

## Genetics of Some Wool Traits in Sheep: A Review

### ABSTRACT

Greasy fleece yield, staple length and fibre diameter are complex quantitative traits influenced by various genetic and environmental factors. Among non-genetic factors year of birth, gender of lamb, centre of rearing, parity and type of birth are known to influence wool traits in different sheep genetic resources. To develop effective breeding objectives and accurately evaluate genetic potential, more precise analysis of genetic parameters and correlations between growth traits is essential. However, inconsistent results were observed across breeds and studies, highlighting the need for breed-specific optimization strategies. Greasy fleece yield, fibre diameter and staple length are critical determinants of wool quality and quantity. Wool traits are moderately (20–50%) to highly heritable ( $\geq 50\%$ ), so improving quality and quantity of a wool clip can happen even after one generation. The significant variations observed among breeds underscore the need for breed-specific optimization strategies. By integrating genetic and environmental factors, sheep breeders and producers can develop effective breeding programs, improve wool production, and enhance profitability. Wool traits are moderately to highly heritable, however, very low and very high estimates have also been reported in different sheep genetic resources. The heritability estimates correspond to the genetic variation in a trait. Gene mapping has identified chromosomal regions influencing fibre quality and production, enabling more efficient selection of superior wool production. Recent studies have employed various techniques to investigate the impact of fibre-related genes, including the candidate gene approach, transcriptome analysis and genome-wide association studies. It is concluded that wool traits being quantitative in nature are governed by different genes and are influenced by genetic and different environmental factors.

**Keywords:** Wool production, Sheep, Parity of dam, Type of birth, Greasy fleece yield, Fiber diameter, Staple length

### 1. Introduction

Wool is a versatile product in demand mainly because of its physical characteristics that directly influence wearer comfort (Hatcher et al., 2010). Key wool traits influence economic returns in sheep production include greasy fleece yield, clean wool yield, fiber diameter, staple length etc. Greasy fleece yield measures production potential and is a vital trait for evaluating clean wool yield quantity (Mahajan et al., 2018). Staple length (SL) and fiber diameter (FD) are crucial for selecting rams for breeding, as they bear a positive correlation with market prices of wool. Fiber diameter refers to the average width of a single wool fiber cross-section (Holman and Malau-Aduli, 2012). It is widely established as the most important wool trait when assessing wool quality and cost, accounting for approximately 75% of the total price of raw wool (Mortimer et al., 2010). FD value indicates the fineness with which a yarn can be spun and influences the amount of wool that can move through processing machinery at any

given time. Finer wools (low FD) can be processed into yarns suited for high-value apparel textiles, producing lightweight, soft fabrics with superior handle and drape (Holman and Malau-Aduli, 2012). Conversely, coarser wools with high FD values are particularly suited for less luxurious and lower-valued uses, such as carpeting, outerwear or bedding (Poppi and McLennan, 2010). Staple length determines the end-use of wool, whether it will be used in weaving or knitting, and influences wool processing performance (Valera et al., 2009). Longer wools, generally around 51 mm and above, are processed into versatile yarns. Wool fiber staple length is becoming an increasingly important determinant of wool quality and value (Valera et al., 2009). Wools with long staple length are commercially more desirable as they tend to be easier to spin, give fewer stoppages, and ultimately can form stronger and more even yarns (Holman and Malau-Aduli, 2012).

## 2. Greasy fleece yield of first clip and second clip

The greasy wool yield at six months (first shearing) and 12 months (second shearing) are reliable indicators of an animal's lifetime wool production capacity. These traits are positively, significantly and highly correlated among themselves as the wool traits are influenced the same genes (Vesley, 1970) and any variation which may be observed in latter may be caused by environmental factors. The greasy fleece yield of different sheep breeds is reflected in Table 1. Highest and lowest greasy fleece yield of first clip of  $1.08 \pm 0.119$  kg and  $0.43 \pm 0.032$  kg is reported in Corriedale (Mir et al., 2000) and Marwari sheep (Singh et al., 1998), respectively. Similarly, highest and lowest greasy fleece yield of second clip of  $1.01 \pm 0.017$  kg and  $0.125 \pm 0.042$  kg is reported in Corriedale (Dixit et al., 2009) and Marwari sheep (Singh et al., 1998), respectively.

**Table 1: Least squares means of greasy fleece yield of first and second clips (kg) in different sheep breeds**

Breed	Average $\pm$ S.E. (kg)		References
	GFY-1 (kg)	GFY-2(kg)	
Marwari	0.55	0.51	Sharma (1998)
Marwari	$0.43 \pm 0.032$	$0.125 \pm 0.042$	Singh et al., (1998)
Nali	$0.63 \pm 0.019$	$0.69 \pm 0.022$	Sharma (1999)
Bharat Merino	$0.82 \pm 0.02$	-	Tomar et al., (2000a)
Bharat Merino	$0.82 \pm 0.02$	-	Tomar et al., (2000b)
Chokla	$0.95 \pm 0.02$	-	Kumar (2000)
Corriedale	$1.08 \pm 0.119$	-	Mir et al., (2000)
Muzaffarnagri	$0.445 \pm 0.43$	-	Lal et al., (2000)
Marwari	$0.577 \pm 0.005$	$0.57 \pm 0.005$	Dass and Singh (2001)
Muzaffarnagri	$0.533 \pm 0.128$	$0.493 \pm 0.157$	Mandal et al., (2002)
Avikalin	$1.06 \pm 0.02$	-	Ahmad et al., (2004)
Magra	$0.63 \pm 0.008$	-	Dass et al., (2003)
Magra	$0.93 \pm 0.003$	$0.795 \pm 0.005$	Murdia et al., (2003)

Malpura	0.578±0.007	-	Sharma et al.,(2003)
Magra	0.58±0.01	0.584±0.203	Mehta et al.,(2004)
Marwari	0.543±0.014	-	Nehra et al., (2005)
Jaiselmeri	0.788±0.80	-	Arora et al., (2007)
3/4 <sup>th</sup> crossbred Bharat Merino	0.87±0.15	1.01±0.017	Dixit et al., (2009)
Chokla	0.95±.01	-	Kumar and Singh (2011)
Magra	0.757.82±0.11	84.30±0.09	Parihar (2012)
Marwari	0.568±4.19	0.692±5.53	Narula et al., (2011)
Marwari	0.576±0.007	0.657±0.006	Nirban (2013)
Marwari	0.564±0.078	0.494±0.022	Kannojia (2015)
Chokla	0.915 ± 0 .017	-	Yadav (2016)
Kashmir Merino	0.82±0.03	0.80±0.02	Rather et al., (2019a)
Anatolian Merino	2.97±0.19		Sertkaya et al., (2022)
Gang- Fatehpuri sheep	14.88±11.89	3.33±.23	Verma et al., (2024)

### 3. Wool quality traits of sheep

Wool quality is primarily determined by traits such as fibre diameter, staple length, crimp, colour and medullation percentage, which are influenced by both genetic and non-genetic factors and significantly impact wool processing performance and end-use (Valera et al., 2009; Holman and Malau-Aduli, 2012; Baba et al., 2020a). The least squares means of staple length and fibre diameter in different sheep breeds are reflected in Table 2.

**Table 2. Least squares means of staple length (SL) and fibre diameter (FD) in different sheep breeds**

Breed	FD ( $\mu$ )	SL (cm)	References
Bharat Merino	-	3.32±0.07	Dixit et al., (2009)
Marwari	36.15±0.27	4.69±0.05	Dass and Singh (2001)
Magra	32.41±0.28	-	Mehta et al., (2004)
Marwari	32.53±0.38	-	Nehra et al., (2005)
Corriedale	26.30±0.55	4.75±0.16	Sarkar et al., (2008)
Poll Dorset	25.18±1.28	4.04±0.51	Sarkar et al., (2008)
South Down	20.64±0.60	2.80±0.27	Sarkar et al., (2008)
Crossbred	25.21±1.16	3.65±0.21	Sarkar et al., (2008)
3/4 <sup>th</sup> crossbred Bharat Merino	18.89±0.15	3.32±0.07	Dixit et al., (2009)
Kashmir Merino	20.95±0.07	5.22 ± 0.11	Das et al., (2014)
Rambouillet	21.27±0.03	5.64±0.04	Khan et al., (2015)
Harnali	25.85±0.07	5.65±0.03	Lalit et al., (2017)
Rambouillet	21.30±0.02	5.26±0.03	Mahajan et al., (2018)
Kashmir Merino	20.33±0.05	3.86±0.14	Rather et al., (2019a)
Kashmir Merino	20.88±0.07	3.47±0.10	Rather et al., (2019b)
Kashmir Merino x NARI Swarna Merino	21.10±0.13	3.39±0.19	Rather et al., (2019b)
Kashmir Merino	20.96 ± 0.002	4.05±0.01	Baba et al., (2020a)

Gurez	28.31±0.17	4.48±0.07	Ahanger et al., (2020)
Poonchi sheep	24.99±0.13	3.82±0.07	Taggar et al., (2018)
Karnah sheep	21.77±0.05	3.40±0.37	Khan et al.,(2021)
Corriedale	21.20±0.05	3.88±0.05	Baba et al., (2020b)
Anatolian Merino	24.42±0.49		Sertkaya et al., (2022)
Gang- Fatehpuri sheep	14.88±11.89	47.79±1.81	Verma et al., (2024)

#### 4. Effect of sire

Research indicates that sire groups significantly impact wool traits, including greasy fleece yield, staple length and fiber diameter (Singh et al., 1998; Dixit et al., 2009; Parihar, 2012; Nirban, 2013; Holloway, 2017; Rather et al., 2019a). Studies have demonstrated significant differences in greasy fleece yield of second clip due to sire groups in various breeds, including Marwari sheep (Singh et al., 1998), 3/4<sup>th</sup> crossbred Bharat Merino (Dixit et al., 2009), Magra (Parihar, 2012), Marwari (Nirban, 2013) and Kashmir Merino (Rather et al., 2019a). The influence of sire groups on fiber diameter and staple length is also substantial. Random sire effects significantly influence fiber diameter in 3/4<sup>th</sup> crossbred Bharat Merino and Romney ewes (Dixit et al., 2009; Holloway, 2017). Similarly, staple length is significantly impacted by sire groups in 3/4<sup>th</sup> crossbred Bharat Merino and Romney ewes (Dixit et al., 2009; Holloway, 2017). These findings underscore the crucial role of genetics in determining wool quality and quantity. The significant influence of sire groups on wool traits has important implications for breeding programs, highlighting the need for selective breeding for superior wool traits, effective sire selection and consideration of genetic diversity to minimize inbreeding depression. By understanding the genetic basis of wool traits and leveraging genetic information, breeders can make informed decisions to enhance wool production and quality, ultimately improving the profitability and sustainability of sheep farming.

#### 5. Effect of period or year of birth

Management and grazing quality/quantity influence wool production across different periods. Studies demonstrate significant effects of period of birth on greasy fleece yield in Magra (Murdia et al., 2003; Mehta et al., 2004), Nali and Marwari (Sharma, 1998), Malpura (Gowane et al., 2009), and Marwari (Kannoja, 2015). Additionally, significant effects of year of birth on fiber diameter have been reported in Magra (Gajbhiye and Johar, 1983), Nali (Malik et al., 1990), Xinjiang (Wang et al., 1994), Afrino (Snyman et al., 1995), crossbred, Poonchi and Rambouillet (Qureshi et al., 2013), and Rambouillet (Khan et al., 2015; Mahajan et al., 2018). Period of birth also significantly impacts staple length in Nali (Malik et al., 1990), crossbred, Poonchi and Rambouillet (Qureshi et al., 2013) and Rambouillet (Khan et al., 2015; Mahajan et al., 2018). However, non-significant effects have been reported for year of birth on fiber diameter in Merino and Deccani half-bred sheep (Kulkarni and Deshpande, 1990) and Magra (Mehta et al., 2004). Similarly, period of birth has no significant effect on staple length in Kashmir Merino (Das et al., 2014; Rather et al., 2019a) and Harnali sheep (Lalit et al., 2016). Understanding these temporal variations is crucial for

optimizing wool production. By recognizing the impact of period / year of birth, breeders can make informed decisions regarding importance of management and nutrition in wool production traits.

## **6. Effect of gender of lamb**

Researchers have extensively investigated the impact of lamb gender on wool production and quality traits. Dass and Singh (2001) and Murdia et al., (2003) reported significant effects of lamb gender on greasy fleece yield of the first clip in Marwari and Magra, respectively. Similarly, Mehta et al., (2004), Narula et al. (2011) and Parihar (2012) observed significant effects on greasy fleece yield of the second clip in Magra. However, Dixit et al., (2009) found non-significant effects on greasy fleece yield of the second clip in 3/4<sup>th</sup> crossbred Bharat Merino. Lamb gender also significantly impacts fiber diameter. Malik et al., (1990) reported significant effects in Corriedale and Russian Merino, while Dixit et al., (2009) observed significant effects in 3/4<sup>th</sup> crossbred Bharat Merino. Conversely, Mehta et al., (2004) found non-significant effects in Magra, and Qureshi et al., (2013) and Khan et al., (2015) and Mahajan et al., (2018) reported non-significant effects in crossbred, Poonchi, and Rambouillet. Regarding staple length, significant effects of lamb gender have been reported by Vesely et al., (1970) in Rambouillet, Malik et al., (1990) in Corriedale and Russian Merino and Dixit et al., (2009) in 3/4<sup>th</sup> crossbred Bharat Merino. However, Qureshi et al., (2013) and Khan et al., (2015) and Mahajan et al., (2018) found non-significant effects in crossbred and Rambouillet. Rather et al., 2019a in Kashmir Merino sheep reported non-significant effect of gender on greasy fleece yield and significant effect on fiber diameter and staple length.

## **7. Effect of farm/ station**

Studies have shown that the centre of rearing significantly affects greasy fleece yield. Murdia et al., (2003) found a significant effect in Magra sheep's first clip. Similarly, Gupta (2000) observed a significant impact of farm on Rambouillet, Merino, Gaddi and their crosses. The place of birth also influences wool traits. Qureshi et al., (2013) reported a significant effect on greasy fleece yield. Gupta (2000) found a highly significant effect of farm on fibre diameter in Rambouillet, Merino, Gaddi and their crosses. However, Rather et al., (2019a) reported significant effects of farm on greasy fleece yield in Kashmir Merino sheep but no significant impact on fibre diameter and staple length. Baba et al., (2020a) reported non-significant effect of farm on FD and SL.

## **8. Effect of type of birth**

Research on Baluchi (Yazdi et al., 1997) and 3/4<sup>th</sup> crossbred Bharat Merino sheep (Dixit et al., 2009) reveals significant effects of type of birth on greasy fleece yield of the first clip (Table 3). However, (Dixit et al., 2009) found non-significant impact on greasy fleece yield of the second clip. Type of birth significantly influences staple length and fibre diameter in 3/4<sup>th</sup> crossbred Bharat Merino, as reported by Dixit et al., 2009). Conversely, Rather et al., (2019a) found non-significant effect of type of birth on staple length, fibre diameter or greasy fleece yield of either clip.

## 9. Effect of parity of dam

Yazdi et al., (1997) in Baluchi and Chander (2012) in Magra sheep reported that parity of dam had a significant effect on greasy fleece yield of first clip. However, Mandal et al., (2002) in Muzaffarnagri sheep reported a non-significant effect of parity on the trait. The effect of parity of dam on the greasyfleece yield of first clip (GFY-1) have been reviewed and summarized in Table 3. The information regarding effect of parity of dam on greasy fleece yield of second clip was very scanty in print and electronic media. Mandal et al., (2002) in Muzaffarnagri and Chander (2012) in Magra sheep reported that parity of dam had significant effect on greasy fleece yield of second clip. The information regarding effect of parity of dam on greasy fleece yield of second clip was very scanty in print and electronic media. Mandal et al., (2002) in Muzaffarnagri and Chander (2012) in Magra sheep reported that parity of dam had significant effect on greasy fleece yield of second clip. Rather et al. (2019a) found non-significant effect of parity of dam on staple length, fibre diameter or greasy fleece yield of either clip.

**Table 3: Effect of genetic and non-genetic factors on greasy fleece yield of first clip in different sheep genetic resources**

Breed/Genetic group	Genetic and non-genetic factors						References
	N	Sire	Period	Gender	Type of birth	Parity	
Bharat Merino	556	*	*	*	NS	-	Singh and Kushwaha, (1995)
Baluchi	-	-	*	*	*	*	Yazdi et al., (1997)
Nali	-	-	**	NS		-	Shanna et al., (1999)
Corriedale	-	NS	**	NS	NS	-	Mir et al., (2000)
Bharat Merino	-	-	**	NS		-	Tomar et al., (2000a)
Cholka	-	-	**	**	-	-	Kumar(2000)
Marwari	1132	-	**	**	-	-	Dass and Singh (2001)
Muzaffarnagri	-	-	-	-	-	NS	Mandal et al., (2002)
Magra	4107	**	**	**	-	-	Murdia et al., (2003)
Malpura	-	-	**	**	-	-	Sharma et al., (2003)
Magra	352	-	NS	NS	-	-	Dass et al., (2003)

Marwari	-	-	*	*	-	-	Nehra et al., (2005)
Jaisalmeri		-	-	**	-	-	Arora et al., (2007)
3/4 <sup>th</sup> crossbred Bharat Merino	2425	**	-	**	**	-	Dixit et al., (2009)
Kajli	-	-	**	**	NS	-	Qureshi et al., (2010)
Magra	-	**	NS	**	-	NS	Chander (2012)
Magra	-	**	*	**		-	Parihar (2012)
Marwari	-	**	**	**	-	**	Nirban (2013)
Chokla sheep	-	**	**	NS	-	-	Kumar et al., (2013)
Corriedale			**	NS			Baba et al., (2020b)

NS indicates non-significant

\* indicates significant at 5% level

\*\* indicates significant at 1% level

N indicates no. of observations

## 10. Heritability

Wool traits exhibit moderate (25-50%) to high ( $\geq 50\%$ ) heritability, indicating that genetic factors significantly influence trait variation. This suggests that genomic selection can substantially enhance wool production progress (Bromley et al., 2000; Burton et al., 2015). However, despite these promising heritability estimates, few genetic markers have been validated for use in genomic breeding strategies specifically targeting wool traits (Becker et al., 2023). The heritability estimates for greasy fleece yield (GFY-1 and GFY-2) and wool quality traits (FD and SL) have been reviewed and summarized in the Table 4. Wool yield traits are moderately (20–50%) to highly heritable. However, low ( $< 0.25$ ) heritability estimates have been reported by Sheikh and Dhillon (1992), Tomar et al., (2000a), Kumar (2000), Mandal et al., (2002) and Nehra et al., (2006) in Kashmir Merino, Bharat Merino, Muzaffarnagari Cholka and Marwari sheep genetic resources, respectively whereas very high heritability estimate of  $0.98 \pm 0.090$  was reported in Marwari sheep by Nirban et al., (2013). Moderate heritability estimates were observed by Mandal et al., (2002), Dixit et al., (2009) and Nirban et al., (2013) whereas Rather et al., (2019c) in Kashmir Merino observed a high heritability estimate. Nehra et al., (2006) and Rather et al., (2019c) in Marwari and Kashmir Merino, respectively observed a low heritability estimate for FD. Lalit et al., (2017) in Harnali sheep reported moderate estimates for FD and SL. Khan et al. (2015) in Rambouillet sheep reported high and low heritability estimates for FD and SL, respectively.

**Table 4: Heritability estimates for greasy fleece yield of first and second clips in different sheep breeds**

Breed	GYF-1	GYF-2	FD	SL	References
Soviet Merino	0.55±0.23	-			Kaul and Tomar (1983)
Russian Merino	0.67±0.21	-			Singh et al., (1984)
Merino	0.67±0.21	-			Mehta (1986)
Rambouillet	0.57±0.64	-			Mehta (1986)
Kashmir Merino	0.19±0.08	-			Sheikh and Dhillon (1992)
Avivastra	0.44±0.09	-			Kushwaha et al., (1995)
Bharat Merino	0.519±0.145	-			Singh and Kushwaha (1995)
Marwari	0.35 ± 0.084	0.31± 0.097			Sharma (1998)
Marwari	0.51 ± 0.058	0.03±0.031			Singh et al., (1998)
Nali	0.57 ± 0.286	0.023±0.144			Sharma et al., (1999)
Bharat Merino	0.02±0.06	-			Tomar et al., (2000a)
Bharat Merino	0.49±0.09	-			Tomar et al., (2000b)
Cholka	0.11±0.06	-			Kumar (2000)
Muzaffarnagari	0.23±0.05	0.38±0.06			Mandal et al., (2002)
Avikalin	0.41	-			Ahmad et al., (2004)
Marwari	0.162±0.117	-	0.216±0.123	-	Nehra et al., (2006)
3/4 <sup>th</sup> crossbred Bharat Merino	0.54±0.013	0.31±0.09	0.46±0.13	0.76±0.15	Dixit et al., (2009)
Marwari	0.98 ±0.090	0.37±0.065			Nirban et

					al.,(2013)
Rambouillet			0.55±0.09	0.15±0.05	Khan et al., (2015)
Synthetic sheep	0.25±0.05	-	0.52±0.12	0.45±0.11	Sehrawat (2016)
Harnali			0.45±0.06	0.38±0.05	Lalit et al., (2017)
Kashmir Merino	0.61 ± 0.08	0.52 ± 0.04	0.23 ± 0.04	0.66±0.10	Rather et al., (2019c)

### 11. Genomic selection and its impact on wool traits

Gene mapping has identified chromosomal regions influencing fibre quality and production, enabling more efficient selection of superior wool-producing animals (Hamadani et al., 2023). Recent studies have employed various techniques to investigate the impact of fibre-related genes, including the candidate gene approach, transcriptome analysis (Yunxia et al., 2021; Liu et al., 2020), and genome-wide association studies (Zhao et al., 2021). Differential and relative expression-based studies (Ma et al., 2022) have facilitated the identification of genes controlling hair and fibre traits, revealing unique expression patterns. Over the past few decades, DNA-based marker technology has enabled the identification of genomic regions, or quantitative trait loci (QTLs), underlying complex traits such as fibre diameter and crimp frequency (Xiao et al., 2022). Wool yield traits are known to be influenced by Leptin, PIT1 also IGF1 genes. Wang et al. (2014) discovered nine significant SNPs for fibre diameter, distributed across seven autosomes. Additional SNP markers have been reported on chromosomes OAR1, OAR5, OAR6, OAR13, and OAR25. KRTAP28-1 Variants. Bai et al. (2019) identified six variants (A-F) of the KRTAP28-1 gene, containing eight SNPs, and detected TG dinucleotide repeat polymorphism. Research has identified QTLs associated with staple length. Seven QTLs were detected on chromosomes 3, 7, 14, 15, 18, and 25 (Itenge-Mweza, 2007). Three QTLs on chromosomes 3, 7, and 25 were linked to staple length. Four putative QTLs were identified on chromosomes 14, 15, 18, and 25. Furthermore, Li et al. (2017) demonstrated that CRISPR/Cas9-mediated disruption of FGF5 activity can promote wool growth, increasing wool length and yield. Hamadani et al. (2023) has published an overview of the important genes governing wool traits and their importance.

### 12. Future research in wool

As currently wool has lost market to synthetic fibre. Therefore, to increase the market value of wool and counter the dominance of synthetic fibers, research should focus on its potential in emerging markets. Investigations should aim to identify and validate novel genetic markers associated with desirable wool traits.

**Conclusion:** Greasy fleece yield, fibre diameter and staple length are critical determinants of wool quality and quantity. The significant variations observed among breeds underscore the need for breed-specific optimization strategies. By integrating genetic and environmental factors, sheep breeders and producers can develop effective breeding programs, improve wool production and enhance profitability. Furthermore, understanding wool traits can inform decisions on nutrition, health and management practices, ultimately contributing to sustainable and resilient sheep production systems. Future research should focus on exploring innovative breeding technologies and management strategies to optimize wool trait expression and drive economic growth in the sheep industry. Research should be focused to increase the market value of wool and counter the dominance of synthetic fibers.

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#### 1. Meta AI

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