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Structural transformation of the Indian sheep sector

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ABSTRACT

Over the period 1950-2025, the Indian sheep sector has undergone substantial structural transformation in its production orientation, technological base and market integration. Although the national sheep population increased moderately from 39.1 million in 1951 to 74.26 million, output growth has been markedly higher. Mutton production expanded nearly tenfold, reaching 1.185 million tonnes in 2024-25, whereas wool production stabilized at 34.57 million kg, indicating a progressive shift from fibre-dominated systems to meat-oriented production. This transformation has been shaped by genetic improvement programmes, development of synthetic breeds, region-specific nutritional strategies, advances in reproductive and animal health management, and evolving policy support. India currently ranks second globally in sheep population, underscoring its strategic importance in the small ruminant economy. Despite the growing dominance of mutton in sectoral value, wool continues to hold regional livelihood significance in arid and hill ecosystems. This review synthesizes long-term trends in population and production dynamics, breed development, technological interventions and emerging market drivers. It also analyses persistent constraints, including shrinking grazing resources, limited genetic gain, suboptimal technology adoption, disease burden, market inefficiencies and climate stress. A strategic pathway is proposed to enhance productivity, resilience, value addition and value-chain efficiency while safeguarding the livelihoods of small and marginal sheep farmers across diverse agro-ecological regions.

Keywords: Breeds, Constraints, Future roadmap, Mutton, Production systems, Wool

Sheep play a vital and enduring role in India's livestock-based rural economy, particularly in regions practicing traditional grazing, mixed crop-livestock systems, and natural farming. According to the 20th Livestock Census, India's total sheep population stands at 74.26 million, marking a 14.13% increase over the previous census conducted in 2012. Sheep account for 13.8% of the country's total livestock (DAHD 2024), reflecting their substantial contribution to India's rural livelihoods. These animals are essential for sustainable livelihoods because they can live on poor-quality grass and harsh weather while still producing valuable meat and wool. While the number of sheep has grown steadily over the last 75 years, the actual money this industry generates has increased even faster. Recent data indicated that mutton contributed around 11.29% of India's total meat output, underscoring its growing consumer demand (BAHS 2025) particularly in urban and peri-urban markets. Mutton production reached 1.185 million tonnes in 2024-25, reflecting a sustained upward trajectory. Wool production was maintained at 34.57 million kg during 2024-25 (BAHS 2025), despite declining demand for coarse wool and increasing competition from synthetic fibres (Fernandes and Prakash 2025). This review traces the evolution of India's sheep sector from its historical roots to its modern technological landscape. Integrating archaeological, textual, economic, genetic, and production evidence, it highlights traditional systems, breed resources, key trends, and the sector's shift toward meat production, along with emerging challenges and future strategies for enhancing productivity.

Legacy of sheep in the Indian Subcontinent: The relationship between sheep and human civilization in the Indian subcontinent is ancient. Evidence from the Indus Valley Civilization (c. 2600–1900 BCE) indicates that sheep were integral to textile production and agrarian life, as reflected by spindle whorls, loom weights, and woven fabric impressions from Harappa, Mohenjo-daro, and Taxila. Mesopotamian records referring to fine wool from "Meluhha" suggest export linkages with West Asia (Potts 1997). During the Vedic period (c. 1500–1200 BCE), sheep gained strong cultural and ritual significance, with the Rigveda mentioning sheep (avi), wool (ūrṇa), milk, and mutton, which compares abundant hair to the fleece of the Gandhāra ewe. By the Mauryan period (c. 322–185 BCE), sheep husbandry was organized enough to be regulated in Kautilya's Arthashastra, which describes state oversight of

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wool quality, breeding, and textile production, reflecting the economic importance of sheep in early Indian statecraft (Kangle 1960).

Traditional sheep production systems in India: India's traditional sheep production system which evolved over centuries continues to sustain millions of smallholders, transhumant groups, and nomadic pastoral communities across diverse agro-ecological zones. Some traditional production systems are discussed below:

Nomadic and pastoral production systems: In nomadic pastoralism livestock herders' move continuously with their animals in response to the availability of grazing and water resources. Movements are generally flexible and adaptive rather than strictly seasonal, allowing pastoral households to respond to spatial and temporal variation in forage conditions. This distinguishes nomadic pastoralism from transhumant systems, where movements typically occur between well-defined summer and winter pastures. In practice, however, the boundary between nomadic and transhumant systems is often fluid, and the terms are sometimes used interchangeably, particularly in historical contexts where precise movement patterns are not well documented (Blench 2001). Nomadic and pastoral sheep production systems are practiced by several traditional communities across India (NCERT 2023), including the *Banjaras* of Uttar Pradesh, Punjab, Rajasthan, Madhya Pradesh, and Maharashtra; *Kurumas* and *Kurubas* of Karnataka and Andhra Pradesh; *Dhangars* of Maharashtra; *Raikas* of Rajasthan; and Himalayan pastoral groups such as the *Changpas*, *Bhotiyas*, *Sherpas*, and *Kinnauris*. In the north-western and Himalayan regions, *Gaddis* of Himachal Pradesh and *Gujjar-Bakarwals* of Jammu & Kashmir and *Gujjars* of Uttarakhand, and adjoining areas practice well-defined seasonal migrations. These communities undertake long-distance movements, often spanning several hundred kilometres annually, in response to seasonal availability of forage and water. Such migratory routes enable efficient utilization of spatially and temporally variable grazing resources, thereby reducing dependence on cultivated fodder and maintaining low production costs. Pastoral mobility also supports the rearing of hardy indigenous sheep breeds such as Changthangi, Gaddi, Marwari, and Deccani, which are physiologically adapted to climatic extremes, rugged terrain, and prolonged walking. As flocks move across diverse landscapes, these systems promote natural gene flow, contribute to biodiversity conservation, and enhance the ecological resilience of rangelands (Primi *et al.* 2025).

Transhumant systems in temperate and Himalayan regions: In the northern temperate and Himalayan regions, particularly Jammu and Kashmir, Ladakh, Uttarakhand, and Himachal Pradesh, transhumant sheep production systems are widely practiced (Misri 1996). Shepherds follow well-defined vertical migration routes along altitudinal gradients, moving flocks to high-altitude alpine pastures during summer and descending to mid-altitude villages, river valleys, or the Shivalik foothills during winter. In Uttarakhand, these seasonal pastures include the *bugyals*, the extensive alpine meadows of the higher Himalaya, while winter grazing often occurs in the *bhabar*, a dry forested belt along the Himalayan foothills in the Garhwal and Kumaon regions. Historical accounts indicate that several *Gujjar* pastoral groups practicing this system originally migrated from the Jammu region during the nineteenth century, gradually establishing cyclical movement patterns adapted to Himalayan landscapes (NCERT 2023).

Extensive grazing systems in arid and semi-arid regions: Extensive grazing systems dominate the semi-arid and arid tracts of western India, particularly in Rajasthan, Gujarat, and parts of Haryana. Sheep graze year-round on fallow fields, community pastures such as *orans* and *gauchars*, open scrublands, and ravine ecosystems (Chaudhry *et al.* 2011). Indigenous breeds such as Marwari, Sonadi, Malpura, and Pugal are exceptionally well adapted to these harsh environments, exhibiting high tolerance to heat stress, poor-quality forage, water scarcity, and long-distance walking. A distinctive feature of these systems is night penning of sheep on croplands, which enhances soil organic matter, nutrient recycling, and soil fertility, thereby forming an integral component of dryland farming systems (Naveena *et al.* 2023).

Agro-pastoral mixed systems in Peninsular India: In peninsular India, agro-pastoral mixed systems integrate sheep rearing with crop cultivation and horticulture. Smallholder farmers allow sheep to graze on crop residues after harvest, while manure deposition improves soil nutrient status and reduces reliance on chemical fertilizers. Income generated from the periodic sale of lambs provides crucial liquidity and risk buffering for rural households. This integrated production model is prevalent in Tamil Nadu, Telangana, Karnataka, Andhra Pradesh, and Odisha, and supports region-specific breeds such as Nellore, Madras Red, Mecheri, and Kenguri (Shinde and Sejian 2013).

A seventy-five year retrospective on the transformation of India's sheep sector (1950-2025): At the time of independence, India's sheep husbandry was almost entirely embedded in traditional pastoral and nomadic production systems that depended on indigenous breeds and centuries-old migratory grazing practices. The 1951 Livestock Census recorded approximately 39.1 million sheep, and national wool production during 1950-51 stood at 27.5 million kg, with no official estimates available for sheep meat output (BAHS 2014). This clearly indicated that wool was the primary product of the sector, while mutton played only a secondary role. The early decades after independence were marked by low productivity and limited technological inputs. Sheep were reared predominantly for coarse carpet wool, and production remained highly dependent on natural grazing resources and seasonal migration. A major turning point in shaping the modern trajectory of the sector came with the establishment of the ICAR-Central Sheep and Wool Research Institute (ICAR-CSWRI) at Avikanagar in 1962, which provided the scientific foundation for progress in sheep breeding, reproductive technologies,

nutrition, health management, and wool-processing research. The expansion of research capacity continued with the establishment of its regional stations enabling region-specific work on local breeds, pasture systems, and production environments. Complementing these research functions, the Central Wool Development Board (CWDB), Wool Research Association (WRA), and numerous State-level sheep and wool development institutions were created which formed an integrated national framework that linked scientific research, field-level development, and value-chain strengthening, thereby laying the groundwork for the sector's subsequent transformation. The major institutional, technological, and production milestones underpinning the transformation of India's sheep sector over the period 1950-2025 are outlined in Table 1.

Sheep population dynamics and current status in India: The long-term changes in India's sheep population are presented in Figure 1, illustrating the evolution of the national flock from 1951 to 2019 based on successive Livestock Censuses. The trajectory reveals a near doubling of the sheep population over seven decades with temporary declines during the mid-1970s and around 2012.

According to the 20th Livestock Census (DAHD 2019), India's sheep population reached 74.26 million, marking

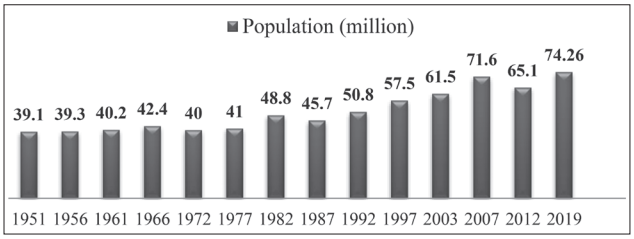

Fig. 1. Trend in India's sheep population from 1951 to 2019, derived from successive Livestock Censuses.

significant expansion in breeds across peninsular and semi-arid states (Figure 2). The most substantial population clusters were recorded in Telangana (19.06 million), Andhra Pradesh (17.63 million), Karnataka (11.05 million), Rajasthan (7.90 million), and Tamil Nadu (4.50 million) (Table 2).

Based on the genetic constitution, sheep population in India can be broadly classified into three groups: indigenous, exotic, and crossbred types. Indigenous sheep significantly dominate the sector and include both well-recognized breeds as well as large non-descript regional populations. Together, they account for about 94.84% of the national flock, whereas exotic and crossbred sheep contribute only 5.51% (DAHD 2019).

Table 1. Milestones in the development of India's sheep sector (1950-2025)

Year / Period	Sheep Population (million)	Mutton Production (000 tonnes)	Wool Production (million kg)	Key Developments / Milestones
1951	39.1	-	27.5	First post-independence livestock census; pastoral & migratory systems dominate; wool primary output
1962				Establishment of ICAR-CSWRI, Avikanagar
1970s	40.0	101.1	37.49	Launch of AICRP on Sheep Breeding (4th Five Year Plan): Programmes for fine wool and mutton production were initiated. These programmes introduced Merino and Rambouillet crossbreeding for fine wool improvement and structured selection for mutton traits.
1980s	45-47	140-165	40-42	Expansion of crossbreeding; pasture development; major disease-control programmes (PPR, BT, ET)
1990s	50-52	180-200	43-44	Conversion of AICRP-Sheep Breeding into Network Project on Sheep Improvement (NwPSI); Shifting to selective breeding of indigenous breeds ; Peak wool-type population; carpet wool industry strong; early rise in mutton demand
2000s	58-70	350-400	40-42	Shift toward meat and dual-purpose breeds accompanied rising domestic mutton consumption. In 2009, the Mega Sheep Seed Project (MSSP) was launched, linking nucleus breeding farms directly with registered farmers' flocks to enable the transfer of superior genetics from farm to field and validate their impact through performance evaluation of progeny from distributed rams.
2011-12	65.07	400	43.0	Mutton share increases to 7.19% of national meat output
2019	74.26	770	36.0	20th Livestock Census
2022-23	-	1,026	33.61	Mutton share rises to 10.51%; Rajasthan contributes 48% of national wool
2025	-	1,140	34.57	Stable flock size; productivity gains; meat-type breeds projected >60%

(ICAR-CSWRI 1983, BAHS 2014, BAHS 2025)

Table 2. State-wise sheep population, composition and growth in India (DAHD, 2019)

Rank	State / UT	Exotic / Crossbred (million)	Indigenous (million)	Total Sheep (million)	% Share of National Total	% Change over 19th Census
1	Telangana	0.18	18.88	19.06	25.72	+48.51
2	Andhra Pradesh	1.08	16.55	17.63	23.70	+30.00
3	Karnataka	0.15	10.90	11.05	14.95	+15.31
4	Rajasthan	0.03	7.87	7.90	10.64	-12.95
5	Tamil Nadu	0.10	4.40	4.50	6.06	-5.98
6	Jammu & Kashmir	0.04	3.16	3.20	4.31	-4.19
7	Maharashtra	0.03	2.67	2.70	3.64	+3.87
8	Gujarat	0.02	1.78	1.80	2.42	+4.66
9	Odisha	0.01	1.29	1.30	1.75	-19.10
10	Uttar Pradesh	0.02	0.98	1.00	1.35	-27.25
	Other States / UTs	0.21	3.11	3.32	4.46	
	India Total	1.88	72.38	74.26	100.00	

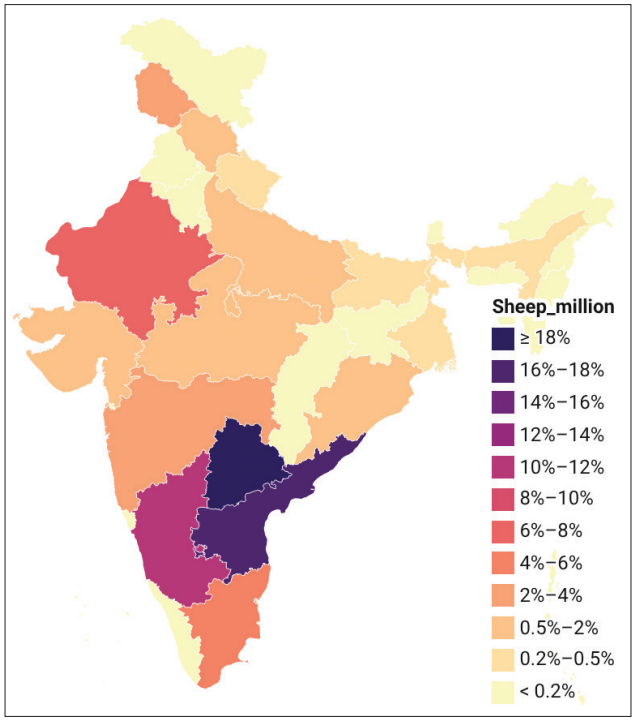

Figure 2. State-wise distribution of sheep population in India as a percentage share of the national total, based on the 20th Livestock Census.

Growth and emerging trends in mutton production: During 2024-25, India produced 10.50 million tonnes of total meat, of which 1.186 million tonnes (11.29%) came from sheep meat (mutton) (BAHS 2025). For much of the period up to 2017-18, mutton contributed a relatively stable share of about 7.5% to total meat production. Since 2018-19, however, its share has risen steadily, reaching an all-time high in 2024-25. This trend points to a sustained shift in consumer preference towards sheep meat.

The southern states namely Andhra Pradesh, Telangana, and Karnataka remained dominant, together contributing 79.94 % of national mutton output (Table 3). Correspondingly, the number of sheep processed for meat in India rose sharply from 73.70 million in 2022-23 to 80.70 million in 2023-24, reflecting an annual increase of about 9.5% (BAHS 2024). This upward trend persisted into 2024-25, with total sheep processed reaching approximately 83.15 million (BAHS 2025). This highlights a clear structural shift in India's sheep sector towards a meat-oriented enterprise, shaped by consumer demand and increasingly well-integrated year-round markets.

The increasing scale of meat (combined from sheep and goat) production was also reflected in its contribution to Gross Value Added (GVA) within India's livestock sector. The GVA from meat (sheep and goats), rose from ₹50,176 crore in 2014-15 to approximately ₹1.81 lakh crore in 2023-24 at current basic prices (BAHS 2025), representing an increase of over 260 percent.

Table 3. Key Sheep meat production indicators in major Indian States in 2024-25 (BAHS 2025)

State / UT	Sheep Slaughter ('000 nos.)	Mutton Production ('000 tonnes)	Share in National Mutton (%)
Andhra Pradesh	26,513.99	418.43	35.27
Telangana	24,675.00	365.00	30.76
Karnataka	10,073.31	165.00	13.91
Tamil Nadu	5,684.74	62.02	5.23
Rajasthan	4,735.27	57.10	4.81
West Bengal	1,950.82	23.15	1.95
Jammu & Kashmir	1,346.31	22.60	1.91
Odisha	1,324.63	17.18	1.45
Haryana	1,019.64	16.00	1.35
Uttar Pradesh	596.89	8.60	0.72
India Total	80,704.16	1186.42	

Wool production trends: India's long-term wool production trend highlights three major phases of structural change (Figure 3). The first phase (1951-1997) shows a strong upward trajectory, with wool output rising from 27.5 million kg to a historic peak of 48.1 million kg, supported by increases in sheep numbers, carpet-wool breed development, and technological interventions. The second phase (1997-2012) represents a period of stability, with production maintaining levels of 43-46 million kg, reflecting a consistent supply base. The third phase, beginning after 2012, initially showed a decline in production, from 43.7 million kg in 2012 to 40.4 million kg in 2019 and further to 33.69 million kg in 2024 which may be driven primarily by changing fibre preferences, a shift toward meat-oriented breeds, and reduced demand for coarse wool. However, the most recent years present a more encouraging picture. After experiencing sharp contractions of -9.05% in 2019-20 and -10.87% in 2021-22, the sector has begun to steadily regain momentum. Growth turned positive in 2022-23, strengthened further in 2023-24 (+2.12%), and continued to improve in 2024-25 (+2.63%), resulting in a recovery to 34.57 million kg in 2025 (BAHS 2025).

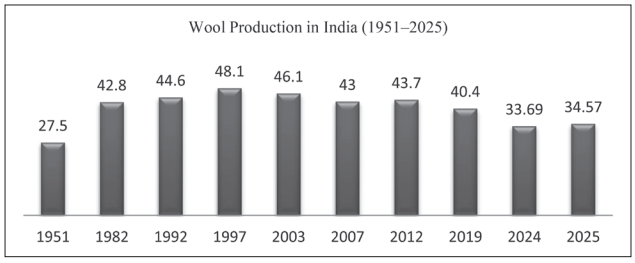

Fig. 3. Long-term trends in wool production in India

In 2024-25, India produced 34.57 million kg of wool, with Rajasthan (47.85%), Jammu & Kashmir (22.88%), and Gujarat (6.22%) as the leading producers; together with Maharashtra and Himachal Pradesh, these states contributed over 86% of national production (BAHS 2025; Table 4). Although wool production has declined over time due to low prices and competition from synthetic fibres, it still supports pastoral livelihoods, carpet weaving, and traditional crafts in Himalayan and arid regions (Singh *et al*. 2021). The slight recovery in 2024-25 suggested that better breeds, improved fibre quality, value addition, and stronger market links could help revive the sector, even as meat production remains the main economic driver in sheep farming.

Sheep milk, an emerging niche potential: Globally, sheep milk forms the backbone of premium dairy industries, particularly in Mediterranean and Middle Eastern regions where it is used to manufacture high-value cheeses such as *Feta, Roquefort, Pecorino Romano*, and *Manchego* (FAO 2024, Park *et al.* 2020). International research consistently shows that sheep milk has a richer nutritional composition than cow milk, with substantially higher levels of protein, fat, total solids, calcium, and phosphorus, resulting in superior energy density and exceptional suitability for processing (Liu *et al.* 2025). These qualities make it a preferred substrate for artisanal cheeses, fermented dairy products, and value-added specialty foods, particularly in regions with established gourmet dairy cultures (Rubio *et al.* 2022).

Table 4. State-wise wool production in India (2024-25) (BAHS 2025)

Rank	State / UT	Wool Production ('000 kg)	Share (%)
1	Rajasthan	16,542.59	47.85
2	Jammu & Kashmir	7,909.97	22.88
3	Gujarat	2,150.41	6.22
4	Maharashtra	1,642.05	4.75
5	Himachal Pradesh	1,485.01	4.29
6	Uttar Pradesh	837.66	2.42
7	West Bengal	773.85	2.24
8	Haryana	679.68	1.97
9	Karnataka	647.29	1.87
10	Punjab	560.50	1.62
11	Madhya Pradesh	348.14	1.01
12	Jharkhand	252.98	0.73
13	Bihar	178.24	0.52
14	Chhattisgarh	76.62	0.22
15	Tamil Nadu	1.98	0.01
	Other States / UTs	422.75	1.22
	India Total	34,573.72	

In India, sheep milk production remains limited because most indigenous breeds produce only 0.5-1.0 kg/day, primarily sufficient for lamb growth rather than commercial extraction. However, experimental work at ICAR-CSWRI demonstrated that milk productivity can be enhanced through strategic crossbreeding. Awassi × Malpura (AM) ewes recorded 19-20% higher milk yield than pure Malpura ewes under semi-arid grazing conditions, indicating the feasibility of developing dual-purpose or triple-purpose (meat-wool-milk) production systems adapted to Indian environments (Sharma *et al.* 2009, Arora *et al.* 2011). Although currently an underutilized resource, sheep milk offers significant opportunities for niche urban markets, artisanal dairy start-ups, functional and nutritional health products, and supplementary income streams for small ruminant farmers. With the rising domestic demand for specialty cheeses and high-value nutrition blends in metropolitan cities, the sheep-dairy segment may hold a considerable potential to emerge as a future enterprise in India.

Indian sheep breeds: There are 47 registered sheep breeds in India (NBAGR 2026). They belong to different utility groups and are distributed in four agro-climatic regions (Table 5). A large number of these breeds are found in the North-western arid and semi-arid and Southern Peninsular regions, followed by other regions.

Table 5. State-wise and utility-wise distribution of registered Indian sheep breeds

State / UT	Utility Type	Breeds
Jammu & Kashmir UT/ Ladakh UT	Carpet wool	Bhakarwal, Changthangi, Gurez, Poonchi, Rampur-Bushair
	Apparel wool#	Kashmir-Merino
	Hardy/mutton	Karnah
Himachal Pradesh	Carpet wool	Gaddi, Rampur Bushair
Punjab	Mutton*	Kajali
Rajasthan	Carpet wool	Chokla, Magra, Nali
	Mutton & carpet wool	Jaisalmeri, Marwari†, Pugal, Sonadi
	Mutton*	Malpura, Kheri
	Mutton and prolific	Avishaan*‡
Gujarat	Mutton & milk§	Patanwadi, Panchali*§
	Mutton & carpet wool	Marwari†
Uttar Pradesh	Mutton	Jalauni†, Muzaffarnagari†
Uttarakhand	Mutton	Muzaffarnagari†
Madhya Pradesh	Mutton	Jalauni†
Maharashtra	Mutton	Deccani†
Andhra Pradesh	Mutton	Deccani†, Nellore, Macherla*
Karnataka	Mutton	Bellary, Hassan, Kenguri, Mandya
Tamil Nadu	Carpet wool	Coimbatore, Nilgiri
	Mutton	Kilakarsal, Madras Red, Mecheri, Ramnad White, Tiruchi Black, Vembur, Katchaikatty Black*, Chevaadu*
Odisha	Mutton	Balangir, Ganjam
	Prolific	Kendrapada*‡
West Bengal	Prolific	Garole‡
Bihar	Mutton	Shahabadi
Jharkhand	Mutton	Chhotanagpuri
Arunachal Pradesh	Carpet wool	Tibetan
Sikkim	Carpet wool	Bonpala

Source: (NBAGR, 2026). * Newly registered NBAGR breeds (post-2020): Katchaikatty Black, Chevaadu, Kendrapada, Panchali, Kajali, Kheri, Macherla; # Developed/composite fine-wool breed: Kashmir-Merino; † Breeds present in more than one state: Marwari (Rajasthan & Gujarat), Muzaffarnagari (UP & Uttarakhand), Jalauni (UP & MP), Deccani (Maharashtra & Andhra Pradesh). ‡ Prolific breeds: Garole, Kendrapada, Avishaan. § Breeds with recognised milk potential: Patanwadi, Panchali.

Synthetic breeds of sheep developed in India: Table 6 summarizes the major synthetic (crossbred) breeds/strains developed in India, along with their genetic composition and primary utility.

India holds a significant position in global sheep husbandry, ranking second in the world after China in total sheep population (WPR 2026). With an estimated 77.4 million sheep, the country surpasses several traditionally recognized sheep-producing nations such as Australia (72.1 million), Iran (52 million), Nigeria (51.4 million) and Turkey (42.1 million). India continues to maintain a steady presence in the global market for sheep and goat meat, with exports reaching 10,829 metric tonnes in FY 2023-24, valued at USD 77.68 million (APEDA 2024). The export basket primarily comprised frozen, halal-certified meat processed through approved export facilities. The Middle East remains the dominant destination, with the United Arab Emirates, Qatar, Kuwait, Maldives, and Bahrain collectively accounting for the vast majority of India's outbound shipments (DGCIS 2024).

Out of 36.93 million Kg of raw wool produced in 2020-21, 85% was carpet-grade, 5% was apparel-grade, and 10% was coarse/coloured wool. The average annual wool yield per sheep remained only 0.9 kg, compared with the global average of 2.4 kg per animal (Ministry of Textiles 2023). Despite this sizeable output and the decrease in production in recent years, domestic wool production remained insufficient to meet the growing requirements of the woolen industry, particularly for apparel-grade and processing-grade wool. As a result, India relied heavily on imports. Raw wool imports ranged from 96.53 million kg in 2014-15 to 81.62 million kg in 2020-21, with import values fluctuating between ₹995 crore and ₹2,159 crore (Ministry of Textiles 2023). Major supplying countries in 2020-21 included Syria, China, New Zealand, Turkey, Australia, Italy, and the UAE (Ministry of Textiles 2023).

Table 6. Synthetic (Crossbred) breeds/strains of sheep developed in India

Synthetic Breed / Strain	Genetic Combination	Developed By / Location	Primary Purpose and Adaptability
Bharat Merino (BM)	Chokla /Nali × Rambouillet /Merino	ICAR-CSWRI, Avikanagar	Fine apparel wool; adaptable to semi-arid regions, North temperate region, Southern peninsular region including the sub-temperate climate of Kodai hills
Avikalin	Malpura × Rambouillet	ICAR-CSWRI, Avikanagar	Carpet wool; Semi-arid, Southern peninsular region including the sub-temperate climate of Kodai hills
Avivastra	Chokla / Nali × Rambouillet/Merino	ICAR-CSWRI, Avikanagar	Fine wool production; semi-arid region
Avimanns	Malpura / Sonadi × Dorset / Suffolk	ICAR-CSWRI, Avikanagar	Meat-type; rapid growth and early maturity
Avishaan	Garole × Malpura × Patanwadi	ICAR-CSWRI, Avikanagar	High prolificacy; improved growth and reproduction; across agroclimatic regions
Avihill (Gaddi synthetic)	Gaddi × Australian Merino	ICAR-CSWRI, NTRS, Garsa	Fine apparel wool; North temperate region
Hissardale	Magra× Australian Merino	CCSHAU / Govt. Livestock Farm, Hisar	Fine wool; semi-arid region
Indian Karakul	Marwari × Malpura × Sonadi	ICAR-CSWRI, ARC, Bikaner	Pelt; arid region
Kashmir Merino	Gaddi / Bhakarwal × Rambouillet / Soviet Merino	J&K Sheep Husbandry Department	Fine wool; suited to temperate highlands; north temperate region
NARI-Suwarna	Deccani × Madgyal × Garole	NARI, Phaltan	Mutton; high prolificacy; semi-arid region and southern peninsular region
Nilgiri Synthetic (Sandyno)	Nilgiri × Merino	Sheep Breeding Research Station (SBRS), TANUVAS, Sandynallah	Fine wool; Nilgiri hill ecosystem
Patanwadi Synthetic	Patanwadi × Merino / Rambouillet	GAU, Dantiwada	Carpet wool; adaptable to arid and semi-arid regions

Global profile of India in sheep husbandry and trade

Even as raw wool production declined, woollen products continue to perform strongly in India's export basket. The country exports tops, yarn, fabrics, ready-made garments, and carpets, of which carpets account for the largest share, sustaining India's global leadership in hand-knotted and machine-made carpet segments. Between 2015-16 and 2020-21, carpet exports consistently remained in the range of ₹9,000-12,000 crore (Ministry of Textiles 2023). Key export destinations for woollen yarn and fabrics include Italy, South Korea, the United Kingdom, the United States, Sri Lanka, and Germany (Ministry of Textiles 2023).

Emerging and novel technologies for sheep improvement in India: India possesses rich ovine biodiversity adapted to diverse agro-ecological regions. Molecular characterization using microsatellite and single nucleotide polymorphism (SNP) markers has enhanced understanding of genetic diversity, breed differentiation and population structure (Kumar *et al.* 2021). Marker-assisted selection and emerging genomic tools offer opportunities to accelerate genetic gain for growth, carcass traits, disease resistance and reproductive efficiency. Although genomic selection is widely implemented in advanced sheep-producing countries, its application in India remains limited due to fragmented flock structures, inadequate performance recording and economic constraints. Nevertheless, ongoing initiatives in genomic resource characterization, breed registration and germplasm conservation constitute important steps toward precision breeding and long-term genetic improvement under Indian production conditions.

Assisted reproductive technologies have emerged as critical tools for the rapid dissemination of superior germplasm and enhancement of reproductive efficiency. Estrus synchronization protocols using progesterone devices in combination with $PGF_{2\alpha}$, GnRH and eCG have been standardized for Indian field conditions, enabling improved breeding management and controlled lambing (Kumar *et al.* 2025a). Efforts are underway to improve fertility outcomes following transcervical artificial insemination (AI) with frozen or chilled semen (Kumar and Naqvi 2014), as well as laparoscopic AI (Malik *et al.* 2023). Advances in semen cryopreservation, including improved extenders, antioxidant supplementation and refined freezing protocols, have enhanced post-thaw sperm quality and fertility (Kumar and Balaganur 2019, Paul *et al.* 2026). The development of the indigenous mobile Avi MAIL-AI Laboratory represents an important field-level

innovation, facilitating on-site estrus synchronization and AI services in remote and semi-arid regions (Kumar 2025). Although multiple ovulation and embryo transfer (MOET) has been experimentally validated in sheep (Naqvi *et al.* 2006), large-scale adoption remains constrained by technical complexity and infrastructural limitations.

Complementary advances in precision nutrition, health management and digital technologies are further contributing to productivity enhancement. Region-specific mineral mixture supplementation (Kumar *et al.* 2025a) and targeted nutritional interventions during critical physiological stages have improved fertility, lamb survival and growth performance (Kumar *et al.* 2019). Feed block technologies, urea-molasses multi-nutrient blocks (Muralidharan *et al.* 2012), bypass protein supplementation and utilization of agro-industrial by-products have improved feed efficiency under arid and semi-arid conditions. Nutraceuticals and antioxidant supplementation are being explored to mitigate oxidative stress and enhance reproductive outcomes under climatic stress.

Molecular diagnostic tools, including PCR-based detection of major infectious diseases, and strengthened vaccination programmes have improved preventive health management. Further, market-ready technologies including high-quality semen doses of indigenous sheep breeds, synchronization kits, sheep specific mineral mixtures, organic manure from sheep waste, value-added sheep meat and milk products, wool-based biodegradable products and PCR-based Pashmina authentication assays, sheep-hair shearing devices illustrate successful translation of research into commercially viable innovations (Kumar *et al*. 2025a, RuTAG 2025).

Challenges in sheep rearing in India: Although the sheep sector plays a crucial role in supporting pastoral and smallholder livelihoods across diverse agro-ecological regions, the farmers increasingly face a range of biological, ecological, market, institutional, and socio-economic challenges.

Disruption of migratory pastoral routes: The long-established migratory corridors are increasingly disrupted due to administrative barriers, weak inter-state coordination, fencing of common lands, and limited recognition of pastoral mobility.

Shrinking access to grazing and forest resources: Access to natural grazing resources continues to decline due to the reduction of common property lands, restrictions on forest grazing, unclear grazing rights, and competing land uses. These pressures have contributed to rangeland degradation, loss of forage diversity, and adverse effects on growth, reproduction, wool yield, and lamb survival, especially in arid and semi-arid regions (De *et al.* 2021, Chinnathambi *et al.* 2025).

Genetic constraints and limited breeding support: Although indigenous sheep breeds are well adapted to harsh environments, many exhibit modest growth rates, lower body weights, coarse wool, and limited milk yield (Kumar 2021a). Genetic improvement remains slow due to limited availability of quality breeding rams, weak performance recording, and the restricted reach of organized breeding programmes.

Anatomical constraints limiting cervical/trans-cervical artificial insemination (AI): Unlike cattle, rectal manipulation is not feasible in ewes, and the cervix is narrow, rigid, and tortuous, which restricts transcervical access to the uterus and hampers the passage of AI guns/insemination pipettes. These anatomical barriers substantially reduce the success of cervical or transcervical AI and limit its wider field-level application, particularly under extensive production systems, where controlled handling and precise timing of insemination are challenging (Alvarez *et al.* 2019).

Fertility limitations associated with cryopreserved semen: The use of cryopreserved ram semen presents additional challenges, as fertility outcomes following AI with frozen semen are often lower and more variable under field conditions compared with fresh or chilled/refrigerated semen. Further, ram spermatozoa are highly sensitive to cryoinjury due to their low membrane cholesterol-to-phospholipid ratio, resulting in reduced post-thaw viability, membrane integrity, and fertilizing ability (Salamon and Maxwell 1995).

Animal health constraints and disease burden: Small ruminants are affected by several endemic diseases, including peste des petits ruminants (PPR), sheep and goat pox, anthrax, bluetongue, contagious caprine pleuropneumonia, clostridial infections and parasitic infestations such as *Haemonchus contortus*. These infections may spread within and between flocks through animal movement, shared grazing areas, and seasonal congregation at markets and watering points. According to BAHS (2025), reported mortalities for ovine and caprine during January to June 2024 were highest for PPR (678 deaths), followed by sheep and goat pox (133 deaths), anthrax (55 deaths), contagious caprine pleuropneumonia (30 deaths), bluetongue (3 deaths), and black quarter (5 deaths).

Adoption of livestock insurance: Farmers' reluctance to adopt or continue livestock insurance has been documented in field-based studies for other animals. Many sheepherders report limited familiarity with insurance procedures, while valuation caps and scheme design features restrict perceived benefits.

Theft, dog attacks, and uncompensated losses: Incidents of ovine theft and attacks by stray or feral dogs have emerged as major concerns, particularly during migration and night halts in remote areas as reported by many farmers. Injuries caused by dog attacks frequently result in delayed mortality, compounding economic losses that remain largely outside existing compensation frameworks.

Market inefficiencies and weak value chains: Sheep marketing remains largely informal and intermediary-driven, limiting price transparency and bargaining power for producers. Many livestock markets lack basic facilities such as weighing, grading, health certification, cold storage,

and hygienic slaughter infrastructure (Muthukumar *et al.* 2021). Wool markets face even greater constraints, with limited access to shearing sheds, grading, washing, storage, and aggregation facilities, particularly in remote and hill regions (Ministry of Textiles 2023).

Perception and promotion challenges for wool: Coarse wool continues to suffer from negative perception, often viewed as inferior despite its strength, durability, and suitability for carpets, felts, insulation, and technical applications. The absence of objective grading, branding, and consumer awareness has constrained its market potential (Singh *et al.* 2022). Compared to synthetic fibres, wool receives limited promotion, despite being renewable, biodegradable, and environmentally friendly.

Youth exit: Rapid expansion of industrial and service sectors have generated attractive non-farm employment opportunities that draw rural men and youth away from agriculture and livestock rearing, resulting in changing household labour dynamics (Jothilakshmi *et al.* 2014). Further, increased use of smartphone has reshaped social behaviour and aspirations among younger generations, reflecting a broader shift towards digitally mediated lifestyles. Together, these transitions may indirectly influence occupational choices by reducing interest in physically demanding, low-prestige, and mobility-intensive livelihoods such as sheep rearing.

Climate change and environmental stress: Climate variability in the form of rising temperatures, erratic rainfall, prolonged droughts, and declining water availability has intensified feed stress, reduced neonatal survival, and impaired reproductive performance (Godde *et al.* 2021, Das *et al.* 2025). Given the concentration of sheep in semi-arid and arid regions, climate stress compounds existing nutritional, genetic, and health challenges (Shinde and Sejian 2013).

Future prospects and a strategic roadmap for India's sheep sector: Long-term progress of sheep sector should rely on combining genetic improvement with better nutrition, effective animal health care, wider and more practical use of assisted reproductive technologies, modernized value chains, climate-adaptive practices, and stronger institutional support. Some of the key priority areas shaping this roadmap are outlined below.

Transition to adaptive semi-intensive and managed mobility systems: Sustaining sheep production would require a gradual shift from nomadic grazing towards adaptive semi-intensive models. Evidence showed that stall-feeding can enhance animal performance while reducing dependence on long-distance migration (Devi *et al.* 2020, Zhao *et al.* 2023, Bąkowska *et al.* 2025). This becomes particularly important as land pressure increases and per capita agricultural land availability continues to decline in India (0.12 ha in India vs. 0.29 ha globally), prompting policy attention toward restoring degraded scrublands, pastures, sandy and ravinous areas (NITI Aayog 2024). Such restored wastelands can potentially be integrated with sheep grazing and fodder development to reduce pressure on cultivated land and natural pastures. Where mobility remains indispensable, such as in border and Himalayan regions, managed seasonal movement supported by mapped corridors, and coordinated inter-state guidelines can sustain transhumant systems while reducing conflicts, transaction costs, and production risks.

Fodder-centric production and silvopastoral landscape development: Scientific studies support the use of complete feed blocks, pelleted diets, and crop-residue-based rations as effective means to improve feed efficiency, reproductive performance, and growth under stall-feeding or semi-intensive conditions (Ben-Salem and Nefzaoui 2003, Ahmed *et al.* 2020). At the landscape level, silvopastoral systems integrating trees, shrubs, and perennial grasses have been shown to enhance biomass availability, soil health, and ecosystem resilience, particularly in arid and semi-arid regions (Nechifor *et al.* 2022, Bhatt *et al.* 2024, Kumar *et al.* 2025b). Complemented by rotational grazing and community-managed fodder banks, these approaches offer a sustainable pathway to secure year-round feed resources.

Genetic improvement and breed development: Selective breeding supported by structured performance recording, open nucleus breeding systems, and region-specific breeding objectives has demonstrated measurable genetic progress under field conditions (Naveena *et al.* 2023). Large proportions (>50%) of non-descript sheep can be systematically upgraded through a continuous large scale National level grading-up programme using local elite rams of well-established breeds, preferably by AI with fresh diluted chilled liquid semen, within their respective breeding tracts, enabling rapid genetic improvement for higher productivity under field conditions. Genomic tools and molecular breeding approaches, including, genomic characterization, genomic selection and breed fingerprinting, can be integrated into sheep improvement programmes to ensure breed authentication and traceability across value chains (Kumar 2021b). Simultaneously, conservation of resilient indigenous breeds such as Marwari, Deccani, Gaddi, Changthangi, and Nellore remains critical due to their tolerance to heat stress, nutritional scarcity, and rugged terrains (Raja *et al.* 2022). Development of dual- and triple-purpose strains (meat-wool-milk) through multi-trait selection will further support diversified and resilient production systems.

Overcoming anatomical barriers and strengthening AI technologies: Economic evidence from sheep production systems shows that farms adopting AI achieve higher genetic merit of replacements, greater product diversification, and higher gross and net revenues than farms relying solely on natural mating, although with higher labour and capital costs, highlighting AI as a pathway for long-term economic sustainability (Liagka *et al*. 2025). Given the anatomical complexity of the ewe cervix, future strategies should emphasise context-specific reproductive technologies. Wider use of laparoscopic intrauterine insemination (LAI) with frozen semen can bypass cervical barriers and improve

conception and lambing rates (Myers and Kasimanickam 2025). At the same time, research should focus on improving transcervical devices, cervical relaxation agents, semen packaging, and oestrus synchronisation to gradually enhance the feasibility of non-surgical AI under controlled field conditions.

Scaling field-level AI delivery and improving cryopreserved semen fertility: In India, *Avikesil* (intravaginal progesterone sponge) provides a practical tool for oestrus synchronisation. Integration of Avikesil with the Avimail semen transport system developed at ICAR-CSWRI (Avimail enables door-to-door insemination using extended chilled semen can facilitate wider dissemination of semen doses and greater replication of elite rams under field conditions (Kumar *et al.* 2025a). Parallel research should priorities improving fertility with cryopreserved ram semen through advances in semen extenders, cryoprotectants, and freezing–thawing protocols tailored to the unique membrane characteristics of ram spermatozoa to enhance post-thaw viability and reproductive performance.

Strengthening animal health systems: Efforts should focus on strengthening preventive health measures, vaccination programmes against PPR, sheep pox, and clostridial infections, alongside standardized parasite-control protocols. Expansion of mobile veterinary services, periodic health camps along migratory routes, enhanced disease surveillance, supported by field-level reporting and improved laboratory networks, will aid early outbreak identification and containment.

Digital animal identification for insurance, disease surveillance and AI Delivery: Digital identification systems using ear tags, RFID or QR-linked databases can support accurate registration, proof of ownership and verifiable history during insurance claims, reducing fraud, disputes and settlement delays. Once established, such systems can also underpin disease surveillance (by linking animals to health events, vaccinations and mortality), reproductive management (through AI service recording, breeding history and progeny tracking) and movement controls during outbreaks. International experience demonstrates the utility of integrated identification platforms; for example, Australia's National Livestock Identification System (NLIS) provides lifetime traceability and supports biosecurity, market assurance and compensation mechanisms (Government of South Australia 2025).

Modernization of wool value chains: In the wool sector, upgrading shearing, sorting, grading, washing and storage infrastructure, alongside the establishment of wool cooperatives and Common Facility Centres, can improve quality and price realisation (IBEF 2023). Coarse wool's inherent properties like flame retardancy, high nitrogen content, acoustic insulation and biodegradability make it suitable for aviation and defence textiles, eco-fertilisers, construction insulation and eco-apparel, many of which are already commercialised in Europe. Branding initiatives such as Bharat Wool may further help reposition regional wool types, support "vocal for local" value chains and expand niche markets.

Modernization of meat value chains: Modernization of slaughterhouses, expansion of cold-chain and logistics infrastructure, and promotion of halal-certified processing can strengthen domestic distribution and export competitiveness (APEDA 2024). Parallel branding streams such as jhatka-certified meat can further serve consumers preferring alternative slaughter practices. Greater value addition through marinated cuts, ready-to-cook products, minced and formed meats, dehydrated snacks, and pet-food ingredients can diversify income and reduce wastage. Internationally, countries such as New Zealand, the EU, and Australia employ carcass classification, electronic identification (EID), cold-chain auctions, and integrated export plants to ensure quality, traceability, and origin-based branding, securing premium prices.

Modernization of milk value chains: Although sheep milk remains a niche sector in India, investments in hygienic milking, chilling, and collection infrastructure could support specialty products such as cheese, yoghurt, and ghee that command premium prices. International models based on PDO cheeses (e.g., Pecorino, Roquefort, Feta) show how GI tagging, cooperatives, cold chains, quality standards, traceability, and direct-to-consumer platforms can build high-value rural enterprises.

Climate resilience and adaptive strategies: Given the concentration of sheep populations in climate-vulnerable semi-arid regions, enhancing resilience is imperative. Long-term breeding strategies should prioritize adaptive traits such as heat tolerance, disease resistance, and efficient utilization of low-quality forage (Shinde and Sejian 2013). Adoption of climate-smart grazing practices, improved water-harvesting systems, and wider use of heat- and drought-tolerant breeds can significantly strengthen adaptive capacity under changing climatic conditions (FAO 2023).

Institutional strengthening and human resource development: Institutional support and capacity building are essential for sustainable sectoral transformation. Farmer training through central and State Animal Husbandry Departments can promote adoption of scientific practices, while strengthening shepherd cooperatives, Farmer Producer Organizations, and SHG federations can enhance collective bargaining and reduce transaction losses. Integrating traditional pastoral knowledge with modern extension systems and promoting gender-inclusive training will also empower women shepherds, who play a key yet often under-recognized role in flock management.

Over the past 75 years, India's sheep sector has shifted from a wool-based system to a largely meat-oriented enterprise. While flock numbers have grown modestly, productivity and economic value have increased significantly, with mutton production rising nearly tenfold. Wool output has stagnated due to changing textile demand, dominance of meat breeds and competition from synthetic fibres. Nevertheless, sheep remain vital for rural livelihoods, providing liquidity and risk support under

low-input systems. India's resilient indigenous breeds offer strong potential which can be unlocked through scientific breeding, assisted reproductive techniques adoption, better animal health, improved grazing management, stronger markets, and climate-smart institutional support.

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