds are Nellore, Deccani, Marwari, Bellari, Jaisalmeri, Mecheri, Hassan, Ramnad White, Patanwadi, and Kenguri which contributes 19.17, 10.15, 6.70, 3.79, 2.92, 2.33, 1.40, 1.39, 1.25, 1.10 %, respectively of the total sheep population and remaining sheep breeds contribute < 1% (DHADF, 2016). 70% of sheep found in southern regions and mostly produce meat, 15% of sheep found in Rajasthan, Gujarat and Uttar Pradesh produce carpet type wool and meat and only 6% of sheep found in Jammu & Kashmir, Himachal Pradesh and Uttrakhand produce fine wool and meat.

8.2 Newer technology intervention for enhancing mutton production

A good number of newer technologies have been developed by the ICAR-CSWRI, Avikanagar for enhancing mutton production in the country (Shinde et al., 2017). These sheep technologies and innovations are summarized below:

- Traditional philosophy of “More sheep means more money to more money from less sheep”
- Introduce prolificacy in sheep to produce twins/triplets
- Introduce sheep of extraordinary growth and feed efficiency
- Accelerated lambing system to produce 3 lambs in 2 year
- Marketing of sheep on live weights for better realization of value
- Estrus synchronisation to produce lambs as per market demand
- Stall feeding of sheep on balance ration for higher meat yield and quality
- Disease management practices to reduce mortality losses
- Market-oriented production to attract prime price for produce
- Diversified functional and healthy meat products
- Establish state of art slaughterhouse in production areas
- Skill development of farmers in commercial lamb production

8.2.1 *Genetic Improvement of sheep for enhancing mutton*

There are 44 sheep breeds distributed across the country which are well adopted to different agro-climatic regions. Under the prevailing condition, animals with better growth rate, feed efficiency, physical size, better adaptability to climate, resistance to diseases, and market demand should be preferred for mutton production. Native sheep should be improved by adopting selective breeding and low producing non-descript sheep should be upgraded by well defined, pre-dominant breed of high genetic merit (Kumar et al., 2021). Lambs born from elite ram receive a higher price in the market. The animals with extraordinary growth like fat-tailed sheep should be introduced in specific pockets where environmental conditions and feed resources are optimum for enhancing rapid growth in meat production in the country (Naqvi et al., 2016). Fat-tailed lambs attained bodyweight of 28.50 kg and 43.20 kg at three and six months of age. There is a huge demand for fat-tailed sheep and also fetches a premium price in the Indian market.

8.2.2 *Introducing Prolificacy in sheep for faster multiplication*

The majority of Indian sheep produce a single lamb per lambing except for few small prolific sheep of the eastern region like Garole, Kendrapada, and Edka, who produce twins/triplets. A new genotype '*Avishaan*' (GMM X P), which produces twins/triplets and also has higher body weights, better survivability, and milk yield developed at ICAR-CSWRI, Avikanagar (Sharma, 2020). Avishaan sheep produces 72% more lambs than native single-bearing Malpura sheep and provide 46% more weight than Malpura at three months of age with the survivability of >96%.

8.2.3 *Improving the reproductive efficiency of sheep for more mutton*

ICAR-CSWRI developed a cost-effective 'progesterone' impregnated intra-vaginal sponges 'Avikasil-S' for oestrous synchronization and artificial insemination (AI) with chilled semen. These sponges bring the ewes in estrus simultaneously with a success rate of 80% (De et al., 2015). The majority of the ewes give birth to a single lamb in a year; three lambs in 2 years can be achieved by breeding at a regular interval of 8 months either naturally or by synchronizing with sponges. The accelerated lambing system produced 50% more lambs in comparison to a conventional system. Besides, nine lambs can be harvested from a ewe life against six lambs under the conventional system.

8.2.4 *Improving the nutrition of lambs for higher meat yield and quality*

In sheep husbandry, a major portion (90%) of the income comes from lamb sales. In the existing production system, lambs are sold at an early age of 3-4 months with a bodyweight of 12-14 kg.

There is ample scope of increasing pre-weaning weights by nutritional inputs (Sahoo et al., 2015). The study conducted at the ICAR - CSWRI indicated that Malpura lambs could reach > 30 kg body weight at six months with ADG of 170-180 g and feed efficiency of 5.0-5.5, 57-58% lean, 22-24% fat, and 23-24% bone contents (Bhatt et al., 2018).

8.2.5 Improving health management

Farmers incur around 18-20% production losses due to diseases and mortality. A prophylaxis calendar has been developed based on the epidemiology of sheep diseases, which contains timely vaccination, drenching, dipping, and tactical health care. Animals should be regularly vaccinated against enterotoxaemia (ET), Sheep pox, *Peste des petits ruminants* (PPR), and Foot and mouth disease (FMD). Annual health management calendar, that includes timely vaccination, drenching, and dipping, when effectively implemented in a flock results in morbidity and mortality reduction. The annual cost comes to around Rs 70-75 per sheep and reduced mortality losses to < 5.00 % and saves 10% of animals.

8.2.6 Value addition of mutton and live animal marketing

Market for processed meat in India is growing at a faster rate. Value-added meat products developed from meat are ready-to-eat, ready to serve and eat, and more appealing. Non-meat components like low-value meat cuts, edible meat by-products can be used. Processing promotes entrepreneurship and employment. Functional and healthy meat products like low fat, low sodium/salt, fibre rich and natural antioxidants fortified meat products could be developed. ICAR–CSWRI, Avikangar has developed numerous (nuggets, patties, kabab, sausages, loaf, salami, kofta, cookies, pickles, *etc.*) ready to eat and heat and serve sheep meat products for the consumers (Gadekar et al., 2013). The marketing of live sheep is unorganized in the country and several intermediaries are involved. And pay less return to sheep farmers. The majority of sheep are sold in the market on physical appearance without actual weights and body conformation. This leads to the poor realization of price to farmers.

8.2.7 Skill development and capacity building of people in the mutton sector

There is a need for enhancing the skills and capacity building of people in improved and upgraded meat production and processing techniques. Farmers should be trained in scientific rearing for the production of healthy and hygienic meat. Similarly, the people in the processing sector should be trained for hygienic, clean meat and products production.

The growing demand for mutton and value-added meat products can be fulfilled by improving per animal productivity (more from less sheep) economic and balance feeding and improved management practices and their adoption in farmer's field. The direct tie-up of farmers with processors and consumers may be encouraged for better prices for meat to farmers. Organised marketing may increase the profit margin and get remunerative prices. Further, safe, hygienic, and quality products as per consumer convenience may be accessed in the market.

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Chapter 9

Quality Control for Hygienic Mutton Production

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9.1 Introduction

Sheep husbandry has a major economic impact on the farmers of rural society, chiefly among the small landholders, and provides a ready source of income through sales of live animals. Generally, sheep are reared by farmers for multiple purposes such as mutton, wool, security, hides, and manure. Furthermore, sheep have short generation intervals which make it possible to increase their production over a shorter time as compared to cattle, buffalo. Mutton is a nutritious source of protein and a valuable commodity in developing countries and its consumption in India is nearly 720 thousand metric tons in 2020 which is increased compared to the previous year (Statista Research Department). However, meat is a perishable food substance and a good medium for the proliferation of micro-organism, thus a high risk for meat-borne disease. The risk of transmission of disease increased with increased processing, mishandling, improper temperature, and humidity during the storage period. Meat-borne diseases are a major concern for the human-being due to poor hygienic and sanitary standards adopted during the food chain i.e. the slaughter of an animal and further processing of meat and its products.

Meat hygiene comprises scientific activities to ensure safe and clean meat production from farm to table. It includes defined steps of practices, principles, and monitoring activities through the competent authority. Production of hygienic mutton for the consumers involves a variety of hygienic procedures like personnel hygiene, cleaning, and sanitization of the animal house as well as an abattoir and their various equipment, etc.

9.2 Meat hygiene principle

There are three principles of meat hygiene which needs to be followed during slaughtering and meat processing.

- Prevention of microbial contamination through appropriate cleaning and sanitation approaches during slaughtering and meat product manufacturing.
- Minimization of microbial growth in meat and its products by using various preservative methods, such as low temperature.
- Elimination/reduction of the threat of contagious infection by applying suitable treatment.

9.3 Quality Control measures

Various meat-borne emerging pathogens do not inevitably cause the evident symptom of disease in the food animals. Ensuring that food is safe from the hazard of pathogens requires controls along the entire continuum from farm to fork. Two types of quality control measures are generally implemented at various stages of meat production: (i) Good farm practices (good hygienic practices and good manufacturing practices); (ii) Hazard Analysis and Critical Control Point (HACCP) System (Fig. 9.1).

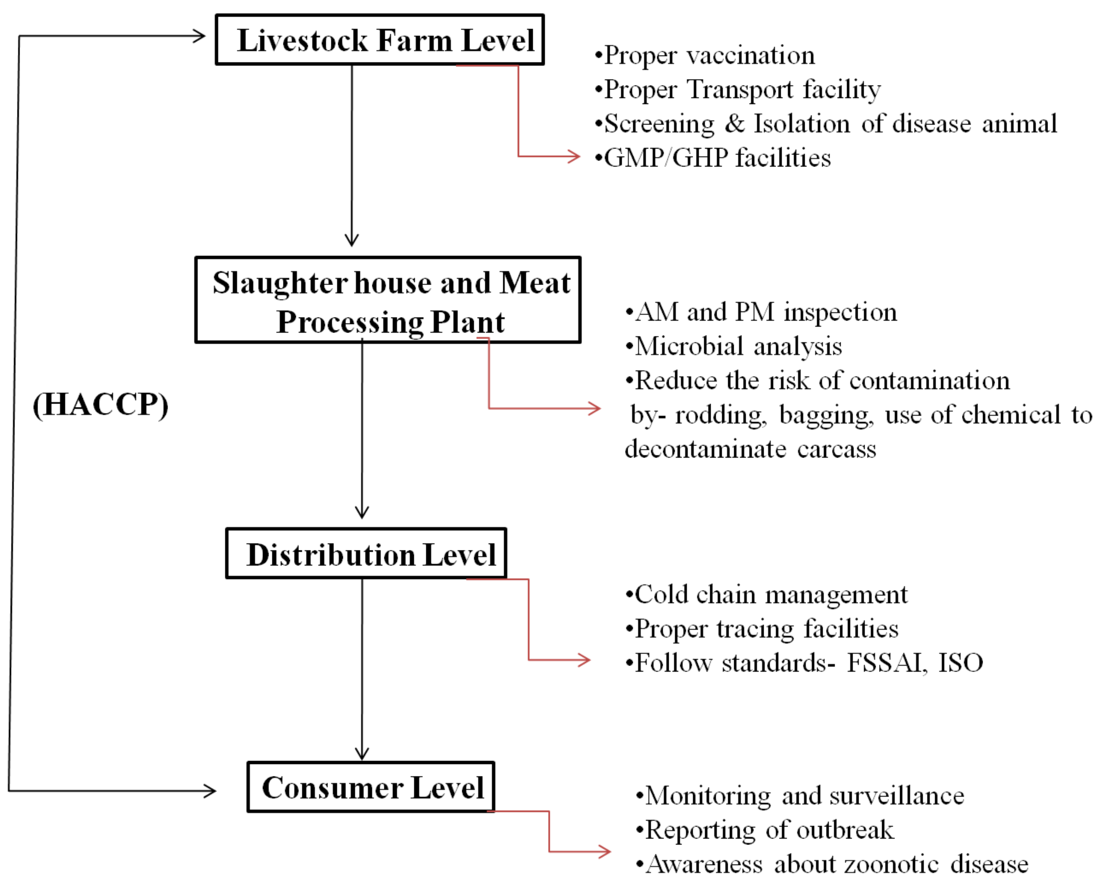

Fig. 9.1 Various strategies to be adopted to control the microbial infections throughout the food chain

9.3.1 Good farm practices

Good farm practices including good hygienic and manufacturing practices (GHP & GMP) are considered as one of the most efficient ways to stop the entering of micro-organism into the meat processing system. GMP refers primarily to technical aspects of the whole production process of meat, while GHP is based on the hygiene aspects of the production chain. Under good farming practices, control measures are taken to reduce or eradicate and shedding key pathogenic micro-organism by food animals. Along with, GMP/GHP is a pre-requisite program that must be implemented in place before the HACCP system. Furthermore, GHP is enough to manage hygienic standards in lower-risk food products such as cereals, grains. However, GHP alone is inadequate for high-risk foods, *i.e.* meat, milk, egg. Within slaughterhouse, GMP/GHP programs provide important principles for hygienic production of meat, which includes:

a). Hygiene of meat processing plant (design, construction)

- The floor of the processing plant should be flat, even, water-resistant with no cracks or destruction, and constructed with adequate drainage. The junctions of the floor with walls should be smooth and cleanable angles.
- The roof should be gap-free, water-resistant, and finished to minimize the shedding of particles.
- Window in the walls of the plant should be placed up to 2 m height from floor area for easy washing of wall and floor. Doors should have smooth, nonabsorbent surfaces, easy to clean and disinfect at a regular period.
- Sufficient ventilation should require in all rooms of the meat processing plant. Meat cutting/deboning rooms should be air-conditioned and requires temperature should be10-12°C.
- The surface areas which are direct contact with meat and meat product should be durable, free from open seams, cracks, and easy to sanitize.
- The drainage systems of the plant should be properly planned and constructed. The sewage discharge of the effluent treatment plant should fulfill the specification of the environmental pollution board.
- Natural or artificial lighting should be provided in the meat processing plant for various operations.

b). Hygiene of machinery and equipment

- Equipment, machinery, and re-usable containers should be durable, easy to clean and sanitize to ensure product safety by avoiding the contamination of meat. Equipment should be made of food-grade material such as stainless steel or similar material.
- The materials of equipment should be non-toxic, food-grade, and not pass on colors, odors, or taste to the meat.
- The contact surface of working tables, meat hooks blades of knives, saws, cleavers, and axes with meat should be made of stainless steel.

c). Hygiene during meat processing

- Ideally, the temperature of the meat cutting room should in the range of 10-12°C with low air humidity.
- Visual contamination of meat should be removed with the use of a sharp knife and in the case of local infection, detached the superficial or external layer of meat. Reject the carcass or flesh in case of universal infection.
- Meat pieces or carcasses, which unintentionally had contact with the contaminated surface, never should take back onto the operational area or processing surface.

d). Worker's hygiene

- Workers of meat processing plants should be screened for infectious, and zoonotic diseases, at least every 6 months.
- The worker should not have any wounds, injury, and open-cut which are coming in direct contact with meat and meat products.
- During work in a meat processing area, the person should maintain a high grade of individual hygiene and dress in a fresh uniform, headgear. The personnel's fancy items like hanging jewelry, rings, and bangles should not be war during operational work. The nails of workers should be clipped, hygienic, and without nail paint. Outdoor shoes should not be permitted. Suitable actions such as transient over a foot bath, shoe covers, separate footwear for indoor use, etc. should be implemented.
- Strict lavatory cleanliness must be followed in the factory to reduce the risk of *Salmonella* infection.

e). Recall, Identification, and traceability of the product.

- Effective methods should be in place to facilitate quick recall of any batch of packed meat and meat product. Supervision of the recalled items should be maintained until they are damaged, used, or reprocessed. The food establishment system should be appropriate, effective, manageable, and retain an efficient procedure for recognition and traceability of the food product from producer to consumer.

9.3.2 Hazard Analysis Critical Control point (HACCP)

Within the meat chain, HACCP provides the basis for the food safety management system. HACCP is a system to ensure the safety of meat products from fark to fork. It is based on scientific and systematic principles applied to every stage of the meat production and processing chain. HACCP procedures were developed by Pillsbury Company of the U.S in association with NASA in the 1960s and later described by H.E Bauman in 1971 about its food safety credentials. HACCP is considered as a pro-active that ensures the safety of the product by recognized the international food standards as a worldwide guideline to controlling the various types of hazards in food. The 7 basic principles in a HACCP plan are outlined by CAC, 1991.

1. Identify the potential hazards (physical, chemical, biological) associated with meat production at all stages from the farm, slaughterhouse to the distribution center.
2. Determine the critical control points.
3. Establishment of critical limits
4. Monitor the critical control points.
5. Establish the corrective action.
6. Establish verification procedure.
7. Establish documentation and record-keeping.

9.4 Application of seven basic principles of HACCP

1. Hazard analysis: What are the possible hazards?

Physical hazards*:* Entry of deleterious extraneous elements in the production chain, e.g. insect, thorns, wood splinters, hair, mould, rodent droppings, cigarette butts, buttons, tags, metal, glass, etc. either naturally or deliberately, injuries caused/occurred to meat and other products.

Chemical hazards: Various types of chemicals are used in various stages of the meat production chain. Agricultural chemicals are used on crops that flow into the food chain as livestock feed. Chemicals are used directly on the animals or used in the diet for some therapeutic use. Industrial chemicals like sanitizers cleaning compounds, lubricants, paints, and coatings. Food chemicals such as preservatives, acids, food additives, coloring matter, etc.

Biological hazards: Microbiological hazard is major among biological hazard. The source of a biological hazard is fecal, water, raw materials, environment, worker, equipment, and food contact surface. Eg. *Salmonella sp.*, *E. coli* O157:H7, *Listeria monocytogenes*, *Campylobacter sp.* and *Clostridium perfrengen.*

2. **Determine Critical Control Point (CCP)**

The CCPs are located at any point in a meat production chain where hazardous microorganisms need to be destroyed or controlled. ICMSF recognizes **CCP1:** To ensure elimination of hazards and **CCP2:** To minimize the hazards.

3. Establish critical limits: A critical limit is defined as one or more approved tolerance that must be meted out to make certain the effective control of CCP over a microbiological health hazard. The various critical limits criteria are used in the food system such as time, temperature, salt concentration, water activity level, pH, etc.

4. Monitoring of CCPs: From the monitoring standpoint, failure to control CCP is a critical defect. Monitoring of CCPs should be proper, continuous and at a hundred levels using various types of methods.

5. Corrective actions: Adequate steps must be taken to eliminate the actual or potential hazard involving the HACCP plan due to variations in CCP according to the type of food.

6. Verification: Verification consists of a review of flow chart/critical limits/ monitoring system records and detailed analysis of finished products.

7. Effective record keeping and documentation: It includes records and documentation of control charts, CCPs monitoring, corrective actions, and responsible staff.

9.5 Other strategies adopted during hygienic mutton production

1. Clean livestock policies: Fleece and feces of sheep are the major sources of microbial contamination of carcasses. These microbes may be contaminated carcasses during slaughter and dressing operations. The fecal contamination risk on the carcass from the gasto-intestinal contents can be reduced by some of the specific techniques, including "rodding" (a method used to close the esophagus), and tying off the bung can also reduce contamination of the meat. For example, several EU countries have enacted "clean cattle policies" to reduce the risk of *E. coli*

O157:H7 transmission from the hide. Furthermore, during ante mortem examination, the level of fecal material and other visual contaminates on the animal hide is judged.

2. Inspection of the animal before and after slaughter

Antemortem inspection carried out in lairages before slaughtering of food animals by the antemortem inspection unit of the slaughterhouse. The aims of AM inspection to screening out suspected diseased or injured animals for isolation slaughter (e.g. rabies, anthrax, mastitis, metritis, fracture, laceration, fever, emaciation, etc.). During the antemortem examination, the welfare of meat animals in an abattoir is also taken care of by providing the facility for emergency slaughter in case of fracture, unavoidable pain, etc. Post-mortem examinations are also conducted at the PM inspection rooms just after the slaughtering and dressing of animals by the meat inspector in the proper light. Three judgments of PM inspection are: a) passed for human consumption, b) partially condemned, or c) fully condemned. Partially condemned meat relates to the conditions of the carcass which are not severe. These are mostly non-infectious or mild infections.

3. Decontamination of the carcass

Various approved chemicals such as organic acids, chlorine, sorbates, polyphosphates, ozone, hydrogen peroxide, lysozyme, and other disinfectants are used for the decontamination of carcasses. Recently, thermal and non-thermal methods are being considered at the commercial level such as microwave, X- rays, gamma irradiation, high hydrostatic pressure (HHP), ohmic heating, microwave, radiofrequency, steam pasteurization, etc.

4. Use of hurdle technology

The hurdle technology concept was first given by Leistner in 1978. It is a method of using old and innovative emerging preservation techniques to set up a series of preservation factors that act synergistically towards the prevention of the growth of microorganisms. Various types of hurdles are identified in the food system such as physical hurdles (high temperature, low temperature, UV rays), physicochemical hurdles (aw, low pH), microbial-derived hurdles (antibiotic, protective culture bacteriocins), etc.

5. Microbial analysis of meat and meat product

Conventional methods used for the identification and characterization of bacteria associated with meat and meat products rely on the use of specific bacteriological media. However, these methods are lengthy, labor-intensive, and do not discriminate between closely related organisms. To overcome these, alternative approaches have been developed in recent years to detect micro-organisms such as flow cytometry, impedimetric, immunological techniques, and nucleic acid-based assays. The Molecular based method is allowed for the identification of bacteria at the sub-species level, which is aiding epidemiological and taxonomic studies. These methods are PCR, real-time PCR, restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD), loop-mediated isothermal amplification (LAMP), polymerase spiral reaction (PSR), etc.

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Chapter 10

Slaughtering and Carcass Evaluation of Sheep

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10.1 Introduction

The rearing of ruminant animals is an integral part of the agricultural system throughout the world. Small ruminants are important, cost-effective livestock particularly in temperate and tropical climatic conditions. Agriculture with small ruminant rearing is beneficial for rural peoples, small landholding, and landless farmers. These small ruminants are cash crops at the time of need money and play a significant role in the up-gradation of rural livelihood. Among small ruminants, sheep have their dignity worldwide as producing high quality meat and wool. Sheep is suitable to rear in a low inputs system and adapted to adverse climatic conditions. In India, the sheep are distributed throughout the country in four agroclimatic zones and are mainly reared for mutton and wool purposes.

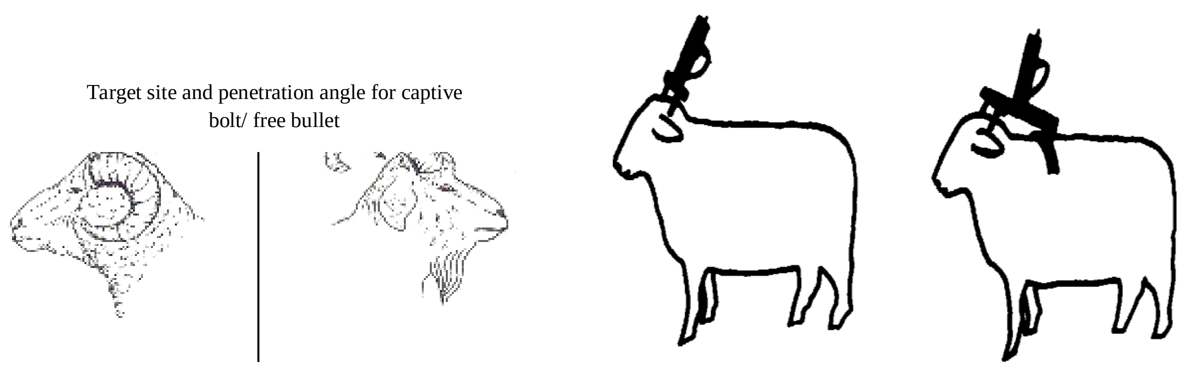
A scientific slaughtering operation in sheep is essential to get hygienic quality of mutton, good quality of the skin, and other edible offals. Evaluation of carcass traits of sheep is to determine the influence of sex, age, feed, and climatic conditions on birth weight, daily weight gain, dressing percentage and to know the expected meat quality and quantity of animals. Carcass evaluation helps to make a strategy to animal keepers, traders, and buyers about the factual price of animals and to produce high-grade, reliable, and nutritious meat for an existing highly competitive market. Carcass evaluation is also facilitating the trade of meat between the countries and categorizing the quality and quantity of different cut-up parts of animals by which consumers can purchase quality meat according to their needs and choice. In the existing scenario, conventionally the animal traders fix the price of animals based on a subjective evaluation by judging animals' live shape and appearance. The animal keepers will get the right price for their animals with proper knowledge of different carcass traits.

10.2 Slaughter procedure of sheep

Laws enforced by the government, customs, and rituals of the people affect the predominant slaughter methods throughout the world. In the religious slaughter method, animals are in a state of consciousness at the time of bleeding. Jewish (Kosher), Jhatka (Sikh), and Halal (Islamic) slaughter are the common ritual slaughter methods that are following throughout the world. In the humane slaughter/scientific slaughter method, animals are in a complete state of consciousness before bleeding. Stunning is the procedure to achieve complete unconsciousness of animals either by mechanical, electrical, or chemical means. It is performed before bleeding to eliminate excitement and possible cruelty. The slaughtering procedures commonly include stunning, bleeding, skinning, evisceration, and postmortem inspection of animals.

10.2.1 Stunning

Stunning is the procedure to make the animal unconscious by use of captive bolt pistol/free bullet/striking hammer in the mechanical method, electrodes or probes in the electrical method, and use of carbon-di-oxide gas in the chemical method. Either mechanical or electrical stunning method is used in sheep (Fig. 10.1).



i. Head only ii. Heat to back

a. Mechanical Stunning. b. Electrical Stunning

Fig. 10.1 Stunning methods used in sheep

10.2.2 Bleeding

After stunning an animal should be retained in the proper position for bleeding. The vertical or hanging position is attained by hackling the sheep below the hock from one hind leg. Retaining the animal horizontally in a slab or clear platform is performed under the horizontal bleeding method. The bleeding operation is completed by sticking or inserting the knife over the neck to sever the blood vessels and let out blood.

10.2.3 Skinning

A skinning/flaying operation is the procedure to remove the skin over the carcass. In sheep, it is performed by initial cutting of the skin around the hind leg to expose and relax the tendon of the hock. The tendon is used for hanging the carcass over the rail. It is known as the legging procedure. The second operation is pelting, which removes the entire skin and prepares- the body of the animal for evisceration. Skinning is the skillful work in the entire slaughtering operation and should be performed by an experienced person to avoid any cuts in the skin. Skinning is performed in both vertical and horizontal ways.

10.2.4 Evisceration

After removal of external structures such as skin, feet, and head; cut the animal body from the mid-line to dislodge the stomach and intestine after loosening it from the body cavity attachment. To avoid contamination of carcass from the stomach and intestinal content the seal oesophagus and intestine properly. The sealing of oesophagus and rectum is called rodding and bunging respectively. In the next step, detach the kidney, liver, gall bladder, spleen, kidney fat, and caul fat from the body cavity. After cutting of thin muscle of diaphragm exposed the chest cavity to separate the heart, lungs, trachea, and oesophagus. After removal of all the internal structures, split the carcass into the fore and hindquarter by cutting in between the 12th and 13th rib.

10.3 Post-mortem inspection

Postmortem inspection of sheep is performed in the hanging position of the carcass. In this procedure carefully inspect all the detached internal organs, body cavity, and lymph nodes of animals to protect the consumer from zoonotic diseases. The risk of zoonotic disease transmission is an increase in poorly managed slaughterhouses due to unsatisfactory slaughtering techniques, or without any meat inspection. Along with, slaughterhouse workers, byproduct utilization plant workers, food habits of veterinary doctors, social and cultural factors of the people also play a significant role in the transmission of such meat-borne zoonotic diseases.

10.4 Carcass evaluation of sheep

Classes and Grades

Sheep meat is categorized mainly in three classes based on the age of the animal.

a) Lamb - the obtained meat from the young ones about 4-12 months old of both sexes called lamb.

b) Yearling mutton – the flesh from male and female sheep from 1 year to 20 months of age. The meat of this class is darker, coarser, slightly thicker exterior fat with whiter bone compared to lamb.

c) Mature mutton - It is the meat from adult sheep over 20 months in age of both sexes. As the age increases hardening and ossification are common in bones and the broken joint fails to break in adult sheep.

I. Yield Grades

United States Department of Agriculture (USDA) defined the yield grade of sheep based on the expected yield of the carcass into five categories (1, 2, 3, 4, 5) where 1 attained the highest anticipated return, and 5 the lowest.

Yield Grade (Sheep) = (back fat thickness x 10) + 0.4

Backfat thickness (BFT) is the only feature used in the assignment of yield grades.

II Quality Grades

According to the Bureau of Indian Standard (BIS), the quality grades of sheep carcasses are into Prime, Good, Commercial, and Utility base on the expected eating quality of cuts. Confirmation, maturity, flank streaking, and finish are the features that reflect to estimate lamb quality grades. The general build, form, shape, and contour of the animals are included in the confirmation. Higher conformation means blocky and dense carcass, flabby neck, wide and turning brisket, meaty legs. Distribution of fat in the muscle of carcass with their quality, quantity, colour, and character makes the finish of carcass. Tenderness, juiciness, and flavour come under the palatability of the meat that influenced the carcass quality. These are the combined characteristic of flesh and fat.

The classes are divided based on conformation, finish, and quality of the individual carcasses, into the following four grades (BIS, 1995), as shown in Fig. 10.2.

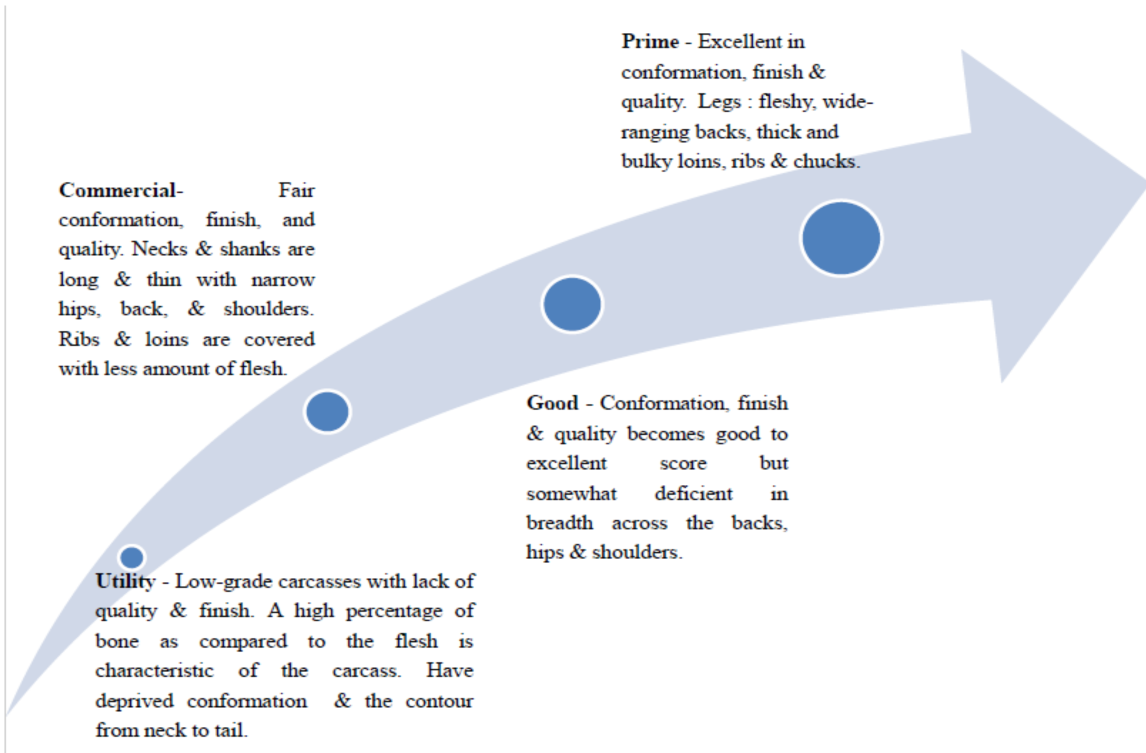


Fig. 10.2 Quality of grades of sheep carcass

10.5 Carcass measurements

In the live condition of animals recorded the body measurement such as weight, length, height, heart, and punch girth just before bleeding. The following body measurements are estimated (Mamdouh, 2014).

Body length: Horizontal expansion from the point of shoulder to pin bone.

Height at withers: Vertical distance from withers to the floor.

Heart girth: Circumference of the body just behind the forelegs.

Paunch girth: Circumference of the body just before the hind legs.

Round circumference: Circumference of the round just under the body.

Hot carcass weight

The weight of the carcass within 1 hr. of slaughter is known as hot carcass weight. After the recording of hot carcass weight make the longitudinal incisions to split the carcass into two halves. Carcass measurements are taken on the left half side (Sen et al., 2004).

Cold carcass weight

Cold carcass weight is used to know the chilling loss in the carcass and recorded after 24 hr. of refrigerated storage.

Dressing percentage

The dressing percentage of the carcass is of two types i. Live weight basis 2. Empty body weight basis. Hot carcass weight, live weight before slaughter, and weight after removal of ingesta are used to calculate the dressing percentage by the formula given below:

$$\text{Dressing percentage (Live wt. basis)} = \frac{\text{Hot carcass weight}}{\text{Live weight}} \times 100$$

$$\text{Dressing percentage (Empty body wt. basis)} = \frac{\text{Hot carcass weight}}{\text{Empty body weight}} \times 100$$

Rib eye area (REA)/Loin eye area

Ribeye area (REA), in square inches, is measured between the 12th and 13th ribs and gives an estimate of the amount of muscle/lean content in the carcass (Fig 4). REA measurements reflect differences in the proportion of muscle-to-bone within the carcass and usually range from 1.5 to 4.0 square inches. The rib eye area/loin eye area is measured by planimeter with standard procedure.

10.6 On-line determination of carcass traits

With the advancement of technique, some recent technologies are used in modern slaughter houses to know the carcass traits of the animal. These techniques are accurate and give results in less time. Ultrasound is a nondestructive technique of measuring fat and muscle in live animals (Houghton and Turlington, 1992). This Ultrasound imagery and body shape have been used to predict the meat yield of live sheep (Berg et al., 1996). The use of video image analysis (VIA) comprises a video camera to generate an electrical 'map' of the article which can be examined through the use of thresholds to distinguish between fat and lean tissue. Electromagnetic scanning is another technique based upon conductivity differential between lean and fat tissue. The amount of energy absorbed by carcass or meat cuts is an index of the conductive mass. Lean tissues are approximately 20 times more conductive than fat.

Scientific slaughtering procedures of animals in the right and ethical way with an evaluation of carcass traits will be helpful to produce safe and hygienic meat to consumers and also beneficial to animal keepers to fetch a premium price for their animals.

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Chapter 11

Designer Mutton Production

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11.1 Introduction

Meat is a rich source of nutrients with better bioavailability. It supplies proteins, fatty acids, which are essential for the functioning, maintenance, and repair of body tissues. Meat provides many health-promoting substances which include micronutrients like iron, zinc, and selenium, it also contains vitamins B, vitamin D and carnitine, taurine, bioactive peptides. The mutton is a rich source of conjugated linoleic acids (CLA). The CLA has anticancerous, immunomodulatory, anti-atherosclerotic, and antidiabetic (Azain, 2003). Archeological evidence proves that meat-eating played a very important role in human development from ancient ancestors. Earlier humans (Hominin) used to consume fruits and tubers with some food of animal origin while pieces of evidence suggest that the earliest Homo's diet comprised of animal proteins to a larger extent. With an animal protein based diet, the growth and development took place rapidly through improvement in morphological features, skeletal system, digestive system, posture, and improved intelligence level. This indicated that meat played a significant role in Human development (Baltic and Boskovic, 2015). Nowadays this scenario is the opposite as carbohydrate has been a major component of man's diet leading to rising incidences of CHDs and cardiovascular diseases (CVDs). In the modern era, there is a certain insinuation that meat consumption is associated with coronary heart diseases (CHD) and cardiovascular diseases (CVDs). It is still unclear about meat's role in CHD and CVDs as these are multifactorial diseases.

The global human population is increasing at an alarming speed and in years to come it is predicted that the world human population will reach 9-10 billion. As per the forecast, demand for beef and mutton would rise by 200% and by 158% for pork by 2050 (Alexandratos and

Bruinsma, 2012). The rise in human population is at a greater speed in developing countries and where there is a greater prevalence of malnutrition and protein hunger. Therefore, ensuring adequate protein and energy supply could be a major challenge in the future. This suggests an animal protein has to play an important role in nutritional security. Meat is loaded with nutrients and the nutritive value varies with the age of the animal, feeding, and management practices, even within a carcass also different meat cuts have different nutritional compositions. Sheep meat or mutton contains 20-21% proteins, 4.8% fat, while sodium, zinc, phosphorus, and iron contents are 71, 3.9, 290, and 3.3 mg (%), respectively (Table 11.1).

Table 11.1 Composition of lamb and mutton

Parameters	**Lamb**	**Mutton**
Moisture (g)	72.9	73.2
Protein (g)	21.9	21.5
Fat (g)	4.7	4
Energy (kJ)	546	514
Cholesterol (mg)	66	66
Thiamin (mg)	0.12	0.16
Riboflavin (mg)	0.23	0.25
Niacin (mg)	5.2	8
Vitamin B6 (mg)	0.1	0.8
Vitamin B12 (µg)	20.96	2.8
Pantothenic acid (mg)	0.74	1.33
Vitamin A (µg)	8.6	7.8
Beta-carotene (µg)	<5	<5
Alpha-tocopherol (mg)	0.44	0.2
Sodium (mg)	69	71
Potassium (mg)	344	365
Calcium (mg)	7.2	6.6
Iron (mg)	2	3.3
Zinc (mg)	4.5	3.9
Magnesium (mg)	28	28
Phosphorus (mg)	194	290
Copper (mg)	0.12	0.22
Selenium (µg)	14	<10

Source: Williams, 2007.

As per guidelines energy intake from saturated fat should be 20-35%, while saturated omega-6, omega-3, and trans fatty acids should be in the range of 8-10%, 2.5-9%, 0.5-2%, and 1% respectively (FAO/WHO, 2008). Similarly, cholesterol intake should be restricted to <300mg/day. Due to increased awareness about the importance of healthier food in human health in the prevention of incidences of coronary heart diseases, hypertension, and cancer, consumer demand for healthier meat and meat products is on the rise. To make meat healthier, the meat could be designed as per the requirements. A concept of "functional foods" is emerged due to consumer perception towards fitness and nutrition to achieve healthier status and further prevention/reduction of the risk of diseases. Of late meat has been considered as a functional food, which can be modified through different approaches like genetic, nutritional, or post-processing, etc. Recent dietary recommendations encourage the consumption of higher levels of n-3 fatty acids. This offers ample opportunities for manipulation of the fatty acid composition of the muscle tissues to reach human nutritional guidelines better by altering the dietary fatty acid composition, by dietary supplementation of antioxidants, viz. Vit E, and selenium, etc., production of meat with increased n-3 polyunsaturated fatty acid content.

11.2 Factors affecting meat quality

The meat quality is a broader term and encompasses those attributes of meat which fulfill the needs of farmers, processors, wholesalers, retailer and finally consumers. The factors affecting meat quality are presented in Fig 11.1.

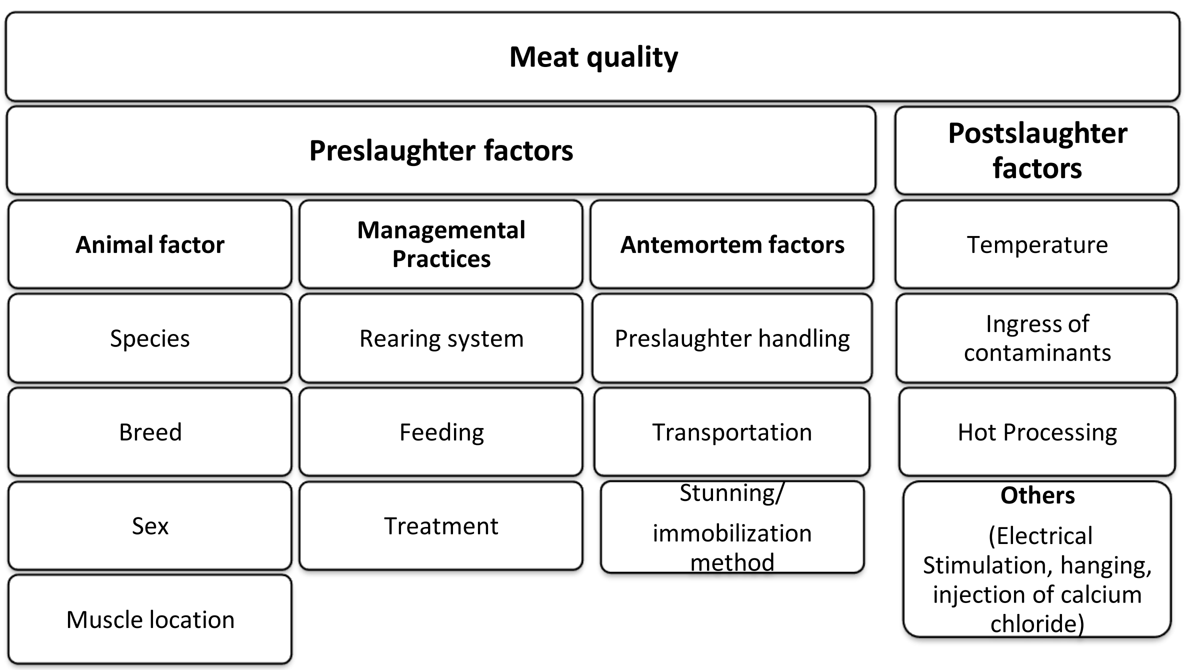

Fig. 11.1 Factors affecting meat quality

The meat quality includes functional quality (yield, carcass composition, pH, color, water holding capacity), eating quality (palatability factors), and wholesomeness (microbiological, nutritional, and chemical quality. Meat quality depends upon several factors that impart peculiar color, texture, and flavor to the meat.

11.3 Approaches for designer meat production

Fig. 11.2 shows various approaches for designer meat production. The approaches may classified as genetic selection and nutritional manipulation.

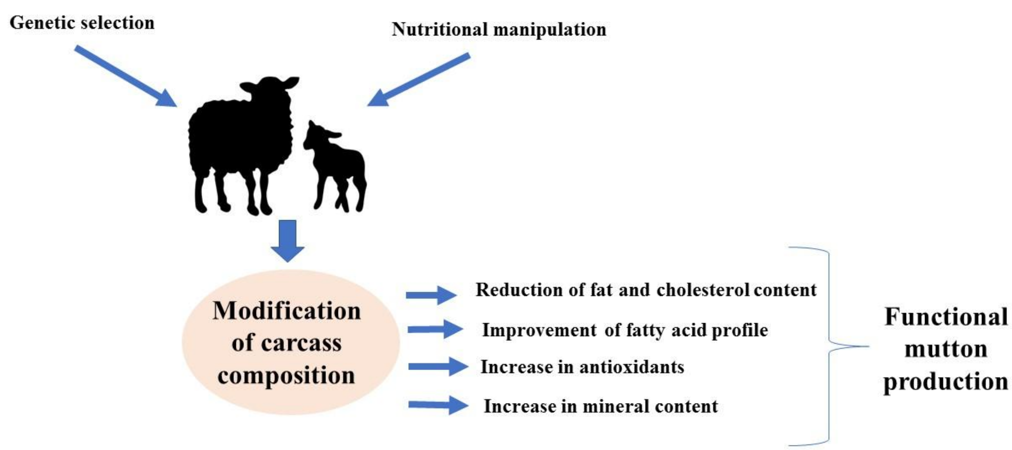

Fig. 11.2 Designer meat production

11.3.1 Genetic approaches:

Health-conscious consumers are demanding meat with lean and less fat content. Advances in molecular genetics have led to the identification of genes that affect meat quality traits. Currently, several genes with major effects on commercial animal production especially on carcass and meat quality traits are known. Callipyge (CLPG) gene is one of the gene mutations on chromosome 18 in descendants of Dorset ram born to a flock of sheep in Oklahoma in 1983. The exact mechanism is unclear but, in this condition, there is DLK1 over-expression. This muscle hypertrophy is exhibited after one month of age. The progeny of such rams display extreme muscling particularly in the hind leg, with lower fat and improved feed efficiency. The animals carrying this gene shows about a 30–40% increase in muscle mass, 6-7% decline in carcass fat and also reduced offal weight with a more compact skeleton (Jackson et al., 1997, Freking et al., 1998). Carwell or ribeye muscling (REM) is another condition, identified in offspring of Poll Dorset rams from the Carwell stud, NSW, Australia, located in the same region of Callipyge. In Carwell condition, there is an increase in the rib eye area & weight 11% and 7% respectively, but its effect on tenderness and its mode of inheritance has not been reported. It is not known if this QTL is an allele of Callipyge (CLPG), or if it is a different locus. Therefore, it has provisionally been named the Rib-eye muscling (REM) locus, with its allele being named Carwell. Introgression of Carwell into flocks has the potential to improve the quantity of the high-priced loin cuts without negative quality side effects.

11.3.2 Nutritional manipulations

Reduction of fat and cholesterol content

The feed offered to the livestock has a significant effect on the composition and meat quality. Particularly, the amount and type of dietary energy influence the calorific value, protein/fat ratio, fatty acids composition, chemical and technological characteristics, and organoleptic quality of meat. The augmented proteins/ energy ratio in faster-growing animals may produce leaner carcasses (Campbell and King, 1982). When diets with high fibre and low-energy content are provided, carcasses are less fattened, the skeleton is more developed and the lipid content of the carcass is very low and water and protein content is high (Parigi Bin et al., 1994). Several Dietary approaches are followed to design the composition of meat.

The β -adrenergic agonists/repartitioning agents can be used to alter the muscularity and ratio of lean-to fat in meat animals. The repartitioning agents reduce the amount of fat in the body and increase protein accretion, so promoting muscular development. These can be used at levels of 1-10 mg/kg in the feed. The carcass yield is improved up to 5-6% in cattle and sheep. This is increase in carcass yield is attributed to more carcass weight and reduced size of the viscera. The carcasses have better conformation. The increase in muscle development is accompanied by a reduction in subcutaneous, intramuscular, and inter-muscular fat (Warris, 2000). The effect of dietary supplementation of Cr from chromium picolinate (0.25 mg/kg) lambs was evaluated. The growth of lambs was comparable while some reduction in carcass fat was observed (Kitchalong et al., 2005). The microalgae (Schizochytrium genus) are a rich source of docosahexaenoic acid (DHA) and could be used as a source of protein and energy in the ovine diet. Dietary inclusion (0, 2, 4, and 6% of dry matter) of microalgae meal improved Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), omega–3 fatty acid, and conjugated linoleic acid (CLA) content of lamb meat. Further, it reduced the total cholesterol content of meat (Roberta de Lima Valença et al., 2021).

Improvement in fatty acid profile

Unlike the production from saturated sources, the body cannot produce any of the essential unsaturated fatty acids, linoleic (C18:2), linolenic (C18:3), and arachidonic (C20:4), unless one of them is available in the diet. The fatty acid profile of meat from monogastric animals could be more easily altered through dietary interventions than in ruminants as ruminal microbes through the biohydrogenation process. The fatty acid profile of meat could be also manipulated through nutritional interventions (Table 11.2), previous studies have reported that feeding protected sunflower seeds reduced meat aroma and flavor, increased different aroma and flavour of lamb meat, increased the concentration of C18:2 in carcass fat (Park et al., 1975). Maintaining lambs on pasture along with concentrated feeding systems produced meat with more monounsaturated fatty acids (Díaz et al., 2011). Dietary manipulation of the fatty acid composition of lamb meat using linseed oil, fish oil, protected lipid (containing more linoleic acid (C18:2 n-6) and α-linolenic acid (C18:3 n-3), fish oil/marine algae (1:1), and protected lipid/marine algae (1:1) indicated that Eicosapentaenoic acid (C20:5 n-3) and docosahexaenoic acid (C22:6 n-3) content of meat was more in lambs maintained on diets containing algae. The meat of lambs maintained on protected lipids showed the greatest levels of C18:2 n-6 and C18:3 n-3 (Elmore et al., 2005) Fat from sheep and goats reared on green pastures is generally yellow due to the accumulation of carotenoid pigment, and it is often not desired by the consumers. However, it has been shown to have a healthier fatty acid profile. Augmented vitamin D may boost tenderization through calcium surge in muscle tissue at the harvest. This increased muscle pool then activates proteolytic enzymes that degrade certain muscle proteins (Swanek et al., 1999). The diet containing forages has the potential to reduce total as well as saturated fat content and improve omega-3 fatty acids rather than using cereals (Howes et al., 2015). In Timahdite lambs, grazing with or without supplementation increased conjugated linoleic acid content (0.88 vs 0.51g percent) than the lambs marinated on concentrate alone (Boughalmi and Araba, 2016). Dietary inclusion of camelina (Camelina sativa L. Crantz) meal augmented total omega -3 fatty acid and n-6: n-3 ratio in the sheep meat (Ponnampalam et al., 2021).

Increased antioxidants

Meat contains saturated, and unsaturated fat, from a health point of view unsaturated fat, is more preferred. The drawback of a higher degree of fat unsaturation is less oxidative stability of meat and meat products. And hence antioxidants are required. Both natural and synthetic antioxidants are available but consumers have a preference for natural antioxidants, therefore oxidative stability could be improved by dietary supplementation of vitamins like Vitamin E. Several studies have indicated a positive correlation between dietary supplementation and increased vitamin E content in meat of these animals (Table 2). In addition to supplementation, grazing is also useful for improving the alpha-tocopherol content of meat as green forages contain a considerable amount of alpha-tocopherol (Ripoll et al., 2013). In mutton, during retail display sufficient amount (3-3.5 ppm) of vitamin E is essentially required to prevent deteriorative changes like colour fading, lipid oxidation, etc. (Ponnampalam et al., 2021).

Increase in mineral content

It is a very well-established fact that meat is a very good source of minerals like zinc, selenium, phosphorus, and iron. It has been reported that Iron, phosphorus, copper, and zinc contents of meat are not much affected by dietary interventions; however, the levels of selenium in meat are highly dependent on dietary intakes (Lynch and Kerry, 2000). Selenium is an indispensable mineral for animals and human being due to its role in controlling different physiological functions as an essential part of selenoproteins. The Se is also a co-factor of antioxidant enzymes. Meat with higher levels of Se is highly desirable as it plays an important role in the oxidative stability of meat. Se exists in organic form as a Selenomethionine. Dietary supplementation of 5% selenium-enriched yeast improved selenium levels in *Psoas major* and *Longissimus dorsi* muscle from 0.29 and 0.30 mg/kg in control to 7.02 and 7.82 mg/kg in the treatment group respectively (Juniper et al., 2008).

Consumers favor healthier food and insist on cleaner meat and meat products containing low fat. A dietary additive such as chromium, in its diverse chemical types, promotes feed efficiency and improves carcass and meat quality, further it lowers fat accumulation in the carcass (Gutiérrez, 2000; Sillence, 2004). Chromium reduced dorsal fat at the 12th rib by 18.4%; however, it does not affect any other meat traits. Chromium was effective in reducing the fat content in carcass and meat therefore, it is useful to obtain leaner carcasses in fattening systems. Still not much is known about the role of chromium in fat metabolism, protein synthesis, and other processes (Arvizu et al., 2011).

Table 11.2 A nutritional approach for manipulation of meat quality

Target group	Diet	Results	References
Lambs	Plant extracts @4% with hydrolysable (Tara; Caesalpinia spinosa) or condensed (Mimosa; Acacia mearnsii) tannins	Tara extracts increased polyunsaturated fatty acids (PUFA) content, γ-Tocopherol content, and oxidative stability of meat. Antimicrobial activity against Enterobacteriaceae during storage in both tannins fed groups	Biondi et al., 2019
Lambs	Vitamin E supplementation (0, 20, 200 & 2000 IU per lamb per day)	Vitamin E supplementation above 100 IU/day/lamb significantly decreased drip loss and pH 24 h, improved percent n-6 PUFA and n-6/n-3 ratio. An increasing tendency ($P < 0.1$) for both total PUFA proportion and the ratio of PUFA/SFA was observed in lambs supplemented with Vit E.	Zhao et al., 2013
Lambs	Vitamin E (0.25, 0.5, 1.0 g/kg compound feed), rosemary extract (0.20, 0.40, or 0.80 g /kg compound feed), or rosemary extract embedded in a fat matrix (0.20, 0.40, or 0.80 g/kg compound feed) for two weeks prior to slaughter.	Vitamin E supplementation improved oxidative and color stabilities of meat	Leal et al., 2020
Lambs	Group-I: Linseed oil Group-II: Fish oil Group-III: Protected lipid (High in linoleic and α-linolenic) Group-IV: Fish oil/marine algae (1:1) Group-V: Protected lipid/marine algae (1:1)	Eicosapentaenoic and docosahexaenoic acid were found in the highest amounts in Gr.IV & V. Highest levels of linoleic and α-linolenic acid in Gr. III & V.	Elmore et al., 2005
Italian merino ewes	Group-I: Pasture fed Group-I: Stall-fed with hay & concentrate	A higher percentage of PUFA (linolenic, eicosapentaenoic, docosahexaenoic), PUFA/SFA ratio, CLA, and a lower n−6/n−3 ratio in intramuscular fat of Gr.1. Percentage of SFA (lauric, palmitic) higher in Gr.2	Scerra et al., 2007
Pregnant and lactating ewe	Group-I: Basal diet Group-II and Group-III 3.75% and 7.5% of basal diet substituted by thyme leaves	The incorporation of thyme leaves caused a decrease in the percentage of SFA, an increase in UFA and PUFA	Nieto et al., 2012
Aohan fine-wool ram/lambs	0, 20, 100, 200, 1,000, 2,000, or 2,400 IU/animal/day vitamin E for one year.	Reduced muscle SFA content and increased ($P < 0.05$) MUFA and conjugated linoleic acid content in the supplemented group.	Liu et al., 2013
Lambs	Vitamin E (30, 150, 275, 400 IU of all-rac tocopherol) or green pasture for two months	Deposition of vitamin E in muscle was directly proportional to the level of dietary inclusion	Jose et al., 2016
Lambs	*Control*: On day 0, injected 1.0	SeMet significantly ($P < 0.05$) increased Se	Knowles et

	ml of a selenium-free solution. *Medium*: On day 0, injected 10 mg of Se as DL-SeMet, followed by the second inj. of 10 mg Se on day 54. *High*: On day 0, 10 mg inj. of Se as DL-SeMet, followed by the second inj. of 20 mg Se on day 54.	concentrations in muscle, blood, kidney, and liver, thus produced Se augmented meat without considerable changes in meat quality.	al., 2020
Apennine lambs	Group-I: Total mixed ration Control group Group-II: Total mixed ration+ Na selenite (0.30 mg/kg Se as sodium selenite) Group-III: Total mixed ration+ selenium enriched yeast (0.30 mg/kg and 0.45 mg/kg Se as Se-yeast)	Selenium supplementation elevated ($P < 0.001$) the Se content in muscle with the most effective increase in Se-yeast supplemented group. Selenite increased total Se while Se-yeast supplementation increased Se-methionine content in muscle.	Vignola et al., 2009
Lambs	Group-I: Commercial concentrate (conc) + vit. E (10 mg α-tocopherol/kg of conc) and without selenium (Control); Group-II: Conc. with 500 mg vit. E /kg of conc. Group-III: Conc. with 0.3 mg sodium selenite/kg of conc. Group-IV: Conc. with 500 mg vitamin E and 0.3 mg sodium selenite/kg of conc.	Vitamin E maintained the lightness of the meat while selenium increased its values till 11 days. Sodium selenite alone acts as a pro-oxidant by increasing metmyoglobin and lipid oxidation. Dietary vitamin E prolonged the shelf life of meat in modified atmosphere packaging for an additional 4 days in terms of lightness, hue angle, metmyoglobin formation and lipid oxidation.	Ripoll et al., 2011
Lambs	Group-I : Basal diet (BD) with 3% rapeseed oil (RO) Group-II: BD with 2% RO and 1% fish oil (FO) Group-III: BD with 2% RO, 1% FO and 0.1% carnosic acid (CA) Group-IV: BD+2% RO, 1% FO, 0.1% CA and 0.35 mg/kg selenized-yeast Group-V: BD + 2% RO, 1% FO, 0.1% CA and 0.35 mg/kg selenate.	The diet with selenate (SeVI) reduced atherogenic and thrombogenic fatty acid levels in meat. The diet with Selenate reduced the fatty acid content in meat. The diet with FO, CA, and SeVI reduced the sensory attributes of meat. The diet with FO and CA reduced the ratio of n-6PUFA to n-3PUFA in meat.	Jaworska et al., 2016
Rambouillet ram lambs	Group-I: Basal diet (control) Group-II: enriched-chromium yeast (Basal diet+0.3 mg of Cr/kg dry matter).	Carcass characteristics and animal performance, meat composition, the fatty acid profile of meat were comparable. The backfat thickness was increased while intramuscular fat content was reduced in the treatment group.	Rodriguez-Gaxiola et al., 2020

11.4 Conclusion

Meat is a powerhouse of nutrients. Meat is a very important component of a balanced diet. The meat could be further tailored by genetic and dietary interventions to reduce cholesterol, minimize saturated fat levels, and improve the oxidative stability of meat during storage. The scientific community has already established that level of desirable fatty acids, antioxidants, and minerals like selenium could be significantly improved in the meat through feeding practices of food animals. This is however more challenging task in meat production from ruminants due to ruminal biohydrogenation of dietary lipids. In addition to production approaches, post-harvest approaches could be also beneficial to produce low fat, low sodium, fibre enriched; low-calorie meat products to add further value and make them more functional/healthier for human consumption.

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Chapter 12

Meat Quality and Authenticity: A Proteomic Approach

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12.1 Introduction

Proteomics can be defined as the systematic determination of protein structure, sequence, quantity, activity, interaction, and state of modification, in a particular cell at a specific time (Campbell, 2003). More precisely, proteomic analysis directly deals with the measurement of proteins with respect to their presence and relative abundance (Wilkins et al., 1996). Meat quality is not a single value; it encompasses a diverse array of characteristics relating to color or appearance and palatability (texture/tenderness, flavor, and juiciness), nutritive aspects including composition, proteins, mineral, and fatty acid profile and in a broad sense also includes meat safety (Leheska et al., 2008; Verbeke et al., 2009). Unlike genomics, the proteome is dynamic and varies with the physiological state of the organism. It is well known that many aspects of meat quality are heritable, quantitative traits for example fiber characteristics or metabolic pathways in live muscle or postmortem condition. Even if the genetic background is determinant, environmental conditions and meat processing contribute in a major way to the development of meat quality.

Meat authentication has been a major concern of producers, regulators, and consumers in the modern era. Health-conscious consumers demand a clear and detailed description of the meat they consume especially processed meat products where a visual differentiation of components is merely possible. According to Montowska and Pospiech (2012), issues of meat and meat product authenticity can be categorized as follows: i) replacement of ingredients, most frequently by cheaper meat species, ii) addition of undeclared constituents of animal origin, e.g. offal, mechanically recovered meat (MRM), etc. iii) proportion of ingredients incompatible with the product label or specification, iv) sale of fresh meat that had earlier been frozen, v) improper labeling of the geographic origin of the products, vi) specification of meat derived from domestic animals as meat obtained from game animals, vii) undeclared addition of plant proteins or milk, and viii) sale of products manufactured non-ecologically as ecological products. As the amino acid sequence is species-specific just like the DNA sequence, extraction of proteins or peptides are more feasible compared to DNA extraction and primary amino acid sequence of peptides are more resistant to processing conditions than the DNA sequence, proteomic technologies have emerged as a complimentary methodology to the DNA-based approaches in determination of meat authenticity. Recent advancement in the field of proteomics has allowed the researchers to explore the biomarkers to be exploited as indicators of meat quality and authenticity (Fig. 12.1). Identification of protein markers would offer a powerful tool to be transferred to the meat industry for improved assurance of meat quality.

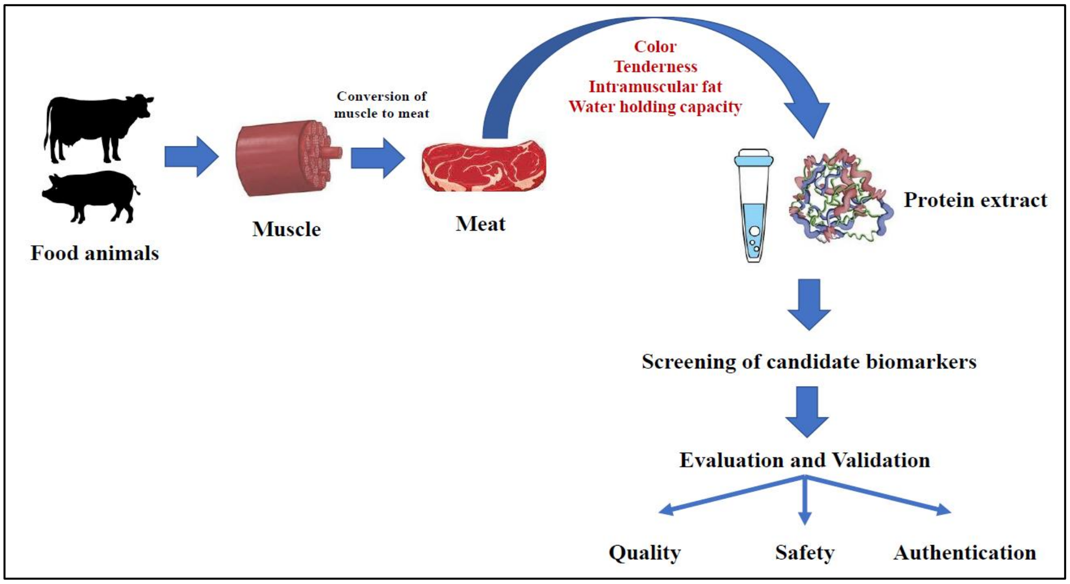

Fig. 12.1 Proteomic workflow in the search for protein biomarkers regarding meat quality and authenticity

12.2 Meat Quality

Meat color is an important quality attribute that critically influences consumer purchase decisions (Nair and Zhai, 2020). The color of raw meat is a combination of the influence of sarcoplasmic protein myoglobin and the changes in reflection due to protein denaturation (Aaslyng, 2002, Miller, 2002). Thus, proteomic approaches can help in understanding changes in meat color as well as examine the fundamental basis of muscle-specificity in meat color. Proteomic analysis of sarcoplasmic proteins of pig *Semimembranosus* muscle characterized by high and low lightness (L*) values revealed differential expression of 22 proteins or fragments (Sayd et al., 2006). Mitochondrial enzymes of the respiratory chain, hemoglobin, and chaperones (HSP27, α-β crystallin, etc.) were in abundance in darker meat with more oxidative metabolism, whereas, enzymes of glycolysis were overexpressed in the lighter group. Zapata et al. (2012) compared breed-specific sarcoplasmic proteins in the *Pectoralis major* and *Supracoracoideus* breast muscles and suggested that pyruvate kinase, which exhibited greater abundance in *Pectoralis major* of broilers, could be utilized as a marker for a rapid pH decline that might be related to "pale poultry muscle syndrome".

Tenderness is a complex, multi-factorial trait, and the post-mortem variation in tenderness between species, breed, age, muscles, and processing conditions was explored in recent years utilizing different proteomic tools. Lametsch et al. (2003) first explained the potential relationship between post-mortem proteome variations and meat tenderness in porcine *longissimus dorsi*. These authors reported that postmortem degradation of actin and myosin heavy chains is highly related to meat tenderness. Many researchers have predicted heat shock proteins (HSPs) as a potential biomarker of meat tenderness (Kim et al., 2008; Laville et al., 2009; Polati et al., 2012). Their role in meat tenderization may be attributed to their ability to preserve cellular proteins against stress-induced denaturation and possible loss of function (Feder and Hoffman, 1999) and stabilizing the muscle filament assembly during the period of stress (Feasson et al., 2002; Perng et al., 1999). Kiran et al. (2016) successfully identified few important proteins including complement C1q subcomponent subunit B, uroplakin-1b, aspartate aminotransferase, myosin-IIIa, glycogen phosphorylase, cytosolic carboxypeptidase 3, and phosphatidylinositol transfer protein β isoform which may be useful as biomarkers for differentiation of young and old Indian water buffalo meat.

Water holding capacity (WHC) is not only important to sensory acceptability and economic reasons but also due to its consequent effects on meat quality. Loss of water and soluble constituents in the form of drip occurs as a result of denaturation of contractile proteins and shrinkage of myofibrils during rigor development (Bertram et al. 2004, Offer et al. 1989). several proteomics studies have been performed to increase our understanding of the underlying mechanisms governing this trait and to identify potential protein biomarkers for WHC. Candidate protein markers (creatine phosphokinase M-type, desmin, and a transcription activator) relevant to drip loss in porcine muscle have been identified by van de Wiel and Zhang (2007) using 2-DE. Yu et al. (2009) found a relationship between the decline in heat shock protein expression (α-β crystallin, HSP27, HSP70, and HSP90) and increased drip loss in *Longissimus dorsi* muscle, a possible cause resulting in poor meat quality. Table 12.1 represents some of the important candidate protein markers involved in the regulation of meat quality characteristics.

Table 12.1 Proteins involved in meat quality attributes

Species/muscle	Quality characteristics	Proteins involved	References
Pig *Longissimus dorsi*	Texture (WBSF) Color (L*) WHC (drip loss)	MLC I, desmin, troponin T, cofilin 2, F-actin capping protein β subunit, ATP synthase, carbonate dehydratase, triosephosphate isomerase, actin & its relevant peptides, peroxiredoxin 2, α-βcrystallin and HSP 27 kDa	Hwang et al. (2005)
Pig *Longissimus dorsi* *Biceps femoris*	WHC (drip loss)	Creatine phosphokinase M-type, desmin, actin dependent regulator of chromatin a 1 isoform b	van de Wiel and Zhang (2007)
Pig WHC (drip loss, Expressible moisture)	Color (L*, a*, b*)	α-β crystallin, HSP 27, HSP 70, HSP 90	Yu et al. (2009)
Bovine *Longissimus dorsi*	Texture (WBSF)	MHC, MLC, actin, troponin C, desmin, and tubulin or their fragments, HSPβ6, cysteine- and glycine-rich proteins, α- and β-hemoglobin	Zapata et al. (2009)
Bovine *Longissimus thoracis*	Tenderness (sensory analysis)	Succinate dehydrogenase, actin, MyBPH, HSP27, α-crystallin	Morzel et al. (2008)
Bovine *Longissimus thoracis*	Texture (WBSF)	Peroxiredoxin 6	Jia et al. (2009)
Indian water buffalo *Psoas major* *Longissimus lumborum*	Tenderness	Calcium-transporting ATPase type 2C and calcium/calmodulin-dependent 3′,5′-cyclic nucleotide phosphodiesterase 1B heat shock protein beta-1	Kiran et al. (2015)
Indian water buffalo	Tenderness	complement C1q subcomponent subunit B, uroplakin-1b, aspartate aminotransferase, myosin-IIIa, glycogen phosphorylase, cytosolic carboxypeptidase 3 & phosphatidylinositol transfer protein β isoform	Kiran et al. (2016)
Yak *Longissimus lumborum*	Drip loss	Heat shock protein, myosin light chain, and triosephosphate isomerase	Zuo et al. (2016)
Chicken whole muscle proteome	PSE meat (pale color and drip loss)	Actin alpha, myosin heavy chain, phosphorglycerate kinase, creatine kinase M-type, β-enolase, carbonic anhydrase 2, proteasome subunit alpha, pyruvate kinase, and malate	Desai et al. (2016)

dehydrogenase

12.3 Meat authenticity

Meat authentication is the process that verifies that the product complies with its label description. Recent advancement in the field of omics especially proteomics has allowed the researchers to explore the biomarkers to be exploited as indicators of meat quality and authenticity (Fig. 12.2).

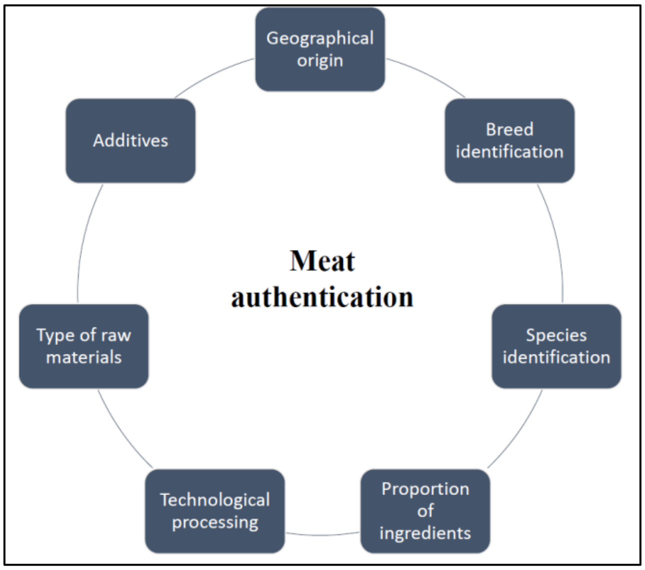

Fig. 12.2 Potential problems of meat authentication

Table 12.2 reviews the meat authentication studies using proteomic approaches. The robustness of proteomic technology was reflected in the research work carried out by Naveena et al. (2017) to authenticate ruminant species, such as cattle, water buffalo, and sheep. Myofibrillar proteins from meat mix were fractionated using OFFGEL fractionator followed by SDS-PAGE of individual fractions, in-gel trypsin digestion of selected protein bands, and protein identification using tandem mass spectrometry. The proteomic approach was successful in the identification of MLC-1/MLC-2, a peptide marker for authenticating contaminating buffalo meat in sheep meat mix as low as 0.5% in both raw and cooked meat mixtures. Fornal and Montowska (2019) were able to successfully identify unique peptide markers of duck, goose, and chicken in highly processed multicomponent food products using liquid chromatography and high-resolution quadrupole time-of-flight mass analyzers. Researchers have also utilized immunosensing for the detection of meat adulteration (Kuswandi et al., 2017; Lim & Ahmed, 2016; Mandli et al., 2018; Masiri et al., 2016). Using an electrochemical competitive immunosensor based on an antipig IgG polyclonal antibody, as low as 0.01% pork adulteration, could be identified within 20 min. The lateral flow device was able to identify 0.01%, 0.1%, and 1% pork from raw meat, beef meatballs, and cooked meat, respectively (Kuswandi et al., 2017; Masiri et al., 2016).

Table 12.2 Meat authentication using proteomic approaches

Meat mixes	Analytical approaches	Species-specific proteins/peptides	References
Cattle, pig, sheep, goat, chicken bone collagen	MALDI-MS/MS	GPSG EOGTAG POGTOG PQGLLGAOGFLGLOGSR (sheep	Buckley et al. (2009, 2010)
Bovine and porcine meat and bone meal (MBM)	MALDI-TOF MS and HR-QTOF MS	Detection of species-specific osteocalcium derived maker peptides with high sensitivity	Balizs et al. (2011)
Raw and heat-treated mutton	Lateral flow assay kit using PCR amplification and hybridization of amplicons to the probe	Displayed had a sensitivity of 0.01 picogram of sheep DNA and 0.01% for the detection of adulterated meat; results were visible within 5 min	Yin et al. (2016)
Raw and cooked ground sheep meat and buffalo meat up to 0.5% substitution	OFFGEL electrophoresis with MALDI-TOF MS and ESI-QTOF MS/MS	Detection of contaminating buffalo meat in sheep meat as low as 0.5% in meat mixes containing species specific peptides derived from MLC-1 (EAFLLFDRTGECK and EAFLLYDRTGDGK for water-buffalo and sheep respectively) and MLC-2 (FSKEEIK and FSQEEIR for water-buffalo and sheep respectively)	Naveena et al. (2017)
Water buffalo, sheep, and goat meat mixes	2DE (in-gel) and OFFGEL electrophoresis coupled with MALDI-TOF MS	Detection of up to 1.0% substitution of sheep and goat meat in buffalo meat using the in-gel method, whereas OFFGEL approach detected up to 0.1% substitution of sheep and goat meat in buffalo meat	Naveena et al. (2018)
The raw and cooked meat of pig, chicken, duck, cattle, and sheep	UPLC-Triple TOF-MS	Identification of eighteen unique species-specific heat-stable peptide biomarkers (WGDAGATYVVESTGVFTTMEK for pig meat, CLAAALIVMTESGR, FCGWYDADLSPAGQQEAR, and MTEEEVEELMK for chicken)	Wang et al. (2018)

12.4 Conclusion

Understanding the biological pathways and processes underpinning meat quality are being accelerated by the application of proteomic approaches. With the growing demand for animal protein and increasing awareness among consumers regarding the composition of meat, it becomes essential to authenticate the source of meat correctly. Analysis of multi-/all-component targets in a single assay platform is a long-term requirement and technological challenge in the meat industry. Further studies using proteomics integrated with other -omics methods such as genomics, transcriptomics, and metabolomics will augment our efforts to address the challenges of meat production, quality, processing, and safety.

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Chapter 13

Wool Production and Quality in Indian Perspective

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13.1 Introduction

Wool, nature's gift to sheep, enjoys the status of being luxury fibre! The luxuriousness is owing to unique properties and thereby the higher cost of the fibre. The superior warmth, comfort, and flame retardancy are some of the well-known properties of the wool fibre. Due to these properties, wool is being used for manufacturing premium apparel, carpets, and upholstery since the early civilization of our society. With the change of time, synthetic fibres dominated the natural fibres including wool. The cheaper price and high production rate of synthetics gradually replaced wool in various applications. However, wool is still an important basis of textile industries, especially in the decentralized sector. Wool harvest and processing have remained a livelihood source for many families since their generations. Further, the petroleum crisis and increasing sustainability awareness highlight the importance of wool fibre. Besides textile production, wool has been used in technical applications such as industrial felts where synthetic fibres failed to perform. This article briefly describes the global scenario of wool production and quality and mainly focusing on the Indian context.

13.2 Wool production

According to the international wool textile Organization (IWTO) statistics of 2020, the global clean raw wool production was 109,098 mkg produced by more than 1.163 billion sheep. Australia, China, United States, and New Zealand are the world's leading producers of wool. Table 13.1 shows that there has been an overall reduction in global wool supply in past decades, however, the fall in fine wool production is more pronounced than that of medium and coarse wool. In 1990, around 50% of global wool produced was fine grade wool (≤24.5 µm), but by 2010, this proportion declined to 36%. In contrast, the share of coarse wool (≥ 32.5 µm) has increased from 30 to 42% over the same period. However, the share of medium wool (24.6-32.5

μm) has remained unchanged at around 22% (Rees and Kim, 2010). An increased preference for dual purpose (wool and meat) sheep breeds due to less profit in wool growing, was a major factor behind the reduction of global fine wool production (Rees and Kim, 2010). In addition, the rising use of medium (24.6–32.5μ) and coarse grade wool (above 32.5μ) in home textiles over fine wool in apparel contributed towards higher production of medium and coarse wool.

Table 13.1 World wool production (MT) for three grades of wool from the year 1990 to 2010

Year	Fine	Medium	Coarse
1990	0.948	0.440	0.610
2000	0.580	0.300	0.515
2010	0.428	0.280	0.500

Source: IWTO (Rees and Kim 2010)

India ranks 3rd after Australia and China in sheep population with 65.06 million sheep heads, however, among wool-producing countries, India ranks 9th due to lower wool productivity (0.9 kg/sheep/year) as compared to the world average of 2.4 kg/sheep/year. India accounts for approximately 2% of global wool production. Fig. 13.1 shows the wool production in India for 25 years. The wool production steadily increased from 1992 (38.8 million kg) to 2002 (50.5 million kg) which was the peak of all time. Following years witnessed a drop in production (44.6 million kg) mainly due to draught in 2004-05. The lowest production recorded in 2008-09 (42.8 million kg). Afterward, the wool production increased with marginal growth of 1% and reached 48.14 million kg in the year 2015. Due to hardship in sheep rearing practices and an increase in slaughter rate of sheep from 38 to 65%, the Indian wool production dropped to 43.05 million kg in 2016-17 and remained stagnant in 2017-18 (43.2 million kg). It is further dropped in 2018-19 to 40.2 million kg. However, the rise in wool production is expected in near future as a consequence of sustainability awareness and steps towards mitigation of climate change impact.

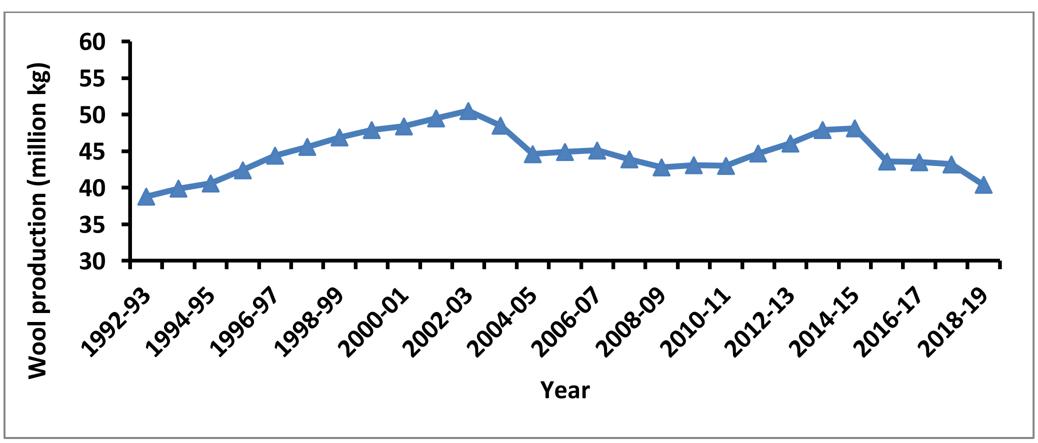

Fig. 13.1 Trend of wool production in India (MOA, Govt. of India report)

Table 13.2 Wool production in India

State	**Sheep population ('000)**	**No. of families (In lakhs)**	**Wool quality**	**Wool Production ('000 Kg.)**	**Woolen Products produced**	**Wool Price (Rs./kg)**
Jammu & Kashmir	3389.49	0.85	Apparel Grade 24-28 µ	7411	Handloom, shawls, Carpets, Namda & tweed fabric	80-110
Himachal Pradesh	804.87	0.40	Apparel Grade 22-28 µ	1500	As above	40-90
Uttarakhand	368.76	0.17	Apparel Grade 22-28 µ	558	As above	30-120
Rajasthan	9079.70	2.50	Carpet Grade 28-38 µ	13924	Carpet, Handloom shawls, Suiting's	30-110
Uttar Pradesh	1353.65	1.10	Carpet Grade 28-38 µ	1404	Carpet, Handloom shawls, Suiting's	30-60
Madhya Pradesh	308.95	0.15	Carpet Grade 30-38 µ	414.52	Yarn	30-60
Gujarat	1707.75	0.16	Carpet Grade 28-38 µ	2267	Yarn, suiting's & Handloom shawls	30-110
Maharashtra	2580.38	1.03	Carpet Grade 28-75 µ	1418	Yarn, suiting's & Handloom shawls	10-30
Karnataka	9583.76	5.33	Coarse Grade 28-75 µ	4392	Coarse quality rugs	10-30
Telangana & Andhra Pradesh	26395.58	9.34	Coarse Grade 28-75 µ	5593	Coarse quality rugs & shawls	10-30
Total	**65000**	**20 lakh**		**41475**		

Table 13.2 describes state-wise wool production, quality, and price along with sheep population and number of families supported by sheep husbandry. Rajasthan (33%), J & K (18%), Karnataka (10%), Telangana, and Andhra Pradesh (13%) are major wool-producing states/union territory. These states contribute about 75% of the total wool produced in the country. The rest of the wool is produced by other states i.e., Himachal Pradesh, Uttarakhand, Madhya Pradesh, Maharashtra.

The total wool sector gives employment to more than 15 million people out of whom nearly 5.8 million are involved in the wool processing sector, 2 million families in sheep rearing, and the remaining are in wool traders and merchants. In the wool sector, mostly full family members are associated with wool production and allied activities.

13.3 Wool quality

The wool produced all over the world can be broadly grouped into three grades: fine, medium, and coarse. The wool below 25 μm in diameter is a fine wool that is used for the manufacturing of apparel. The medium wool having 25–35 μm diameters are suitable for carpets. The coarse wool, considered as waste, has more than 35 μm fibre diameter. Indian wool is almost exclusively of broader micron and used in the manufacturing of carpets and rugs. Out of produced wool in the country, the highest (60-80%) is carpet grade wool followed by coarse wool (20-40%) and fine apparel grade wool (5-10%). The fine wool produced in India is processed on the semi-worsted spinning system in the decentralized sector for shawl manufacturing. India is exporting woollen items (Handmade carpets, RMG, Fabric) worth Rs.11484.82 crore (2017-18) including carpets (Rs.9196.99 crore). Wool production is not sufficient to meet the demand of industry hence India has to import raw wool. India has imported 79.95 million kg raw wool (2017-18), both apparel and carpet grade, worth Rs. 1884.59 crore. (Annual Report, MOT, 2017-18).

The wool produced in India has diverse quality attributes due to different climatic conditions across the country. Wool classification is based on the agro-climatic conditions and breeds of sheep available. Except for the Northern temperate region, the majority of wool produced is medium-coarse and thus not suitable for the production of quality fabrics viz. suiting, knit wears, etc. India has 42 registered sheep breeds. Among them, 13 breeds of North-West arid and semi-arid regions contribute maximally to the carpet quality wool production. Apart from these 8 sheep breeds of North temperate region produces a fine and medium type of wool which are suitable for shawl and knitwear.

Further reading:

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Chapter 14

Physical and Chemical Properties of Wool

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14.1 Introduction

Wool is an important natural fibre sourced from sheep, goats, lamas, and rabbits, etc. It belongs to a family of natural protein fibres. Wool is composed of a protein called keratin. The other keratins materials present in nature are feathers, horns, beaks, nails, and outer skin layers. The wool keratin is produced of a copolymer of 18 amino acids such as glycine, alanine, serine, proline, valine, and threonine, etc. Wool fibres have been used as a textile fibre for various applications such as apparel, home textiles, and technical textiles for years.

14.2 Physical properties of wool

Fiber length and diameter

Length and diameter of fibre is an important factor to control the quality of the wool. Processing performance, textile properties, and the comfort perceptions of wearers are affected by the length and diameter of wool. Wool fibre value and quality are directly associated with its properties such as diameter and length. The staple length of wool is an important factor of wool processing performance and fibre breakage as well as the yarn tensile characteristics. In general, a longer fiber length is better than a shorter staple length. Fibre spinning process with long staple length is easier than short-staple and long-staple fibres produce stronger and more even yarns compared to shorter staple fibre. Fibre diameter is also an important factor to determine the wool fibre quality. Fiber diameter has a major role in fiber stiffness, which then affects the stiffness, drape, and feel of the fabric. The fiber stiffness also affects how soft or how prickly the fabric feels when it is worn next to the skin. The wool fiber diameter can be determined by various methods such as micro-projection, laserscan, and image analysis methods. Based on the fibre diameter, the wool fibres are graded into fine, medium coarse, and coarse wool.

Fibre tensile strength

One of the most important properties of fibre is the tensile property. Tensile properties of yarns and fabrics depend on both complex fibers arrangements inside the yarn and fabric structure, and also on the tensile properties of fibers. As shown in Fig. 14.1, the tensile properties of wool are quite variable but, typically, at 65% relative humidity and 20 °C, individual fibres have a tenacity of 140–180 MPa, a breaking elongation of 30–40%, and an initial modulus of 2.7–3.9 GPa. It is observed that when wool fibre absorbs moisture, its tensile strength decreases.

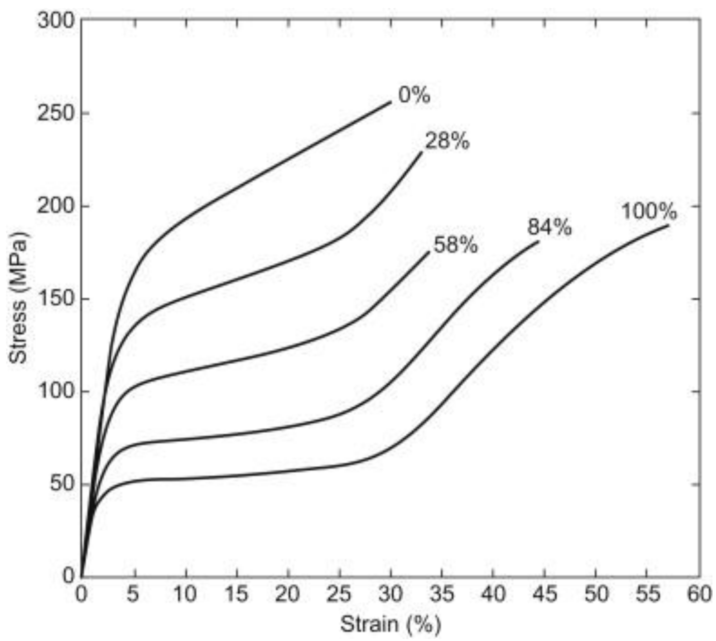

Fig.14.1 Stress-strain curves of wool fibres at different relative humidities

Resiliency

Wool has very well resilient property. The term resiliency refers to the property of the wool fibre to bounce back to the original position after the application of force. The disulphide bonds in the amorphous parts of fibre can stretch when the fibre is extended. When the fibre is released from its extended position the disulphide bonds pull the protein molecules back into their original positions. This property is highly important for carpet-grade wool.

Hydroscopic nature

Wool is the most hygroscopic material among the natural fibres, moisture absorption reaching 33% to its dry mass. Owing to the protein structure, wool absorbs a large amount of moisture, which attach by a hydrogen bond to the amino acids. The moisture absorption of wool results in a dissipation of heat which is around 110 J/g for 18% moisture take up.

Conductivity of heat

Wool has a poor conductivity of heat and therefore makes it ideal for cold weather. The resiliency of the wool is important in the warmth properties of the fabric. Wool fibres do not pack well in yarns because of their crimp and scales. This makes wool yarn fuller and capable of inserting much air. Air is one of the best insulators since it keeps body heat close to the body. The medulla of the wool fibre contains air spaces that enhance the insulating power of the wool.

The wool fibre can take up moisture in vapor form. The absorbency of fibre is a factor in the warmth of clothing. In winter, when people go from a dry indoor atmosphere into the damp outdoor atmosphere, the heat developed by the woolen garments in absorbing moisture keeps protecting their bodies from the impact of the cold atmosphere.

Felting Properties

Felt is a textile material that is produced by matting, condensing, and pressing fibers together. Felting is the irreversible shrinkage of the wool fibre. Wool has very good felting properties because of its peculiar structure and a high degree of crimp. The serrated scale of the wool moves towards the root ward direction under high temperature and causes it to curl into each other as a result felting occurs in the wool. This interlocking of the scales causes shrinkage in the woollen materials. Wool can make felting even when mixed with other fibres. Unlike bonded non-woven fabrics, felts do not require an adhesive substance for their production. Sometimes woven fabrics which are made of blended woolen yarn may be felted, making them thicker and more compact. Such fabrics, sometimes called woven felts which serve many of the same purposes.

14.3 Chemical Properties of Wool

Effect of moisture

Wool is a hydrophilic protein fibre. The protein in the wool contains -CO.NH- group which can attract the moisture present in surrounding air. It can absorb and desorb moisture vapour as surrounding conditions around it change. This process is a form of equilibrium reaction. Under standard atmospheric conditions of 65% RH and 20°C wool absorbs about 13-18% of moisture.

Effect of heat

Wool is sensitive to heat but does not catch fire easily. Wool has the highest Limiting Oxygen Index value (LOI) among natural fibres. Its LOI value lies between 24 and 27. Wool becomes soft during elevated temperatures. At 130°C it started decomposing and chars at 300°C.

Effect of sunlight

The effect of sunlight causes yellow or dull-colored woolen fabrics. The ultra-violate rays present in sunlight cause the peptide and disulphide bonds to break. This leads to polymer degradation products on the surface of the fibre. The extensive exposure to sunlight weakens the wool fibres very much. Wet woolen fabrics are more prone to be faded exposed to sunlight than dry fabrics.

Effect of alkali

Alkaline solutions can easily damage woolen fabrics. Wool can be dissolved in 5% sodium hydroxide solution at boiling temperature. Weak alkali solutions like sodium carbonates can damage wool when used in hot conditions, or for an extended period. Wool treated with alkaline solutions, the disulphide cross-links present in wool is opened and gets dissolved.

Effect of acids

The protein fibre wool is more resistant to acids than alkali treatment. Acids can hydrolyze the peptide groups present in wool but leave the disulfide bonds intact, which crosslink the polymers. Weak acids have little effect on wool but concentrated acids weaken or dissolve the wool fibres.

Effect of Bleaching

Bleaching agents which contain chlorine compounds may damage the wool fibre. Bleaching agents like hypochlorite will cause wool to become yellow and dissolve it at room temperature. It is suitable to bleach the wool hydrogen peroxide bleaching agent.

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Chapter 15

Wool Fibre to Fabric Conversion

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15.1 Introduction

Textile clothing consumption is growing over the years due to the increase in population, rapid urbanization, and rising disposable income levels. An increase in clothing consumption leads to the enhanced requirement of its raw material for the manufacture of clothing namely textile fibres. Textile fibres used in the manufacture of clothing are classified into major groups as manmade fibres and natural fibres. Commonly used manmade fibres in clothing are polyester, viscose, nylon, and acrylic. Natural fibres that are dominantly consumed in the manufacture of clothing are cotton and wool. Among the textile fibres, polyester and cotton together meet 82% of the world fibre requirement and the remaining 18% is met by cellulosic, nylon, polypropylene, acrylic, and wool. Wool's contribution to world fibre consumption is 1.3% (Pattinson *et al.*, 2015). Wool in the form of fibre and as a converted product is traded worldwide. Wool is found in applications in diversified product manufacturing that range from apparel to industrial textiles. Major methods used to convert wool fibre to the fabric are weaving, knitting, carpet making, and felt making. Among the methods of conversion of fibre to yarns, CSWRI is having a woolen spinning system coupled with sectional warping, handloom, and finishing machinery for the preparation of blankets. Details of various sequences of the process involved in converting raw wool from fibre to fabric are covered in this manuscript (Fig 15.1).

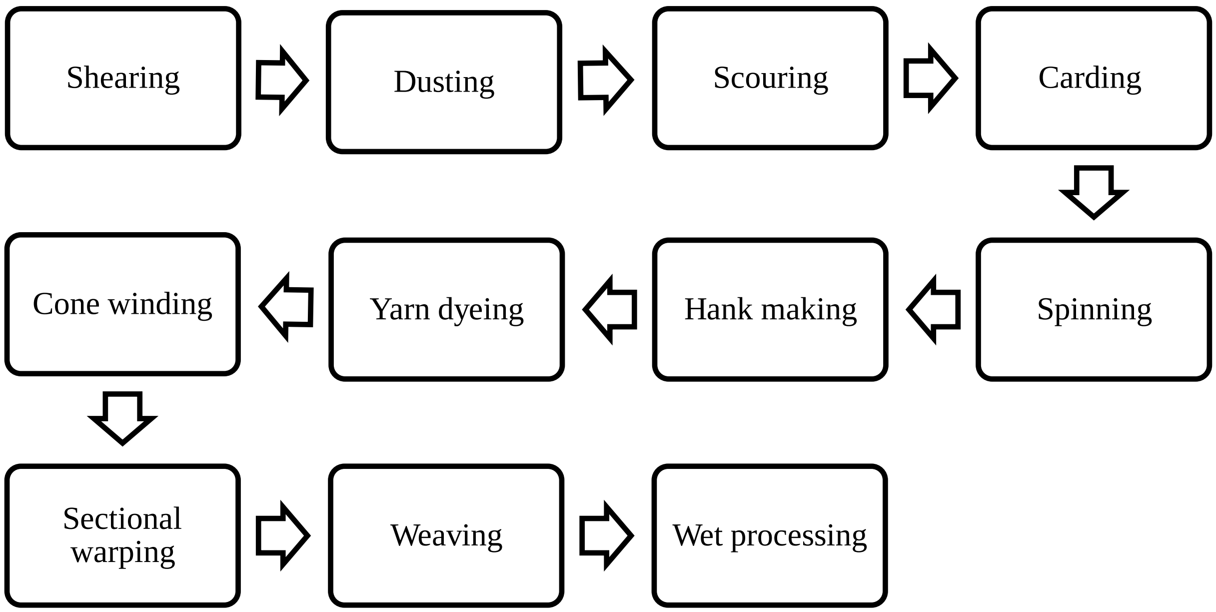

Fig 15.1 Wool process flow chart

15.2 Wool shearing

Wool processing involves a sequence of steps like dusting, scouring, carding, spinning, hank making, yarn dyeing, cone winding, sectional warping, weaving, and wet processing. Wool is removed from the skin of the sheep either manually or using the machine. In the manual shearing process, scissors are used to remove the wool. Manual process has certain problems like skin injury, double cutting, and high shearing time. In the manual process, the shearer may not go near to the skin and in the process, the wool length obtained will be shorter. There is a chance of the shearer cutting the skin and causing injury to the sheep. Machine shearing is the preferred method to manual shearing due to the reduction in shearing time. Before shearing, Sheep should be washed and wool should be in a dry condition at the time of shearing. If not, there is a chance of wool picking up dust during shearing. Sheep should be separated by breed/black face/white face and the sheared wool should be kept separately. In Rajasthan, wool is sheared twice a year i.e., in March and September. From a wool processing point of view, the longer the wool, the better the quality of processing, and hence one-time shearing is advocated. The annual wool yield in India is 0.9 kg, whereas the world average annual yield is 2.4 kg.

15.3 Dusting and scouring

Dusting is the first process after the sheared wool reaches the wool processing plant. The dusting machine consists of 6 beaters arranged in an inclined plane. The raw wool is fed from the bottom and emerges from the top. The beaters are having spikes of 4 inches in length rotating at 120 rpm opens the lumps of fibre and beat the wool against the grid bars. The sand and dust get loosened from the wool and falls through grid bars. The waste percentage removed in the dusting machine goes up to 10%. The dusted wool is taken to the next process called scouring.

Scouring is done to the wool to remove grease, vegetable matter, and other impurities that are left out even after dusting. Wool is scoured in three bowls (tank) systems in the plant. Each tank is filled with water and then sodium carbonate (3%) and non-ionic detergent (1%) are added and then the temperature is raised to 50 °C. Then the wool is dropped into liquor and is agitated for 30 minutes and then wool is squeezed through rollers to remove the excess water. The process is repeated in the next two tanks and finally, the hydro extractor is used to remove the remaining water. The scoured wool is dried by spreading it on the floor.

The next step after scouring is carding. Before carding, to avoid the generation of static electricity and to enable smooth processing without any fibre breakage, 4% lubricant (mahua oil) is sprayed on the wool along with the addition of detergent as an emulsifier.

Carding machine

The major objectives of carding are:

- To open the clumps of wool that is formed during scouring
- To align the fibres parallel in the longitudinal direction
- To intermingle fibres and to see that uniform distribution of fibres across the card is happening such that linear density of roving is maintained in its full length of production
- To remove the remaining impurities like trash, dust, sand, and vegetable matter
- To produce homogenous roving with equal distribution of weight per unit length of roving

The objectives of carding are achieved using rotating cylinders, lickerin, workers, strippers, and rollers. Carding consists of two carding units with the feeding side card is called a cross lapper and the delivery side card is called a condensing unit. The elements of carding machine are shown in Fig. 15.2. Carding machine has a feeding unit, lickerin, cylinder, workers, strippers, and doffer.

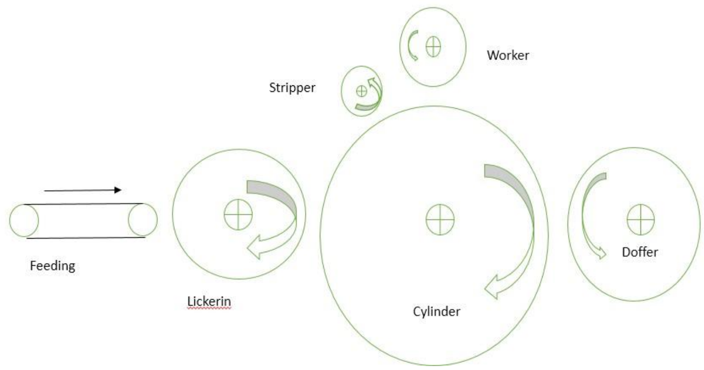

Fig. 15.2 Carding elements

All elements are mounted with metallic clothing to comb the fibres. Wire points of cylinder and worker are in opposing direction and worker is rotating slower speed than a cylinder. The main opening and blending happen at the worker cylinder region. Fibres are transferred from cylinder to worker then it is stripped from worker and then returned to cylinder. This transfer and re-transfer lead to individualization and blending. Each carding unit has several types of horizontal rollers rotating in a clockwise direction for some rollers and an anti-clockwise direction for other rollers. The biggest roller is called a cylinder. All the rollers are having sharp pins and the fibre clumps get opened due to the penetrative action of pins. The impurities like sand, dirt, and dust fall under the cylinder. The opened and individualized fibre is finally converted into a roving of several strands and wound onto spools. After the spools have reached full size, they have taken out and placed at the feed roller of ring spinning. The roving as it comes off the card has no twist. It is held together by the oil and natural scales that exist on the surface of the wool fibres. The main difference between woolen carding and worsted carding is that the output of the former is roving and for the latter it is sliver.

15.4 Ring spinning

The roving is drafted and twisted at the ring-spinning machine. Drafting is stretching between rollers. During stretching fibres get straightened and this results in an improvement in strength but there is a slight loss of extension. During drafting, the linear density of the yarn is adjusted to get the required yarn count. The spinning frame inserts the actual twist on the roving and turns it into yarn. The yarn is collected on wooden bobbins. For blanket making, a yarn count of 4.0 Nm is made at the spinning system. Metric count indicates the fineness of the yarn and for example yarn count 4.0 Nm means that 4 metres of yarn weigh one gram.

The yarn from wooden bobbins is converted into skein (Hank) form and then taken for yarn dyeing. In yarn dyeing, colour is applied to the yarn. The coloured yarn is converted into a warp beam in a sectional warping machine. This yarn is used in the warp direction. The same coloured yarn is converted into pirns and used in a shuttle for weft insertion. In a small-scale wool processing plant, handloom is used to convert yarn into fabric. The blanket fabric is woven with the specification of 23 ends per inch, 18 picks per inch, and with a width of 4 ft. The blanket developed out of this fabric has a size of 8 ft x 4 ft and weighs about 2.0 kg.

The loom stage blanket fabric is taken to a milling machine. This process shrinks the material down to a smaller size while matting up the fibres into a thicker and softer felt-like fabric. First, the fabric is steeped in a soap bath to clean and soften the wool. Around 10 blankets are sewn together and is run between the rollers until it had become shrunk down enough.

The milled and scoured blankets are taken to the raising machine to raise the fibres. The raising machine is having cylinders covered with fine steel wires which draw out the fibres of the wool from the surface of the fabric and give it a soft, fleecy finish.

Next, the blanket is fed to the stenter machine, which is a drying machine with a device for holding the stretched wet blanket while it travels through the machine. The usual method consists of two endless chains on which steel pins are mounted. As the chain moves through the machine the cloth is fed onto the pins and it is held taut while being dried. The distance in width between the chains can be adjusted to allow for differing widths of blankets. This machine does drying and heat-setting of the blanket.

15.5 Spinning methods

Wool is processed through three routes namely woollen spinning, semi-worsted spinning, and worsted spinning. Woollen yarns are made through the shortest route that involves mainly carding and spinning. Semi worsted incorporates an additional process called gilling apart from carding and spinning. In the case of worsted spinning, two additional processes called gilling and combing are used before the wool is converted into yarn. In broad terms, woollen spinning is mainly used for the making of furnishings and blankets, semi-worsted is mainly deployed for carpet making yarns and the worsted spinning system is used for yarns that can be used in apparels. The worsted spinning system mainly uses long-staple fibres that are longer than 5.0 cm. Finer fibres with <27 μm are preferred for worsted spinning.

15.6 Gilling

In case of worsted yarn making, after carding, the sliver is taken to the gilling machine. The main objective of the gilling machine is to straighten, align and blend slivers from different cards. A gilling machine is also called a gill box or gill. Most of the fibres in the card sliver are having trailing hooks and these hooks to be straightened to improve fibre length and to reduce comber waste. The gilling machine consists of back rollers, front rollers, top, and bottom fallers. Several card slivers are fed simultaneously at the back rollers. Slivers are taken forward by fallers to front rollers. During this travel, top and bottom fallers are penetrated through the sliver web and moved at a speed slightly higher than back rollers. Fallers give a combing effect when the front edge of the fibres gets caught at the front roller. Similarly, fibre back end is held by the fallers as their speed is less than that of the front roller speed. This differential speed at back and front of the fibre leads to the removal of trailing hooks and straightening of fibre. A typical draft of 5 to 15 is used at the gilling machine. The total distance between the back and front roller is called a ratch. Similarly, the distance between the back roller and nip/faller line is called as back ratch, and the distance between the front roller and faller line is called as front ratch. Ratch setting should be optimized such that one gets maximum uniformity and minimum fibre breakage during gilling.

The worsted industry employs three gilling machines in between carding and combing. The combing machine has to be fed with trailing hooks to straighten it. However, in the case of the cotton system, this is in opposite wherein you have a feed sliver with more leading hooks. Feeding leading hooks as dominant in the input will lead to high waste in combing. There should be an odd number of machines between card and comber to get the right direction of feeding at comber.

15.7 Worsted combing

Combing is an important process in worsted yarn making. Combing helps to remove short fibres, neps, contaminants, mix fibres and prepare output sliver for the next process that is gilling. Woollen comber of rectilinear type is shown in Fig 15.3. The combing cycle consists of feeding a short length of silver, holding fed sliver in nipper, combing the front end by cylinder to remove neps, short fibres, and straighten hooks, and delivering the combed sliver through detaching rollers. During the process, the noil is extracted and noil% varies from 6 to 10%. Combed sliver is given two finishing gillings and moisture is adjusted to 18% and then taken to the next process called roving.

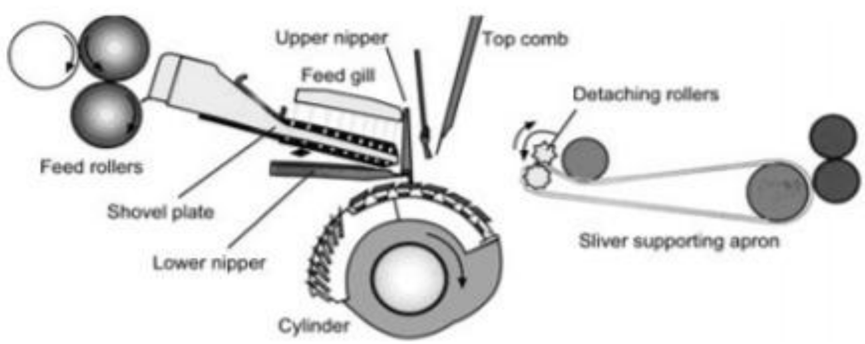

Fig 15.3 Combing machine principle

15.8 Roving machine

A roving machine is used to convert sliver into roving form through drafting and twisting. This process is used to reduce the draft at the ring spinning process. Very high drafts at the spinning machine will lead to poor drafting and uneven yarn. The roving machine is normally equipped with 3 over 3 rollers drafting which stretches the sliver. The stretched sliver called roving is wound to bobbin after insertion of twist. The roving machine is also called a rubbing frame. The delivery speed of a typical roving machine is 150 rpm with rubs/m of 6.

15.9 Worsted ring spinning

Worsted ring spinning employs a 3/3 drafting system with aprons. Roving is fed at the back of the drafting system, the drafted roving is twisted in a ring and traveller system and then wound on to cops. The spindle speed achieved in ring spinning is 12,000 rpm. After spinning, the yarn is taken to steaming to set the twist and to avoid snarling. Steaming is done at 84^0C for 20 minutes and allowed to cool for 8 hours for stabilization of moisture and twist. The next step after steaming is winding

15.10 Winding

Winding is used to converting the smaller package to a bigger package. During winding, yarn faults are removed. Electronic yarn clearers are used to remove the yarn faults. Yarn faults are replaced by spliced joints. Spliced joints have a strength of 80% of that of single yarn strength. Depending upon yarn count, the delivery speed is set from 700 to 1200 m/minute. After a single yarn winding, the wound package is taken to assembly winding wherein two yarns are wound in parallel in an assemble winder. The assembly wound package is creeled in Two for one twister (TFO). TFO machine inserts two twists in one spindle rotation and prepares yarn for weaving. Thus doubled yarn is prepared for weaving.

15.11 Weaving

Weaving is the process of converting yarn into fabric using equipment called a loom. Before the yarn is taken to the loom, various preparation processes are involved and one among them is sizing. Sizing is not required for worsted yarn as it uses double yarn. So yarn is taken directly to sectional warping. Cheese from winding is mounted on the creel of the warping machine that has a capacity varying from 480 to 544. The yarn from creel is passed through guides and tensioners and then wound to beam as sections. The machine speed is 600 m/minute with a drum diameter of 0.83 to 1.00 metres. After the preparation of sections, the yarns are passed on to the weavers beam and then drawn through heald wire and reed through knotting. If new construction is involved then manual drawing in is used. Weaving is carried out projectile looms having a width of 1.9 or 3.8 m at a speed range of 260 to 300 rpm. Picks per inch can be varied from 91 to 230. After preparation of fabric is sent to the finishing section to carry out the processes like bleaching, dyeing, and calendaring.

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Chapter 16

Quality Parameters of Fibre, Yarn, and Fabric

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16.1 Quality in the textile industry

In the era of the globalised clothing industry and increasing competition, the term 'quality' can survive one's business. The quality of fabric can be anything from consistency, aesthetic feel, perceived attributes, and functionality. Many times, consistency in quality has the edge over quantity, especially in the international market. The buying is done on three basic perception parameters – the fabric looks good, feels good, and offers good value for money. The functionality is associated with the performance, brand image, and end-use of the fabric. The measurement of specific properties during various stages of fabric manufacturing ensures the good quality of the fabric and its end-use. It starts from ensuring fibre quality followed by yarn and fabric quality.

Consistency
Cost
Performance
Prediction
Process control
Product development

Such quality control at each stage (fibre, yarn, and fabric) avoids defects during manufacturing which not only minimises the cost of production but also maintains the consistency of the product. The importance of quality testing also lies in customer satisfaction. For instance, the garment fabric prepared with a good drape will delight customers where the drape of the fabric is evaluated first and made better using suitable finishing treatment. Quality testing also predicts the performance of fabric under different conditions. Quality testing is invariably a major component of any research and product development program. Without testing, one cannot know the existing quality of the product thus the scope for further development remains unknown. There are numerous test parameters for fibre, yarn, and fabric made up of, but not limited to, wool. Hence, it is essential to know what quality parameters for fibre, yarn, and fabric should be tested.

16.2 Fibre quality parameters

Wool fibre is a raw material for the spinning industry. One should know and check the fibre quality parameters to ensure uniform and better quality of the yarn from the given wool fibre. Wool fibre quality is mainly determined by diameter, length, crimp, and strength of fibre.

16.2.1 Fibre diameter and medullation

The fibre diameter is the most important one which decides the end uses and spinning limit of fibre. The fibre diameter can be measured using a microscope. Recently the microscopic examination has become computerized and enabled with software analysis. Their automation brought preciseness and user-friendliness. The computerized microscope requires around 20 minutes to measure 300 fibres. Whereas the quickest method, Optical fibre diameter analysis (OFDA) takes only 40 seconds to measure 3000 fibres or so. The wool fibre diameter varies from 20–100 µm.

Besides fibre diameter, medullation is another distinct feature of some wool. The medullation refers to tubular hollow space at the center of the fibre. The medullation appears black under the microscope. Pure wool fibre is without medulla. Partially medullated fibre is called hetro. Coarsely medullated fibres and the medullated fibres whose medulla is continuous are called hairy fibres. Kemp is a highly medullated wool fibre, whose medulla has the width of the fibre or 80 percent of the total diameter of the fibre.

16.2.2 Fibre staple length

The staple is a bunch or tuft of fibres that naturally cling together in a fleece. Staple Length is the length of a staple obtained by measuring it in the unstretched condition. The staple length depends on the frequency of wool shearing. The lesser the frequency (once/year), the longer would be the fibre. Wool fibre staple length varies from 40 mm to 150 mm. Up to 60 mm length is spun on the woolen system. The fibres from 60- 100 mm spun on semi-worsted spinning. The worsted spinning requires a longer length of the fibre with a minimum cut-off of 45 mm.

16.2.3 Fibre crimp

This is the unique property of wool fibre. The crimp in the wool has a wavy structure as shown below in Fig. 16.1. The high thermal insulation in wool is attributed to the crimp property of fibre. The crimp is measured visually and expressed in crimp number per unit length or crimp per cm. The crimp frequency varies from 2-10 crimps/cm.

Fibre with crimp Fibre without crimp

Fig. 16.1 Fibre with and without crimp

16.2.4 Fibre strength

Fibres with low strength break easily during processing and lead to a lot of wastage. In addition to that, yarn made out of weaker fibres also low in strength and causes yarn breakages during weaving. The strength of individual fibre can be measured using a universal tensile testing machine. However, this measurement is laborious and time-consuming. Instead, the strength of the bundles of fibres can also be measured. The bundle strength measurement better represents the population compared to the individual fibre method. The bundle fibre strength of wool varies from 12-18 cN/Tex.

16.3 Yarn quality parameters

Good yarn quality ensures a better quality of the fabric. The important yarn quality parameters include count, twist, and strength. These yarn quality parameters largely decide the fabric construction details and the chemical processing route.

16.3.1 Yarn count

Yarn count describes the fineness of the yarn. There are two different systems to measure the yarn count. One is indirect count which denotes length per unit mass. Another is direct count which denotes mass per unit length. The higher the number in the indirect system, the finer the yarn would be and vice-a-versa in the direct system. The finer yarn results in more thread per unit length compared to the thick yarn.

16.3.2 Yarn twist

The twist is essential to keep component fibres together in a yarn. The strength and feel of the manufactured product depend on the amount of twist in the yarn. The twist introduced in the yarn during spinning depends on the count of yarn produced, the quality of fibre used, and the end-use of that yarn. The twist is defined as the spiral deposition of components of yarn and generally expressed as no of turns per unit length of yarn.

16.3.3 Single yarn strength and extension

The yarn should have sufficient strength and extension to withstand various stress and strains during fabric manufacturing. The yarn strength is measured using a universal tensile testing machine. Besides strength, it is important to determine the extension (elongation at break) to know the elasticity of the single yarn. Wool fibre and yarn are generally weaker than cotton and polyester yarns.

16.4 Fabric quality parameters

Fabric manufacturing is the second last step of the textile industry before chemical processing. Often, fabric manufacturing and its construction is pre-determined to cater to suitable end-use. Fabric can be manufactured using weaving, knitting, and nonwoven technique. The choice again depends on the end-use. Broadly, fabric quality parameters can be grouped into structural properties, mechanical properties, and functional properties.

16.4.1 Structural properties

Structural properties include threads/unit length, weave, cover factor, and areal density. These are generally measured when the fabric is prepared on a loom and after chemical processing of fabrics to determine the effect of chemicals on the fabric structure. The weave represents the thread up-down order during weaving. The fabric can be woven using different weaves like plain, twill, and satin. The cover factor indicates the tightness of the fabric. It depends on thread density and thread count. The chemical processing may improve the fabric's structural properties; however, they can deteriorate the fabric's mechanical properties due to the harsh nature of chemicals used while chemical finishing of textiles.

16.4.2 Mechanical properties

The critical mechanical properties include fabric strength (Tensile & Bursting), abrasion resistance, pilling, and friction behaviour of the fabric. The tensile test is the ability of the materials to withstand a pulling force. It is a measurement of force per unit cross-sectional area. The tensile test refers to the measurement of strength, modulus, and elongation properties of the fabric. Bursting strength is another way of strength measurement where the fabric is stressed in all directions at the same time. In this test, the resistance of the fabric to bursting is measured. Although generally used for knitted fabrics, the test is applied to non-apparel fabrics such as parachutes, sacks, and net. The measurement of the abrasion resistance of the fabric predicts the durability during the actual use of the fabric. It correlates with wear performance which depends on the end-use of the fabric. The mechanical deterioration of threads in the fabric is determined by rubbing the fabric surface against a geometric shape. Abrasion adversely affects the fabric strength and visual appearance. For each mechanical test, various standards have been prepared to ensure reproducibility and preciseness.

16.4.3 Functional properties

The fabrics can be manufactured for a specific function besides apparel. Those fabrics required specialized tests depending upon the functionality. For instance, the fabric intended to use as umbrella fabric should be tested for waterproofing. Similarly, firefighter clothing should be tested for flame retardancy and flameproofing. The clothing for the winter season and the clothing to be used in high-altitude areas should have good thermal insulation. Examples of functional fabric properties include waterproofing, bulletproofing, impact resistance, stab resistance, etc. Wool fabrics are known for better thermal insulation and high flame retardancy.

For each quality parameter of wool fibre, yarn and fabric, there is a standard test method prescribed by the Bureau of Indian Standards (BIS) and various other international agencies like the American Standard of Testing Material (ASTM).

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Chapter 17

Chemical Processing of Wool

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17.1 Introduction

Wool is one of the most ancient fiber used by mankind for the preparation of textiles. The conversion of the fiber sheared from the sheep to various textile products includes a series of mechanical and chemical processes. The important wet processing techniques involved in the processing of wool are tried to cover in this chapter. Additionally, the chemical modification of wool aiming at functionalization is also tried to cover to the maximum possible extent.

17.2 Scouring

The main objective of the preparatory process is to make the textile substrate ready for subsequent processing. It might be either an additive process by giving additional functionality to the fiber or a subtractive process by removing the unnecessary impurities. Scouring is the first stage of the preparatory process employed in wool processing. After removing the soil and other dust particles from the sheared wool, the wool fiber will be transferred to a scouring bath. The bath containing mild alkali (sodium carbonate) and a soap. A typical scouring recipe is shown below.

Recipe

Material	– X g
MLR	– 1:30
Wetting agent	– 1.0%
Sodium carbonate	– 2.0%
Duration/ Temperature	– 30 minutes / 55°C

After adding the required chemicals to the scouring bath, the wool will be loaded. Once the temperature of the water is reached 50-55°C, the wool will be agitated frequently. This process is continued for 30 minutes. After 30 minutes, the wool will be taken out and squeezed to remove the excess water. In the next step, the wool will proceed in the same conditions, but without soap and alkali. (i.e., only with warm water). Finally, the wool fiber will be taken to the third bath and washed in cold water to remove the soap, alkali, and impurities, if present. The process is similar to the washing of our clothes in the washing machine.

The sheared wool may contain a significant amount of soil, vegetable matters, grease, suint (dried perspiration of sheep deposited in the wool), and dung. All these matters are soluble in water and (or) mild alkali. During scouring, the grease (wax) particles are saponified by sodium carbonate and thus become soluble in water. Warm temperature (50-55 °C) during scouring will accelerate the rate of saponification. Hence, a good pre-treatment is required to ensure uniform dyeing and finishing of woollens.

17.3 Carbonisation

The sheep, while grazing accumulates various types of vegetable matters which will be adhered to its body. The major vegetable matters include burs, seeds, and twigs. A certain extent of these will be removed during the de-dusting and scouring, however, some will remain with the wool fiber by hooking. The presence of these vegetable matters may affect the aesthetic appearance of the wool fabric, once the fibers are converted into fabric. They may also reduce the strength of the yarn. So it is necessary to remove these impurities while making an apparel quality wool fabric. As per ISI standards, the limits have been put for low burr (3%) medium (5%), and heavy burr (> 5%). If the vegetable matter is more than 5% it is removed by carbonization. This process removes vegetable-based impurities like a burr, seeds, dust adhered in the greasy wool fleece by acid backing followed by neutralization. Sulphuric acid converts the cellulose biomass into dehydro-cellulose followed by charred mass and it can be removed by crushing and beating. This process is generally preferred for the light color shade and only wool, which is meant for apparel.

Recipe

Material – X g

MLR – 1:30

H_2SO_4 – 5.0 %

Duration – 30 minutes

17.4 Dyeing

Man is fascinated with color and the process of imparting color to the textiles is known as dyeing. The selection of the dye greatly depends on the type and nature of the fiber. For example, wool and silk can be dyed with acid, basic, and metal complex dyes, whereas cotton is dyed with reactive or sulphur dyes. Being a protein fiber, during dyeing, wool is forming a chemical bond with the dyes and attached firmly. The carboxylic acid and amino group in the wool open up good reaction sites for dyeing. Wool can be dyed either in fiber or yarn or in fabric form. For each type of substrate, different methods and machines are used. A recipe for the dyeing of acid dyes is shown below.

Recipe

Acid dyes: X%

Wetting agent: 0.5 %

Glauber's salt: 5-10%

Acetic acid: 1-3%

MLR: 1:20

Temperature/Duration: 90 °C, 60 minutes

During dyeing, the wetting agent ensures uniform wetting of fabric through the surface. The glauber's salt improved the color exhaustion. The dyeing is carried out in the mild acidic condition (pH-4), for which mild acetic acid is used. While applying the temperature, the dye molecules are getting sufficient energy to reach the wool fabric from the dye liquor and further fix firmly. After dyeing, the fabric is given a hot wash, followed by a cold wash to remove the unfixed dyes, if any present. Today in wool industries, the majority of the woollens are dyed with acid and metal complex dyes. Whenever exceptional brightness is required, basic dyes are employed.

17.5 Chemical modification of wool

Chemical modification of wool is performed to improve the quality parameters like felting shrinkage, luster, pilling, handling, and dyeability. Initially, the two major objectives of the chemical modification of wool were to impart shrink resistance and mothproofing. Many chemicals have been attempted for the same, however; very few could find commercial applications. Recently much attention is given to surface modification of wool for technical textile applications like composites, conductive polymers, etc. some of the reported literature is described below.

17.5.1 Grafting

Most of the grafting treatments are performed to enhance the poor hydrophobic and thermal stability of natural fibers. Reports are available on the grafting of natural fibers with silane, chitosan, isocyanate, acetic anhydride, etc (Ranjbar Mohammadi et al., 2010, Zhang et al.,2019). Wool is having two reaction sites, amine and a carboxylic acid group. Due to the presence of two functional groups, the wool is more prone to chemical reactions in comparison with other cellulosic fibers like cotton. The wool with progressed functional residences may be used for the development of unconventional products, which includes wool-based adsorbents for the recovery of metal ions, hearth retardants, and functional textiles with improved antibacterial, conductivity, and dye uptake properties.

17.5.2 Chlorite Treatment

The chlorination of wool is also known as "degradative treatment" by which the fiber is stripped of its scales to decrease the felting potential and to allow the production of machine washable wool garments. Commercially, the most important degradation methods have used either chlorination or per mono sulfuric acid treatment, both of which have wide importance in the preparation of wool yarns, garments, and fabrics.

17.5.3 Nano finish

Nanotechnology has brought a new sector of applications to the textile industry. Coating the surface of textiles with nanoparticles has become the usual approximation for the production of highly active surfaces to have antimicrobial, flame retardant, UV blocking, water repellent, and self-cleaning properties (Samanta et al.,2017; Jose et al., 2019). The nano finish creates carefree fabrics that reduce superior liquid repellence and furnish wrinkle resistance. These enhanced fabrics allow water and oil spills to easily bead and roll off the fabric without piercing the fibers and preserve in fabric the entire life of the garment. Many attempts have been reported on the application of nanoformulation for achieving various finishing on wool. This includes moth repellency, fire retardancy, water repellency, etc. (Jose et al., 2019; Jose et al., 2018).

17.6 Bio-chemical modification of wool fiber

17.6.1 Enzyme treatment

Enzymes are employed for various industrial processes. The major objectives of enzymes used in textiles are acceleration of reaction rate, specific activity, and low pollution load. Unlike acids and alkalies, the enzymes are safe to handle and do not affect fabric handle properties. Today most of the textile industries are using enzymes for pre-treatments like desizing, scouring, and various functional finishing (Samant et al., 2020). Enzymes bought changes on textiles through various chemical reactions, *viz*., oxidation, reduction, coagulation, decomposition, and hydrolysis (Ammayappan, 2013).

Since enzymes are selective in the application, very limited enzymes can be employed for the modification of wool. The major objective of the enzyme treatment on woolens is to smooth the surface scale. Depending upon the enzyme, the treatment may enhance physico-mechanical properties, dye uptake, luster, aesthetic values, and comfort properties. Enzymes are also effective in preventing the felting properties of wool (Prajapati et al., 2019). Wool-specific enzymes preferentially attack the disulfide bonds and impart hydrophilicity and shrink resistance to woolens. Scientific studies are available about the use of lipase, laccase, protease, and transglutaminase enzymatic treatment on woolens (Jiajiafu et al., 2015; Soun et al., 2020).

Table 17.1 Application of various enzymes on woolens

Enzyme	PH	Property	Reference
Protease	8.5	Shrink resistance Softness Hydrophilicity Pilling resistance Water retention	Jiajiafu et al., 2015 Prajamati et al.,2019 Mojsov et al., 2011 Ammayappan et al., 2013
Laccase	5.0	Water absorption Shrink resistance Dye uptake Dyeing assistant	Jiajiafu et al., 2015 Yuan et al., 2018 Shin et al., 2001
Transglutaminase	7.0	Handle Lustre Hydrophilicity	Jiajiafu et al., 2015 Soun et al., 2020

17.6.2 Biopolymer treatment

Biopolymers are biodegradable polymers produced either by living organisms or by chemical synthesis. Certain vegetable oils, resins, sugars, and amino acids, etc. are also termed biopolymers. Scientists are continuously working for the replacement of synthetic polymers and the biopolymers such as starch, gelatin, chitosan, and cellulose can be potential candidates for certain applications.

Among various biopolymers, chitosan is the most exploited biopolymer in woolens. It is having multiple objectives such as improvement in hydrophilicity, dye uptake, shrink resistance, and antimicrobial finish. Vilchezet al., (2008) reported the uplifting of the hydrophilic character of wool fabric after the treatment with chitosan. Treatment of various biopolymers viz., wheat starch, gum arabic, and chitosan on the wool fabric was reported by Rani et al., (2020). The pad-dry method of application of the listed biopolymers considerably changed the physicomechanical properties of wool fabric. Chitosan treatment enhanced the tensile and bending properties of wool while no massive change in corresponding properties was found in the case of gum arabic and wheat starch coating. The biopolymer treatment helped to improve the dye uptake and reduced the area shrinkage of wool fabric.

17.7 Conclusion

Consumers always demand comfort, safe, easy care, relaxed dressing, durability & the value for the money they spend. Hence, several modifications are being applied to wool for improving their characteristic properties. Woolen materials are treated with pre-post functional techniques that offer scope to develop diversified woolen products by incorporating all aesthetic properties based on consumer demands. The chemical modification of wool can be regarded as a powerful tool to improve some inferior textile performance of the fibers & to impart new physio-chemical & functional properties suitable for technological implementation, to meet market requirements for better wear & maintenance behavior of textile goods. Enzymes being natural products are completely biodegradable & accomplish their work quietly & efficiently without leaving pollutants are used biological modifications. Antimicrobial treatment ensures the textile product to be more comfortable & safer. Surface modification of wool fabrics also will help in the development of superior textile products with the quality, economy, while addressing the hazards possessed by the generation of large-quality effluents from a conventional chemical process.

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Chapter 18

Conventional Wool Products

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18.1 Introduction

India produces annually 40.4 million kg of wool annually (2019-20), majority of Indian wools are of medium-coarse type, they are suitable to be used in high areal density carpet and furnishing fabrics. Indian wool production is not enough to meet the requirement of raw wool for the woollen industry. The component of fine quality wool to Indian wool is 10% only. Indian fine wool mostly belongs to the northern temperate region of the country, worth Rs. 70 Crores. Besides this under the fine wool category country also produces specialty hairs viz. dehaired Pashmina and Angora fibre in the quantity of about 50 and 10 tons respectively, worth 50 Crores. The fine wool produced in the country is not suitable for high-end apparel and suiting fabrics due to its shorter length. Therefore, to cater to the demand, especially the apparel industries imports almost all the wool in the form of scoured wool or wool tops, worth Rs. 2500 Crores. The medium to coarse quality native wool accounts for 30-32 million kg (60-70%) and also known to carpet grade worth Rs. 300 Crores. The production of carpet grade wool in the country is also not enough and double the quantity of wool about 60-65 million Kg worth another Rs. 1545 Crores is imported**.** Import of carpet grade wool of 32 μm and above are permitted under OGL and the majority of clean wool is imported from New Zealand to meet the requirements of Indian carpet industries. The other wools obtained from different habitat sheep in the southern peninsular region of the country mostly reared for meat and not for wool. The produced wool is very coarse with fibre diameter >45μm and has a very higher proportion of medullated fibres (>60%). It accounts for 15-20% % of total wool production in the country. This wool is not suitable for making carpets and apparel and therefore attracts a very small price in the market.

18.2 Wool Products

In woollens manufacturing like other natural fibres wool also have tough competition with synthetic fibres due to low price and sheep farmer is even not able to meet shearing cost with the sale of fleece. However, like many natural fibres, there are numerous benefits that wool has over synthetic options, that make it a more comfortable, durable, and fashionable choice. Every year sheep produces a new fleece, making wool a renewable fibre source. Besides providing warmth, its unique properties of thermal insulation give warmth/ cool effect to the apparels, It has crimps provides bulk and softness to the made-ups, and also have high flame retardant properties, a fabric made entirely of wool doesn't readily catch fire. Even if it does, it burns slowly and self-extinguishes when the source of the flame is removed. Wool is naturally high UV protection, which is much higher than most synthetics and cotton. It has a large capacity to absorb moisture vapour and sweat next to the skin making it extremely breathable. Woollens made of wool are easy-care due to natural protective layer which prevents stains from being absorbed, they also pick up less dust as they are static resistant and highly elastic it stretches with the wearer, but then returns to its natural shape, so there is less chance of garments sagging or losing their shape. Wool is biodegradable and only a few years to decompose to put fertility into the soil for crop growing. Among the popular wool products men's suiting, knitwear, carpet, blanket, shawl, and upholstery are conventionally catering the need of society. Some of them are described below:

18.3 Men's outfits (suiting)

The suiting fabrics are woven of wool, wool blends with linen, cotton, and synthetics are used for suits, jackets, vests, and trousers, deciding which fabric is best to buy is not easy, given all this variety of options we are presented with. It depends on many factors, such as your age, status, purpose, and income. The suit – whether a two-piece or a waistcoat thing – is a gentleman's pride which speaks about one's style and taste Fabrics of that type come in several weights and patterns (Fig. 18.1). They differ in breathability, softness, lustre, thickness, and thread count. There are summer weights perfect for warmer seasons, as well as denser fabrics ideal for autumn/winter. Wool is the most popular suit fabric and one of the most versatile. It can be worn both in colder and warmer climates. It can be silky smooth and soft. It can be plain or patterned. In general, wool is ideal for business jackets and trousers because it feels nice to the skin and wears well. High-quality wool fabrics are known for their warmth, durability, lustre, and drape. High crimp long wool (64's quality) is especially required for quality yarn production on the worsted spinning system for suiting fabric manufacturing.

Fig. 18.1 Men's suitings

The shortcoming of Indian cross-bred wool is its lower fibre length which makes it unsuitable for apparel end-use. The spinning limit of this wool is 48^S quality and mainly suitable for the manufacturing of shawls.

18.4 Ladies Shawls

Indian fine wool and specialty hairs viz. Pashmina and Angora are produced in the northern temperate region of the country. These fine fibres are value-added to making shawls and marketed as branded to Kullu / Kashmiri shawls (Fig. 18.2). This value chain of fine wool and its Angora/ Pashmina blended shawl manufacturing provides livelihood to more than 2.45 Million peoples of the Himalayan region and contributed to the economic development worth Rs. 2000 crores (approx.) per annum. The shawl industry in India has existed since ancient times for protecting against the cold. The Kullu Valley is famous for its traditional wool shawls – attractively patterned, lightweight but wonderfully warm. The handloom industry provides an income for thousands of local women. Many are organised into shawl-weaving cooperatives with workshops especially prevalent in Shamshi (northern Bhuntar), have stores and showrooms line on the whole Bhuntar–Manali highway.

Fig. 18.2 Pashmina Shawls

18.4.1 Wool/angora rabbit hair blended shawl

Angora rabbit hair fibres are specialty fibres with enormous commercial value. These fibres possess excellent thermal characteristics and hence provide the necessary comfort in cold weather clothing. The fibre is very fine and smooth. This makes it difficult to spin. There is a constant risk of fibre shedding as there is a lack of fibre to fibre friction. Blending with wool or cotton, Angora rabbit hair fibres improve the handle and thermal comfort properties of the garments. Innovative blends of these fibres with wool; cotton and other fibres can produce value-added products (shawls) (Fig. 18.3) with improved functional characteristics. The fibre is usually blended with other fibres such as fine wool, often with a small proportion of synthetic fibre like nylon, and spun on the semi-worsted spinning system. Based on different wools are used in yarn manufacturing and shawl making, resulting in widely varying shawl prices. Hence, while a lamb's wool shawl might cost, say, ₹1000, a similar-sized one using a blend with added Angora wool (from rabbits) could be ₹2000 to ₹2500, and those using pure Pashmina (from high-altitude goats) could top ₹10000.

Fig. 18.3 Angora blended designed ladies shawl weaving and shawls

18.5 Blankets

Wool is the preferred raw material for the preparation of eco-friendly blankets, especially in the winter season (Fig. 18.4). Wrapping in a sheep wool blanket during winters is the most pleasant feeling you can feel while sleeping or relaxing. Woollen blankets made from fine wool are not only warmer but also give a smooth feel, but they are expensive too. Mixing medium coarse wool with fine wool will help to reduce the cost of the product and made it affordable. This will also add value to the medium coarse wool. The thermal insulation properties are similar to fine wool with the marginal sacrifice of blanket softness**.** Accordingly, a blanket from a wool mix is known to be the type of standard blanket use for military purposes. Wool blankets are also a great option to add to an emergency kit. Their strong material can withstand the elements, perfect in case of a natural disaster.

The demanding society for softer textures, finer fibres, vibrant colors, beautiful designs and shine on blankets emerges an alternate product known as mink blankets which articulate to mink fuzz or other types of fur. Mink blankets are usually produced using acrylic and polyester in the proportion of 85:15 which provides soft texture and warmth.

Fig. 18.4 Check and Plain wool blankets

A good-quality acrylic mink blanket is incredibly luxurious and comfortable. Being synthetic, these mink blankets have poor air permeability and breathability. Correspond to that virgin wool blankets are not only give a soft and luxurious feel but also provides airflow during end uses. The natural breathability of wool blankets keeps individuals warm in the winter and cool during the summer, and thus increasing the interest of buyers.

18.6 Carpets

Carpets are one of the most widely used flooring coverings in both residential and workplaces. The major application of carpet is to decorate the interiors as well as enhance the thermal comfort in place of its use. In commercial application, carpeting is desirable as a component of interiors in luxury rooms of hotels, cinema halls, multiplex, luxury buses, A/C railway coaches, airport corridors, etc. where heavy traffic compressibility and resilient feel and low soiling are important characteristics of carpets. It reduces heat loss through the floor and their excellent thermal insulating properties have been relying on the principle of trapping air to reduce convective heat transfer. In colder climates or regions, it retains warm air longer, an important benefit in our energy-conscious world. Besides it provides eye southing, luxury feels, and comfort to walk. The biomechanical study reveals that the postural sway due to carpet compliance reduces the venous pressure and facilitates blood flow in the lower extremities and feet.

The origination of carpets is still mysterious but it is definite that woven forms of floor coverings. From ancient times, the art of carpet weaving and its commercial production is started in Iran the then Persia. Iran was among the major hub of carpet production and export in the Islamic Era. These carpets are in great demand in Europe and middle-east because of their prominent designs and motifs. Indian style carpet is motivated by Persian carpets. The introduction of carpets in India credited to the Mughal dynasty. Akbar had called for specialized artists and weavers sent from the Persian court to set up workshops in his two Indian capitals in Agra and Fatehpur Sikri. They are meant exclusively to produce novel pieces of decoration and furnishing. Initially, the carpets woven showed the classic Persian style with fine knotting. In the regime of Jahangir, due to fascination with botanical features like floral characters exhibited a variety of herbal species, which was perfectly expressive on carpets. He set up more workshops and this art form reached the peak of its popularity. This is also the period of the culmination of the Indo-Persian style of carpets and makes a strong impression. Indian carpet exquisite of prayer rugs, antique rugs, and carpets, figural carpets, etc. made of high and medium-fine quality wool. Indian style carpets are overwhelmingly rich with a sheer range of patterns, styles, and designs on their bristled surface and in high demand in European and US market till now.

The quality of Indian wool is almost exclusively of broader micron and best suited for carpet manufacturing due to its unique characteristics of better pile coverage, handle, and springiness. Indigenous carpet grade wool about 25-30 mkg which worth Rs. 300 Crores. It has a component of 70% of the total wool produced in the country. Indian carpet industries utilized all the native carpet grade wool and nearly double the quantity to 60-65 mKg of similar imported wool, a majority could be from New Zealand. All these carpet grade wools were used in the manufacturing of yarn and ultimately into high areal density, resilient and lustrous carpets which have high demand in export markets. Carpet Industry is mainly established in the decentralized woolen sector it is one of the prime industries that produce all variants of carpets viz. Hand-knotted, Hand tufted, and Handloom woven carpets (Fig. 18.5). The carpet industry of India is entirely demand-driven and growing with an annual growth rate of 10%. India shares 2nd position in world carpet export market next to Iran and 1st in the quantity of export. Presently, the Indian carpet sector provides livelihood to more than 1.5 million peoples. The export outlay of carpets worth 13,500 Crores with majority contribution to Hand-made carpets (Hand-Knotted).

Fig. 18.5 Methods of carpet weaving

18.7 Namda

The wool produced in the central state of India viz. Utter Pradesh, Bihar, Madhya Pradesh, and southern Rajasthan, and south Indian states including Karnataka, Andhra Pradesh, and Tamilnadu contributes 15-20% of total wool production. The wool produced in these regions is very coarse having a fibre diameter higher than 45μm and also had a high proportion of medullated fibre (60-80%). This wool is not suitable for making carpets/apparel and therefore attract very small price in the market and keeping given the high cost of shearing, the wool business of this wool is not economical.

Traditionally, these coarse wools are utilized by local artisans in manufacturing coarse woollen blankets *(Kambli)* through spinning yarn on charka and weaving on pit loom in the Coimbatore district of Tamil Nadu**.** In Maharashtra, such wool is handspun and woven on a handloom to produce fabric known locally to Guhugari, a cloth used to wear in traditional functions locally. Namda is one of the wool-based handicrafts used as low-cost floor coverings, produced in Tonk district of Rajasthan, it has distinct advantages like sustainability and eco-friendliness. The craft of namda making is not native, to Rajasthan. It is known to have come from a distant land of Iran and Ladakh. In the Nawab era, it is established in tonk city and now a decentralized and industrial hub for namda and woollen handicraft manufacturing. Traditionally, its rich hues and exquisite design are the hallmarks of the Namda. Different geometric figures and artistic designs may be reproduced by using different colour combinations and thereafter stitching on felt sheets. Namda felt sheet is produced without any spinning and weaving. Wool has a special scale structure on its surface. The mechanical action manually or in the machine under alkaline/acidic conditions and processing conditions of high humidity, temperature 40-50^{o}C, and pressure, these surface scale of wool fibres arranged in the form of the sheet are forced to entangled rigorously called to felting. The above process with manual operation is used in traditional Namda-making (Fig. 18.6). The process of Namda sheet making in terms of wool fibre is majorly influenced by fibre diameter, numbers of scale per cross-section, and fibre length.

Fig. 18.6 Traditional Namda making and designing

The poor marketability of these products' limited floral designs results in very low remuneration to artisans engaged in Namda-making. Awareness of advantages of machine-made felt making to develop felt sheet of variable thickness and hardness(density) and skill development of artisan in terms of manufacturing diversified woollen handicraft products. Their skill development in terms of pattern making, designing, cutting, pasting, stitching, and decoration will add a special feature that adds value to the product. Innovative and durable handicraft and home furnishing articles like shopping bags, ladies purses, office stationeries, handmade painting, soft toys, wall hangings, and decorative households are enabled to develop with novel designs (Fig. 18.7). This will not only provide sufficient wages to artisans but also generate employment in handicraft development and its marketing.

Fig. 18.7 Diversified handicraft products

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Chapter 19

Diversified Wool Products and Applications

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Abstract

Natural fibre contributes mainly to the apparel industry due to its inherent properties. Among them, wool is a unique fibre and their products have characteristics like warmth, breathability, moisture absorption, resilience, odour absorption, softness, flame resistance, biodegradability, and recyclability. The wool is used for apparel like suiting and knitwear due to its comfort and hand property. However, their utilisations in the apparel sectors are declined due to the utilization of synthetic fibres, declined sheep population, and current fast fashion. Other than the apparel sector, home textiles and technical textiles sectors have shown an upward trend and it leads to provide huge opportunities for the development of diversified products. This paper highlights the diversified products from wool and their potential areas of application.

19.1 Introduction

The positive attributes of wool fibre in terms of textile fibre is high ignition temperature (750-800°C), high limiting-oxygen index (25-26%), low heat of combustion (196 kJ/g) and heat release (9.6 kJ/g), high nitrogen content (16%) and high moisture content (10-14%). The wool has applications in apparel, interior textiles, and technical textiles. In addition to this, locally available wool fibre has been utilized for handicraft items. However, felting behaviour, pilling formation, sensitivity to laundering, suitable for the only winter season, and presence of medulla have limited their utilization in all categories of apparel. Woollen industry in India is manufacturing the following products worsted yarn, woollen yarn, wool tops, fabric, shoddy yarn, shoddy fabrics, blankets, knitwear, hand-made carpets, and machine-made carpets. Other than conventional products, small scale woollen industries are developing diversified wool products traditionally and they have been mainly consumed locally. It has the potential for the development of diversified products. This chapter reports the present status of products made from Indian wool and its potential application for the 21st century customers.

19.2 Applications of Indian wool

The woollen products manufactured with respect to fibre fineness are summarized in Fig. 19.1 (Shakyawar et. al., 2018).

Apparel: Fine wool with 20–25 micron fineness can be used in the worsted suit and knitted outerwear in blends with Australian fine merino wool; while wool/polyester blended bilayer fabric suitable for highly active sports.

Carpets: Medullated wool fibre has superior resilience and appearance retention property so they have been mainly applied in the carpet industry. The cost of each woollen carpet depends on its pattern, texture, color, and appearance. To enhance the aesthetic appeal with respect to time, 5-10% of coarse wool can be added. It could be removed during usage and it ultimately improves the appearance.

Blankets: Fine and medium wool can be utilised for the preparation of blankets and can be prepared using the non-woven route and woven route.

Upholstery: Fine Wool has good resistance to soiling, staining, and burning so that it has potential application in upholstery and meets the specifications for aircraft, ships, and trains.

Protective Clothing: Wool fibre is difficult to ignite; any flame spreads slowly and is easily extinguished. This property can be utilised for the development of flame-protective fabrics.

Woollen khadi: Woollen Khadi products were made from indigenous wool available in Rajasthan, J&K, Himachal Pradesh, and other parts of the country. Due to lifestyle changes, Australian Merino wool is used in Khadi.

Quilts: It is an alternative to a blanket and consists of two layers of fabrics filled with wool fibre material in the middle. It is well known for its warmness due to its breathability behaviour compared to synthetic fibres

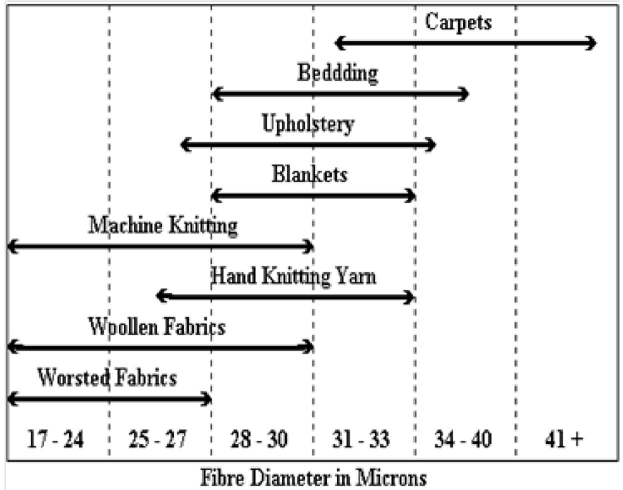

Fig. 19.1 Range of woollen products

19.3 Diversified products

19.3.1 Apparel Fabric

Short staple crossbred fine wool can be utilised for the development of wool-cotton union fabric in handloom and they are used as blankets for the tropical winter season. The union fabrics showed 40% to 50% reduced felting shrinkage in comparison to 100% woollen fabric. Similarly, yarns from Indian crossbred wool and its blends with Australian merino wool were developed from woollen khadi system and fabric was prepared using wool-cotton blended yarns as warp (Meena et. al.,2020; Raja & Thilagavathi, 2010). A hybrid set up i.e. Siro-spinning attachment to NMC charkha was used to improve the quality of woollen yarn over the conventional NMC spun yarns. Results inferred that tenacity and elongation of the yarn were >38% and 65% higher than conventional yarns. Siro spinning masked the short length of cross-bred wool during doubling and improved yarn strength and yarn evenness (Kumar et.al, 2020a). Indigenous Dumba wool has an admixture of fine wool and coarse hairy fibers with 23.2 µm mean fiber diameter and 14 % medullation. The wool fibre has been spun into 21 Nm yarn with the use of nylon staple fibre (carrier fiber) and made into fabric in a handloom. The roughness fabric of the fabric is reduced by enzyme treatment followed by silicone softener treatment (Kumar et.al, 2020b).

19.3.2 Products from Wool waste

During the conversion of wool fibre into yarn and fabric, the noils, soft and hard waste are generated (Sule and Bardhan, 2001). Among them, noils can be effectively utilised in blend with medium, carpet, and coarse wool for their diversification. Comber noil from Bharat merino wool at 10, 20, 30, and 40% blended with Chokla raw wool for the development of blankets. The addition of noil increased the thickness of the blanket and bending length in warp and weft direction. It is concluded that 30% comber noil could be blended with fine and medium wool to get good thermal and smoothness properties of the woollen blanket. Other than utilisation in the conventional spinning system, the noils, soft waste, and hard waste have potential applications in the preparation of non-woven fabric (Felt/Namda)

19.3.3 Handicraft items

The decentralized wool sector is generally deployed new model charkha (NMC) for the production of coarse woollen yarn due to the shorter length and higher fibre diameter of indigenous. Other than yarn production, medium-coarse and coarse wool have been utilized for the preparation of handicrafts and namda. Still, coarse wool is not fully utilized due to its large diameter, high bending rigidity, and torsional rigidity. To mitigate this problem, ICAR-CSWRI has conducted research programs to develop diversified products Turquoise woven foot mat, winter baby bed, striped doormat, embroidered bolster cushion, elliptical bath mat, braided yarns, and felt ball using braiding and sliver felting methods as per Fig. 19.2.

Embroidery bolster cushion

Braided yarn

Striped doormat

Winter baby bed

Wool felt ball for handicraft

Elliptical bath mat

Fig. 19.2 Handicraft items from coarse wool developed by ICAR-CSWRI

19.3.4 Braid

Wool fibre can also be used for the development of braid for industrial and handicraft applications. Indian coarse wool in the core and wool, jute, and cotton fibre in the sheath can be utilised for the development of braided ropes. Braided rope comprising wool sheath and coarse wool core (30% content) was found to give a better braided rope mat performance (Shanmugam et.al, 2020).

19.3.5 Technical Felt

Indian coarse wool is mainly utilised for the production of felt; however, the feltability is very low due to larger fibre diameter (>40 micron), high medullation (>60%), and less number of scales per cross-section. To enhance the felt-ability, it is blended with fine wool and prepared the felt with acceptable norms. Thermal insulation, resilience, and abrasion resistance of coarse wool in blends with medium-fine wool in the ratio of 60:40 could be utilized as technical felts in thermal insulation, sound absorption panels, and oil and chemical absorption applications. In the traditional namda making (felt) process to reduce the fibre shedding during use the optimum blend level is 60% coarse wool and 40% fine wool. Dyeing wool fibre with natural dyes can prevent the moth attack and so the value of the products is improved (Raja et.al, 2013). The home needs proper insulation to provide adequate noise absorption and to control heat levels. Wool fibre has a natural temperature-buffering effect and can be used to maintain the temperature like insulators. Wool insulation batts are comfortable to handle and safe to use. Wool fibre is an ideal material for sustainable building insulation due to the following properties (Causer, 2006).

19.3.6 Bio-composite

Coarse wool fiber has potential in the preparation of green or bio-composite. Wool fabric is reinforced with 40% and 50% epoxy polymer and the physical and chemical characterization indicated that the tensile and bending properties of a composite of 50% wool are higher than the composite of 40% wool (Bharat et.al, 2021; Bharat et.al, 2014). Like thermosetting resin, wool fibre is also mixed with a thermoplastic polymer like polypropylene, and composite is fabricated by continuous extrusion with a suitable compatibilizer. The addition of MAPP has influenced the tensile (59.1%) and flexural (83.9%) strengths of the composites while wool fibre content has a less significant factor. Furthermore, wool has a positive effect on improving fire retardancy of the composite (Kim et.al, 2014). Wool and jute fiber hybrid biocomposites were prepared by varying the fiber and polypropylene ratio in a hot press machine. Tensile, flexural, impact, and hardness tests indicated that the composite with 15% fiber content had the best properties with wool and jute fiber at 1:3 proportions (Tusnim et.al, 2014).

19.3.7 Agro-textiles

Wool fibre has moisture retention properties and when disposed of in soil, it biodegrades without harming the environment and fertilising the land. Needle punched wool nonwoven fabric can be used as a cover fabric and it acts as a buffer and can minimize moisture evaporation, thereby enhancing the rate of germination, preventing weed competition, and promotes even fruit-ripening. This waste wool generated could be a source of fertilizer and retain soil moisture for a long time. It is reported that waste wool is reduced soil salinity and acts as a slow-release fertilizer. It will improve plant growth, green fodder, and grain yield. ICAR-CSWRI has developed a compost i.e, wool waste, sheep manure, and crop residues in 30:50:20 ratio for the nutrient for indoor and outdoor ornamental plants (Kadam et. al., 2014; Zheljazkov, 2005).

19.3.8 Keratin and nanofibre from wool

Wool fibre is a keratin polymer and consists of low and high sulphur proteins and can be used to extract keratin using different extraction methods. Keratin obtained from various extraction methods had different yield, morphology, and physicochemical properties. Wool keratin can be converted into bio-plastic by using different ratios of plasticizers. These protein based films might find applications in a diverse range of fields such as regenerative medicine, bio-plastics, coatings, or packaging (Fernández-d'Arlas, 2019). Electro-spinning has been used to regenerate keratin fibre; however, 100%, electro-spun keratin fibers have poor mechanical characteristics. Keratin/polyethylene oxide blend nanofibers have prepared by combining aqueous keratin solutions and PEO powder with a weight ratio of 50:50 and 7% and 10% total polymer concentrations. There is some possible bonding between PEO and keratin macromolecules and it is responsible for the shear viscosity behaviour. The uses of the keratin/PEO nanofibrous mats are limited due to their water instability and poor mechanical properties (Ammayappan et.al, 2014). Keratin nanofibre is prepared by dissolving keratin in formic acid at 15% and spun in electro-spinning set up to get 250 nm diameter. Thermal treatment is given to improve its stability by the formation of amide bonds between acid and basic groups of some amino acid side chains. These mats could be utilised in tissue engineering as they mimic the native extracellular matrix and in wastewater treatment since they can adsorb heavy metals (Alugi et.al, 2013).

19.4 Diversification through functional finishing

Wool fibre can be modified followed by functional finished with suitable chemical finishing agents to meet the customer's needs. Such finishing can enhance the value as well as the performance of the wool products. Functional finishes improve the performance of fabric under specific end-use conditions by imparting specific functionality. There are five functional finishing i.e. stabilization/shrinkage control finish, appearance retention finish, comfort-related finish, biological control finish, and safety-related finishes can be applied. For wool fibre, the functional finish is mainly targeted to prevent felting shrinkage, moth attack, pill formation in synthetic blends, and degradation by UV radiation and Table 3 proposes suitable functional finishing as per customer needs (Ammayappan et.al, 2013).

Table 19.3 Potential functional finishes suitable for woollen products

Sector	Suitable functional finish	Form	Usage
Apparel	Durable press, Shrink-resistant, Water repellent, Softness, Crease-resistant	Fabric, Top, Fibre	Fashion Garments, Waterproof Garments, Machine washable suits, Thermal underwear, Woven garments
Upholstery / Interior	Flame resistance, Stain repellent, Abrasion-resistant, Water repellent, UV Protection, Mothproof	Fabric, Felt	Root Insulation, Upholstery, Quilts, Blankets, Drapes, Wall Coverings, Floor covering
Carpet /Floor covering	Crease-resistant, Flame resistance, Stain repellent, Abrasion-resistant, Mothproof, Back coating	Fibre, Yarn	Hand-knotted carpets Woven carpets
Technical Textiles	Antibacterial, Flame resistance, Stain repellent, Abrasion-resistant, Water repellent, UV Protection, Colour Fastness, Moth Proof, Microencapsules, Conductive polymer coat	All form	Sound & Vibration Control, Heat Exchangers, Wool Filters for Dust/Chemical Odours, Electrostatic Filters, Police / Military /Firefighters Uniforms
Geotextiles	Hydrophilic	Fibre	Mulching
Hosiery	Shrink resistant, Mothproof, Stain repellent, Pilling resistant	Fibre, Yarn	Socks & Gloves, Children's Nightwear, Infant Apparel

19.5 Conclusion

Other than conventional applications, wool can be explored as a material for insulation, acoustic, and construction, bullet-proofing, automobile, and agriculture through diversified product development. Keratin obtained from wool can be utilised for bio-plastic, nanofibres, feed material, and other pharm material.

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