Agri. Reviews, **33** (1) : 37 - 45, 2012

AGRICULTURAL RESEARCH COMMUNICATION CENTRE
www.arccjournals.com / indianjournals.com

ROLE OF QUALITY ATTRIBUTES OF INDIAN WOOL IN PERFORMANCE OF WOOLEN PRODUCT: PRESENT STATUS AND FUTURE PERSPECTIVES -A REVIEW

L.Ammayappan*, L.K. Nayak , D.P. Ray, and G. Basu

National Institute of Research on Jute and Allied Fibre Technology,
12 Regent Park, Kolkata-700 040, India

Received:21-06-2011 Accepted: 04-02-2012

ABSTRACT

Wool, a natural animal fibre obtained from fleece of small ruminants mainly from sheep and is used for development of various textile products ranges from suiting fabric to carpet due it its distinct properties like resiliency, flame-resistance, warmth, and good reactivity towards dyes. The quality attributes such as physio-chemical, mechanical and morphological properties of wool fibre play a major role in deciding its end use and value addition. Generally, fine wool is used for making suiting fabric with shrink resistant finish; Indian wool can be utilized for carpets and blankets. However, there is a wide scope for product diversification from Indian wool through genetic and technological intervention for improving their aesthetic as well as performance properties. This paper reviews the role of important quality attributes of Indian wool for the product development and value addition.

Key words: Carpet; Indian wool; Luster; Medullation; Value addition.

Wool is a textile fibre obtained from fleece of sheep. It is a protein fibre and has some distinct properties like scale structure, resilient nature, natural crimp, high sulphur content, flame retardant property and natural crimp. Wool has used for warm clothing like suiting fabric, shawl, stole, carpet, blanket, felt and some technical textiles. It is classified into super fine, fine, medium, coarse, carpet and manure grade based on its average fibre diameter (Alexander and Hudson, 1954, Gupta et.al., 1987a, Lewin and Sello, 2000). Australia is the leading producer of super fine and fine wool, while India produces best carpet wool. Indian wools in general are medullated *(spongy cells with more airy packets trapped in the middle of the fibre)* and so they differ significantly from other wool harvested in the world. The most important wool yielding indigenous sheep breeds of India are Chokla, Nali, Magra, Marwari, Malpura, Kheri, Gaddi and Rampur Bushair (Acharya, 1982) . Central Sheep and Wool Research Institute *(CSWRI)*, Avikanagar a premiere research institute for sheep has developed some crossbred sheep named Bharat merino, Avivastra and Avikalin for fine wool and carpet wool. The crossbreds have evolved by crossbreeding of exotic sheep Rambouillet/Australian merino with indigenous sheep Chokla, Nali and Malpura (Arora et.al., 1978a, Gupta 1990).

India ranks third in sheep population with 74.0 million sheep and seventh in greasy wool production with 43 million Kg of greasy wool as against 2060 million Kg greasy wool world production in 2010 (Anonymous, 2012) and contributes 1.8% total world wool production. In India, the greasy wool producing state and their contribution production as follow: Rajasthan-44 %; Jammu & Kashmir-13 %; Karnataka-12 %; Haryana, Uttar Pradesh and Andhra Pradesh-23 %; rest other states (Anonymous, 2011). Indian woolen industries are also importing nearly 60 mKg of wool from Australia, New Zealand and other countries in order to meet the domestic requirements of apparels, worsted yarn and other products. Indian wools have utilized for mainly in carpet and blankets, which leads to under exploitation (Anonymous, 2007). They have potential to develop diversified

*corresponding author's email: lammayappan@yahoo.co.in

products by various value addition techniques. The selection of a suitable value addition process for a textile product depends on its quality attributes like physio-chemical, mechanical and morphological properties of raw fibre (Rama Rao and Gupta, 1991). To exploit the Indian wool, this paper reviews the important quality attributes of with special reference to product development and value addition.

Indian wool: India has 44 indigenous sheep breeds along with many crossbred they harvest wool differing in fineness from 25 to 60 μ. India produces about 55 m kg of raw wool in which 15 mKg is medium fine wool, 30 mKg is carpet wool and remaining are coarse and kempy grade wool. Nearly 40% of available wools in India are mainly medullated (Anonymous 1980a). Similarly grading of Indian wool in the commercial market like mandi is an important protocol for selection of proper raw material for the particular product. Indian wools have classified into five different geno-types based on their gross dimensional properties as shown in Table 1 (Gupta *et.a*l., 1981; Sule 2003a).

Carpet wool has been utilized by the woolen industries in Rajasthan, Haryana, Punjab and Uttar Pradesh for the floor coverings, home upholstery and blankets. Medium fine wool harvested in the hilly regions of the Northern India has been utilized by the local artisans for medium fine apparel fabrics, shawl, stole and Namda. Coarse wool has been utilized for blankets, felt, durries and kempy wool mainly used for coarse blankets by the local people.

Physical properties of Indian wool: The physical properties such as fibre fineness, staple length, medullation, burr content and clean wool yield play a role in deciding the spinning system for the wool. The range values of fibre fineness, staple length, medullation, burr content and clean wool yield are 30 to 70 micron, 30 to 70mm, 10 to 90%, 2 to 15% and 40 to 70% respectively (Gupta, 1990). The physical properties of some of the Indian wools are shown in Table 2 (Anonymous, 1980a) . They are mainly processed in the woolen and semi-worsted spinning system in the industries, while local people hand spinning system. The count of the yarn varied from 2 Nm to 30 Nm, which is mainly depend on the fineness of the fibre. Most of Indian wools are devoid of crimp due to absence of well-defined bilateral cortical structure and have less than five crimps per inch. They vary in colour from lustrous white to irony white. The canary stained wool varies from pale yellow to deep yellow colours (Acharya, 1982; Anon, 1980b). A crossbred named Bharat merino developed by C.S.W.R.I, Avikanagar that has 75 percent exotic fine climatic inheritance and physical and chemical properties of its wool resemble fine merino wool (Parthasarathy et al., 1996). By decreasing the fineness in the range of 23 to 28 micron and increasing the staple length up to 60mm, finer yarn can spun in semi-worsted spinning system. Singh and Mehta (2002) inferred that the price of Indian wool is fixed by its fineness, medullation, impurities, and its economic value and they derive a mathematical expression to indicate the same.

Index price = $[A_1 \times AFD]+[A_2 \times MED]-[A_3 \times IMP]$

Where A_1, A_2 and A_3 are relative economic weightages

AFD - Average fibre diameter in μ

MED - Percentage medullation (%).

IMP - Percentage of impurities (%) like dirt, dust, vegetable matter, grease.

Medullation of Indian wool: Medullation in Indian wools have a honeycombed cellular structure (Sule, 2003b). Medullation is responsible for the higher average fibre diameter of particular wool if these fibres are present in high proportion. The density of medullated fibres decreases with increase in diameter, but kempy fibres show a reverse trend owing to their ribbon-like cross-sectional shape (Rama Rao and Chopra, 1985). Medullated wool show poor resistance to acidic and alkaline attacks and they suffer high strength loss in comparison to non-medullated wool. Medullation in the Indian wool fibre significantly influences the stress-strain characteristics. The breaking load, elongation and work of rupture are higher in medullated fibres than in non-medullated fibres (Gupta *et al*., 1981). Medullation in Indian wool imparts flexibility to fibre and facilitates their recovery from distortion unless the walls of the fibre are very thin as in case of kemps (Sule, 2003b, Blakey *et al*., 1967).

The presence of medullated fibres improved resiliency, visual appearance and handle of the carpet, while compressibility retained and

TABLE 1: Classification of Indian wool based on its geno-type.

Type	Fineness (micron)	Fibre types (%)				Region
		True wool	Hetero type	Hairy type	Kemp type	
Fine cross-bred	23-28	> 95	<0.5	< 5	0	Haryana and Himachal Pradesh
Medium fine	28-34	65-75	< 5	15-25	1-2	Hilly region of North India
Carpet	34-40	30-60	10-25	20-40	0.2-5	Rajasthan,Gujarat, Haryana
Coarse blanket	40-50	20-40	2-10	40-60	5-15	Uttar Pradesh,Bihar, Deccan plateau
Manure grade	50-80	10-20	0-1	35-55	25-45	South peninsular region and eastern India

TABLE 2: Fibre quality ranges of some Indian wool.

Breed	Fineness (micron)	Staple length (mm)	Total medullation (%)
Chokla	28-46	25-47	24-42
Magra	34-52	28-58	25-42
Nali	35-70	32-78	30-52
Marwari	36-42	30-66	25-50
Malpura	42-70	22-56	35-85
Bharat Merino	18-26	35-72	0-4
Avikalin	32-48	30-45	12-36
Gaddi	24-36	22-42	0-8

abrasion resistance decreased. The thickness, bulk, compressibility and resiliency of carpets show positive correlations, while the tenacity and the thermal conductivity of blankets show negative correlation with percentage medullation of wool (Gupta *et.al.*, 1998). Elastic recovery of non-medullated Indian wool is must better than that of fine wool fibres and this contribute to their resiliency. Non-medullated Indian wool showed good delayed recovery at 20 and 35% extensions and shows improved total recovery (Chopra, 1978). Hetero medullation (10-30%) is the optimum limit for resilience property to woolen products, and so 30-40% medullation can be preferred for making of carpet from Chokla, Magra and Marwari wool. Kempy wool (> 70% medullation) gives a chalky white appearance and is generally blended with hetero medullated wool in carpet making. After dyeing they impart light appearance on carpet, when used they usually sheds from the carpet. The removal of kempy wool results in the improvement of overall aesthetic appeal of the carpet.

Mechanical properties of Indian wool: Mechanical properties of a wool fibre like stress-strain property, load-elongation, creep and stress relaxation behaviour have mainly dominated by the characteristics of the alpha helices in the cortical cells. The alpha helix content of non-medullated Indian wool is higher so they are present in a more ordered and oriented form than in fine wool, thus leading to higher modulus and lower creep than the former fibre (Rama Rao,1990; Rama Rao and Gupta, 1992). Non-medullated Indian wool showed a higher stress with a high initial modulus whereas medullated wool fibres have a slightly higher elongation and a lower modulus (Gupta *et.al,* 1987a).

Non-medullated Indian wool shows a high tensile stress at low humidity and low strain level, while the retention of tensile stress at high strain and high humidity is more in non-medullated Indian wool than in fine wool (Rama Rao, 1985). The tenacity and percentage elongation of crossbred wool are lesser than non-medullated Indian wool and fine wool, so they preferred to produce medium fine wool products like overcoat (Arora *et.al*, 1978b). A drawback of spinning of coarse wool was that certain amount of fibres would also removed during spinning due to collapse of medulla and it caused dropping as waste, so it is recommended for spun only 150s tex count yarn (Sharma,1973). The breaking strength of blanket in both directions will be decreasing with increasing in the proportion of medullated fibres. (Gupta *et.al*, 1987b). Due to variation in the mechanical property of medullated and non-medullated wool, the proportion of medullated wool will decide the spinning yield as well as the price and performance of the final product.

Elasticity of Indian wool: Elasticity of wool fibre depends on the presence of percentage ortho-cortex and it plays an important role in spinning. The elongation at break of medullated Indian wool ranges from 43 to 47 %, while non-medullated wool ranges from 35 to 47%. Elastic recovery of non-medullated Indian wool is must better than that of fine wool fibres and this contribute to their resiliency. Non-medullated Indian wool showed good delayed

TABLE 3: Luster value of some Indian wool.

Wool	Reflectance (430 nm)	Florescence (520 nm)	Luster value
Avikalin	237.6	153.3	390.9
Chokla	211.7	141.2	352.9
Marwari	206.2	130.9	337.1
Nali	207.9	133.0	340.9
Malpura	116.7	75.9	192.6
Magra	292.8	197.3	490.1
Bharat merino	144.1	103.9	248.0

recovery at 20 and 35% elongation and shows improved total recovery (Chopra, 1978). Due to presence of greater amount of amorphous region and lower cystine content, non-medullated Indian wool have higher elongation and lower modulus at >65% RH than dry condition (Gupta *et.al.*, 1987b;Ammayappan,2008). Patni and Pokharna (1982) inferred that the elasticity of woolen yarn reduces with increasing in draft during spinning. Due to good delayed elastic recovery of Indian wool, it improved the resiliency and bulkiness of carpet and blanket.

Luster of Indian wool: Luster is a quantitative feature of Indian wool since it improves aesthetic appeal of woolen materials particularly in carpet. CSWRI, Avikanagar has standardized a method for estimating the luster value of wool by summing the square root value of reflectance and fluorescence at 430 nm and 520 nm respectively.

The high in the luster value depicts that good in the final aesthetic appeal of the corresponding woolen products. Magra wool has the highest luster value since it has more number of scales per unit length and scale height than other wools as shown in Table 3 (Parthasarathy *et.al.*, 1994, Parthasarathy *et.al.*, 1995, Parthasarathy and Chopra, 1995). Commercial carpets made from Magra wool fetch more value than Marwari and Chokla wool. In absence of natural luster, processors prefer some chemical finish like acid wash, chlorine treatment in order to impart or improve the luster of the carpet.

Chemical properties of Indian wool: Wool consists of three physical components called cuticle, cortex *(ortho and para)* and medulla (Lewin,2007). Chemically it is composed of eighteen different amino acids in which cystine amino acid content is higher than other amino acids. There is no significant difference in the number of amino acid between Indian wools. The amino acid composition of non-medullated Indian wool was very similar to 64's fine wool (Ammayappan and Moses, 2006). The exception was cystine, the content of this amino acid being much lower in Indian wool (8.66-8.90%) than fine wool (11.78-11.98%) (Anonymous,1980a; Nandurkar *et.al.*, 1978).

Possible factor responsible for this are sulphur deficiency in the Indian pastures. Indian wools differ from fine wool in two main aspects, first its sulphur content and lanthionine content. The sulphur content of the most Indian wools varies from 2.8 to 3.1%; canary stained wools have even lower sulphur content (2.3%) and fine wool have 3.5%. Indian wool has high lanthionine content (2-3.5%) due to the action of alkaline suint on wool fibre, which makes it resistance to moth attack. Tyrosine content of Indian wools (4 to 5.5%) is generally lower than fine wool, and the tyrosine content is related to fibre fineness. The tryptophan content of Indian wool (0.75 to 0.80%) is closely related to fine wool *(0.80 to 0.85%)* (Anonymous, 1980a). The pH, urea-bisulphite solubility, ash content, total sulphur, cystine content and tryptophan of some Indian wool are given in Table 4 (Behera and Shakyawar, 1998).

TABLE 4: Chemical properties of some Indian wools.

Breed	pH	Urea bisulphite solubility (%)	Alkali solubility (%)	Total sulphur (%)	Ash content (%)	Cystine content (%)
Chokla	9.3	11.58	9.58	2.98	0.57	9.12
Nali	10.5	0.60	10.99	2.20	0.94	6.41
Marwari	9.9	6.02	8.54	2.84	1.18	9.33
Patanwadi	9.3	4.80	9.39	2.81	0.86	9.23
Gaddi	8.6	37.46	10.14	3.40	0.58	11.36
Bharat merino	9.4	33.37	3.00	5.27	0.64	10.42
Avikalin	8.6	36.20	3.42	4.72	0.61	10.90

(Source: Behera and Shakyawar, 1998)

TABLE 5: Moisture regain of some Indian wools.

Breed	Moisture regain (%) at 65% RH
Marwari	15.5
Avikalin	15.4
Nali	15.2
Magra	15.3
Chokla	15.4
Malpura	14.9
Gaddi	15.5
Bharath Merino	15.5
Australian 64's Merino	15.9

Indian wools are predominant of para-cortex therefore they are less reactive than fine wool and have lower urea-bisulphite solubility than fine wools. They are easily affected by alkaline suint due to lower density fibres on sheep body and less wax content and exhibit a high alkaline pH which may range from 7.1 to 10.5 depending upon genotype and clipping seasons. Autumn clipped wool exhibited a high pH from 9.3 to 10.5 as compared to the spring clipped wool from 7.1 to 9.0 (Anonymous,1980b). Indian wools have higher alpha keratose and gamma keratose than fine wools and it is due to it's highly cross linking nature. The high-sulphur protein fractions should be rich in matrix (Kulkarni and Moses,1997). Due to presence of more para-cortical cells the dye ability of Indian wool is lesser than fine wool and so care should be taken when dyeing of fine wool and fine wool blended materials (Lewis,1977). Due to absence of crimp and less scales per inch, processors not prefer shrink resistance finish for Indian wool products. However, the value of woolen products could be improved by blending wool with other fibres and applying eco-friendly pretreatment like plasma treatment, enzyme treatment, bio-polymer treatment, UV excimer followed by functional finishing like shrink-resistant finish, hydrophilic finish, water-repellent finish, active-fresh finish and softening finish (Ammayappan, 2008;Moses and Ammayappan, 2008; Ammayappan and Moses, 2009).

Grease and vegetable matter content: The price of the wool is also depending on the clean wool yield and presence of vegetable matter, since the matters create problem in spinning. The higher in the vegetable matter, then there is lower in the value of wool and its end-uses also. Indian wool has nearly 4% grease content as compared to 20% in fine wool, because of its low secondary to primary follicle *(S/P)* ratio. The S/P ratio of fine sheep varied between 15 and 30, while Indian wools between 0.5 and 3.0 (Sule, 1966). It infers that Indian wool needs lesser amount of alkali as compared to fine wool scouring. The scouring yield of Indian wools is comparatively higher and increase with increase in diameter. The inherent alkalinity of Indian wool is sufficient to remove the extraneous matter at 40°C to 50°C in aqueous conditions, since suint content is higher in Indian wool than fine wool (Patel et.al.,1974). Vegetable contaminant is very common to all Indian wool because of their migratory grazing pattern and it is ranged from 5 to 11% (Singh *et.al.*, 1983, Patel,1978). For some specific end uses like fine wool blankets and shawl manufacturing, carbonization of wool is preferred with 5% sulphuric acid in the following process sequence padà dryàcureà dustingà scouring. Care should be taken during carbonization, because improper carbonization makes wool yellowish colouration.

Moisture regain of Indian wool: Moisture regain of a textile fibre plays an important role in the comfort of the clothing. If the fibre has more hydrophilic groups, it will absorb more moisture with increasing in the relative humidity. There is no difference between Indian wool in moisture regain value and fine wool.

During absorption of moisture by a fibre from atmosphere, it will evolve the heat slowly and this process is called heat of wetting. One Kg of wool fibre evolves 159 kJ, when it is going from 40% RH to 70 %RH. This property can useful to adjust body temperature of a human, when he transfers from low humid to high humid condition (Morton and Hearle, 2008). The moisture regain of Indian wool ranges from 14.9 to 15.5% and is similar Australian fine merino (Ammayappan, 2008).

Felting of Indian wool: Felting is a process of irreversible shrinkage of woolen products when they are subjected to rubbing in presence of heat, moisture and chemical. This property mainly depends on the fibre fineness, crimp and number of scales per unit length (Ammayappan *et al.*, 2006). Generally Indian wools felt lesser than fine wools as they are coarse, rigid, have lower differential frictional effect than fine wools. Non-medullated Indian wool that having an average fibre diameter of 26.5 micron and 47.0 % medullation, will definitely be superior in felting properties than medullated wool having 41.4 micron fineness and 79% medullation. Since the aggregate scale interlocking effect of the fibre mass will be predominant in wool, which having finer diameter and high percentage of non-medullated fibres (Mahal *et.al.*, 1972). The directional frictional effect for non-medullated Indian wool, medullated Indian wool and fine wool is found to be 23, 16 and 39% respectively (Blakey *et.al*,1967). In commercial market, medullated Indian wools are used in felt manufacturing in presence of acid / alkali /soap. Fine wool waste, wool noil or spinning waste may he blended with coarse wool in order to improve the felt-ability of the final product.

Canary colouration of Indian wool: Canary colouration of wool occur during autumn clip *(March to September)* of sheep rearing. In autumn season, high heat, humidity and bacterial action make suint into alkaline nature that easily ruptures the epicuticle. The damaged epicuticle is allowing suint pigments and alkali to migrate inside the fibre. The migrated pigment entrapped inside the fibre and caused permanent yellowish colouration. It is called canary colouration. Canary coloured raw wools have high alkaline pH (9.0$\pm$0.7), low UB solubility (6-15%), low alkali solubility, low cystine content (9.5$\pm$0.4) and sulphur content (2.2-3.0%), low tryptophan content and high lanthionine content. High lanthionine content of canary coloured wools make them difficult to set during decatizing of fabrics or steam setting of yarns. Due to this drawback, canary coloured wool has lesser market value corresponding white wool and they can be sorted out during grading. Apart from conventional uses, canary coloured wools are used as filtration media in smoke and toxic products from cigarette. Filters for window air conditioners made from canary coloured Indian wools found 50% more effective than the corresponding white wools. Canary coloured Indian wools pick up dye at a fast rate due to absence of epicuticle (Sule, 1966; Sule, 2003b).

Value addition of Indian wool: Indian wools that harvested in Rajasthan, Gujarat, and Uttar Pradesh are mostly medullated cum carpet-type wool and so, they are mainly used in carpets and blankets. Indian wool is easily susceptible to moth attack, soiling by damaged cuticle, and canary coloured due to tropical climate. Therefore, carpets made from Indian wool require insect resist and soil-resist finish. Application of natural dyes, using of traditional design, moth-resistance finish, yellowing-free bleaching, blending with nylon fibre, mechanical finishing such as milling, raising, sanforizing are used to improve the value of those products (Ammayappan,2009;Shakyawar *et al.*, 2011). To utilize non-medullated Indian wool in a winter apparel or shawl, it can either pretreated with enzyme / plasma (Ammayappan *et.al,* 2012). This pretreatment can improve the surface characteristics of wool fibre. The modified woolen products can finish with hydrophilic polymer, which can improve the moisture management and comfort of the product (Ammayappan and Moses, 2010a; Ammayappan and Moses, 2010b; Ammayappan and Gupta, 2011).

Future perspectives: The utilization of Indian wools is limited in products like carpets, blankets, felts and shawls in the limited organized sectors and small scale industries of selected pockets of Northern India like Bikaner, Jaipur, Tonk, Bhadogi, Ludhiana, Srinagar, Kullu. The private organized sectors utilize fine wool that imported from other countries for exclusively in suiting fabrics. Fine wool production in India is not sufficient for the requirement of local consumption by the artisans. Similarly wool produced from Rajasthan, Gujarat, Punjab and Haryana is not satisfactory with the requirement of carpet industries and so they also imported wool from other countries like New Zealand, Australia and west Asian countries. The wool produced from south peninsular region and east region of India fall under coarse to kempy wool, however their utilization is not still fully explored (Bardhan, 2011). There is no government agency involved in the proper marketing of wool from southern region to wool processing belts in north India. Alternatively, the sheep farmers prefer sheep for meat production preferentially not for wool harvesting.

This is the right time to streamline the strategic plans for the effective utilization of Indian wool that can also generate the more revenue for the sheep farmers. Some of the important perspectives are given below:-

• Breeding program may be oriented towards the produce fine wool producing sheep which are adaptable to Indian condition.

• The cross-bred fine wool may be utilized in blending with other speciality hair fibers like Angora rabbit hair, Pashmina wool, and Yak wool for the economic value addition and fancy products. (Raja *et al.,* 2011; Ammayappan *et al.*, 2011a).

• Indian non-medullated wool may be blended with other textile fibers like cotton, viscose, nylon for more product diversification like upholstery, automobile, technical and home textiles.

• Marketing of south Indian wool and east India wool may be streamlined by the government agencies for their better price realization for the sheep farmers.

• Unexplored coarse wool may be blended with fine wool waste / non-medullated Indian wool / noil for felt manufacturing.

• Indian woolen products may be finished by giving various functional finishes like flame-retardancy, insect-resistance, repellent finish etc., for their diversified value addition (Ammayappan and Moses, 2007; Ammayappan et.al., 2011b; Ammayappan et.al., 2011c)

• Application of locally available natural dyes from secondary agricultural may be further explored for woolen products in small scale industries.

• Utilization technique for canary coloured wool may be diversified into fancy / novel products wither blending with white wool or with other textile fibers.

• Wool keratin / amino acid may be extracted from low grade Indian wool and used for nano-protein fibre / bio-composite, which can diversify its utilization.

• Latest technologies i.e. plasma, bio and nano-technology may be approached for the newer applications of woolen products (Ammayappan *et al.*, 2012).

CONCLUSION

The end use of a textile product depends on its quality attributes of fibre. Indian wool has some unique features like luster, resilience and warmth. India produces variety of wool in which medium fine wool is utilized for fine wool apparel fabrics and shawl; carpet type wool for floor coverings and home textiles; coarse wool for felt manufacturing; and kempy wool for manure or unutilized. The end-use of Indian wool is limited due to fineness, medullation and less staple length. Genetic manipulation on sheep breeding is required to produce fine wool sheep with minimum medullation and sufficient staple length of wool. It leads to increase in the production of fine wool in India as well as development of fine wool products. Today consumer prefers diversified textile products in valuable price. The approaches of advanced technologies like bio-technology, nano-technology, and plasma technology on woolen products can lead to development of diversified products with more value addition and better price realization for the consumer. These value addition on Indian woolen products based on its quality attributes diversify market for the wool processors and fetch more income. The consumption of more woolen products in the market ultimately improves the requirements of Indian wool as well as economy of the sheep farmers.

REFERENCES

Acharya R.M., (1982).*Sheep and Goat Breeds of India*, FAO Publications, Rome, Italy.

Alexander P. and Hudson R.R., (1954).*Wool: Its Chemistry and Physics,* Reinhold Publication Company, New York, USA.

Ammayappan, L. (2009). Quality improvement of woolen products through chemical finishing techniques, *Wool Technology*, (Karim, S.A., Shakyawar, D.B. and Anil Joshi), Agrotech Publishing Academy, Udaipur, India. pp.349-363

Ammayappan, L., (2008). Study on improvement in aesthetic properties of woolen products by different chemical finishes. *Ph.D., Thesis*, Anna University, Chennai.

Ammayappan, L., and Gupta, N.P., (2011). A study on the effect of enzymatic pretreatment on physio-chemical and mechanical properties of woolen yarn, *Manmade Text India*, **54**(7):244-248

Ammayappan, L., and Moses, J.J. (2006), Study of the characteristics of angora rabbit hair in comparison with medium and fine wool fibers. National J Tech, **2**(4):50-62

Ammayappan, L., and Moses, J.J. (2007), Functional finishes for woolen textiles, *Indian Text J*, **118**(1):25-32

Ammayappan, L., and Moses, J.J. (2009). Study of antimicrobial activity of aloevera, chitosan, and curcumin on cotton, wool and rabbit hair, *Fibers Polym*, **10**(2):161-166.

Ammayappan, L., and Moses, J.J., (2010a). Study on physical and handle properties of wool/cotton union fabric treated with enzymes and different pre-polymer finishing chemicals, *Current Chem Res*, **1**(1): 19-25.

Ammayappan, L., and Moses, J.J., (2010b). Study on improvement in handle properties of wool/cotton union fabric by enzyme treatment and subsequent polysiloxane-based combination finishing, *Asian J Tex*, **1**(1):1-13.

Ammayappan, L., Moses, J.J. and Shunmugam, V., (2006).An overview on production of nonwoven fabric from woolen materials, *Inst f Eng (India) -Text Eng*, **87**(2):9-14

Ammayappan, L., Moses, J.J., Asok Senthil, K., and Jimmy K. C. Lam, (2011c). Effect of Alkaline and Neutral Protease Enzyme Pretreatment Followed by Finishing Treatments on Performance Properties of Wool/Cotton Union Fabric: A Comparative Study, *J Natural Fibers*, **8**(4):272–288

Ammayappan, L., Moses, J.J., Asok Senthil, K., Raja, A. S. M., and Jimmy K. C. Lam, (2011b). Performance properties of multi-functional finishes on the enzyme-pretreated wool/cotton blend fabrics, *Text Color Finish*, **23** (1): 1-9

Ammayappan, L., Nayak, L.K., Ray, D.P., and Basu, B., (2012). Plasma treatment on textiles, *Asian Dyer*, **8**(6):34,37-40

Ammayappan, L., Shakyawar, D.B., Krofa, D., Pareek,P.K., and Basu,G. (2011a). Value addition of Pashmina products: Present status and future perspectives–a review, *Agri Review*, **32** (2): 91-101

Anonymous, (1980a).*Final report of the PL 480 project: Evaluation of the characteristics processing performance and end use suitability of various Indian wools*, Wool Research Association, Mumbai.

Anonymous, (1980b).*Canary colouration of Indian wool: (1974)-1979 Final report,* Wool Research Association, Mumbai.

Anonymous, (2007).*Chapter VIII: The wool and woolen textiles industry,* Annual report (2006)-(2007), Ministry of Textiles, New Delhi):93-101.

Anonymous, (2012). Website http://faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569#ancor browsed on January 2012.

Anonymous, (2011).*Chapter IV: Textile exports. Annual Report (2009)-2010*, Ministry of Textiles, New Delhi, pp.109-116.

Arora R.K., Patni P.C., Gupta N.P. and Pokharna A.K., (1978b).Physical and mechanical characteristics of wools of some crossbred sheep, *Indian J Text Res*, **3**(4):116-118.

Arora.R.K, Chopra.S.K and Malhi R.S., (1978a). Mechanical processing of Indian wools, *Indian Text J*, **88**(4): 138-140

Bardhan, M.K., (2011). An overview of recent R&D initiatives by wool research association, *Proceeding of National Seminar cum Workshop on Recent R&D initiatives and Developmental Schemes of wool and woolens*, Wool Research Association, Mumbai, May 2011.

Behera B.K. and Shakyawar D.B., (1998).Indian wool: Present status and future prospectus, *Asian Text J*, **7**(1):38-43.

Blakey P.R. Earlan C. and Jalihal M.R., (1967). Studies on Indian carpet wool (Indian) wool, Part-I: The physical and chemical properties, *Text Res J*, **37** (8):688-696.

Chopra S.K., (1978). Elastic behaviour of Indian wools, *Wool Woolen India*, **15**(1):25-28.

Gupta N.P, Shakyawar.D.B and Sinha.R.D, (1998). Influence of fibre diameter and medullation on woolen spun yarns and their products, *Indian J Fibre Text Res*, **23**(3):32-37.

Gupta N.P., (1990).Some aspects of Indian wools and their grading, *Indian Text J*, **101**:140-142.

Gupta N.P., Arora R.K. and Verma G.K., (1981).As assessment of the characteristics of medullated and non-medullated wool fiber *Indian J Fibre Text Res*, **6**(2):92-95.

Gupta N.P., Patni P.C., Arora R.K. and Singh U.S., (1987b).Influence of medullated fibers on mechanical processing and product performance, *Indian J Fibre Text Res*, **12**(1):46-52.

Gupta N.P., Pokharna A.K., and Arora R.K., (1987a).Use of wool and other fibers, *Indian Text J*, **97**(10):142-150.

Kulkarni V.G and Moses J.J., (1997). Studies on Indian wool. Part-IV, *Asian Text J*, **6**(1):78-84.

Lewin M and Sello, (2000).*Handbook of Fiber Science and Technology, Volume-II*, Part-B. Dekker Series, New York.

Lewin M., (2007).*Handbook of Fibre Chemistry, 3rd edition*, CRC Press, Baco Raton, USA,331-382.

Lewis D.M., (1977).Wool Dyeing, *Review Prog Color*, **8**:10-23.

Mahal., (1972). Types and duration of fiber scales from the wool types of domestic sheep and bulk life, *Indian Text J*, **42**(2):83-86.

Morton, W.E., and Hearle, J.W.S., (2008). *Physical Properties of Textile Fibres*, 4th Edition, Woodhead Publishing Limited, England.

Moses, J.J., and Ammayappan, L. (2008), Effect of silicone and urethane finishing treatment on performance properties of enzyme treated wool/cotton union fabric, *J Text Asso*, **69**(2):68-74.

Nandurkar U., (1978).Sulphur and cystine content of various Indian wools: Part-II. *Wool & Woolens India*, **15**(1):41-44.

Parthasarathy S., and Chopra S.K, (1995). Luster properties of wool – its importance and evaluation, *Indian J Small Rum*, **1**(1): 44-46.

Parthasarathy S., Swain N., Gopi Krishna G., Gour D and Surya A.K., (1996).Physical properties of Bharat Merino wool. *Indian J Small Rum*, **2**(2):29-32.

Parthasarathy.S, Chopra.S.K and Pokharna A.K., (1994). Luster in some imported wools, *Indian Text J*, **104** (12):66-69

Parthasarathy.S, Chopra.S.K, Kushwaha B.P and Rawat P.S., (1995). Luster index for wool, *Indian Text J*, **105**(12):28-30

Patel B.K., (1978).Carbonisation process-Wool property relevance for trade and textiles. *Wool Woolens India*, **15**(1):15-18.

Patel B.K., Sinha R.D. and Ramamurthy T.N, (1974). Wool impurities-their nature, variation and removability, *Wool Woolens India*, **11**(5):13-18.

Patni P.C and Pokharna A.K., (1982). Effect of drafting on the characteristics of woolen yarn, *Indian J Text Res.***7** (2):61-62.

Raja A.S.M., Ammayappan, L., Shakyawar D.B., Gupta N.P., (2011). Production and performance of angora rabbit hair- Bharat merino wool blended shawls, *Indian J Small Rum*, **17** (1), 79-82.

Rama Rao D. and Chopra S.K., (1985).Measurement of medullation of single wool fiber. *Indian J Fiber Text Res*, **10**(3):122-124.

Rama Rao D. and Gupta V.B., (1991).Property structure correlation in wool fibers. *Text Res J*, **61**(10):609-617.

Rama Rao D. and Gupta V.B., (1992).Physical and morphological characteristics of wool fibers. *Indian J Fiber Text Res*, **17**(1):1-8.

Rama Rao D., (1985).Influence of moisture sorption on properties of Indian wools. *Indian J Fiber Text Res*, **10**(2):80-83.

Rama Rao D., (1990).*Property-structure correlation in some wool fibers*, Ph.D.,Thesis, IIT New Delhi, India.

Shakyawar D.B., Raja A.S.M., Gupta N.P., and Ammayappan, L., (2011). Development of Magra wool - nylon blended hand knotted carpets, *Indian J Small Rum*, **17** (2): 207-209.

Sharma P.P , (1973). Mechanical processing of Malpura wool: part I, *Wool Woolen India*, **10**(4):13-17.

Singh U.S., Patni P.C. and Swain N., (1983). Vegetable matter in wools and its removal, *Indian J Fiber Text Res*, **8**(3):93-94.

Singh V.K. and Metha S.C., (2002).A model for marketing and grading of raw wool, *Indian Text J*, **113**:27-30.

Sule A.D., (1966).Canary colouration of raw wool, *Wool Woolen India*, **3**(2):24-29.

Sule A.D., (2003a). Anatomy and fineness grade of Indian wools, *Manmade Text India*, **46**(10): 402-408.

Sule A.D., (2003b). Spinnability and SWOT analysis of Indian wools for pile carpets and other end uses, *Manmade Text India*, **46**(11):25-30.