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UTILIZATION OF INDIAN WOOL IN DECENTRALIZED SECTOR: AN OVERVIEW

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ABSTRACT

Wool has superior warmth, comfort and flame retardant properties. It is being used for manufacturing of premium apparels, carpets and upholsteries since early civilization of the society. With the change of time, synthetic fibre dominated the natural fibre including wool. It has replaced the wool in most of the applications due to cheaper price. However, wool is still an important fibre for textile industries in decentralized sector. The decentralized woollen sector plays an important role in linking the rural economy with the manufacturing woollen industry. This paper provides an overview of wool processing in decentralized sector of India. Possible interventions and research areas are suggested to improve the quality of woollen products as well as newer products produced thereof. There is a need to create innovations in the use of Indian wool for woollen products. New products like wool-based denim will increase consumption of Indian wool. Coarse wool may be explored as material for insulation, acoustical, construction, bulletproofing, automobile and paper industries and agriculture.

Key words: Decentralized sector, Processing, Utilization of waste wool, Wool

Fine wool produced in the temperate regions of the country is consumed by local woollen industries and yarn prepared from it, mostly utilized by local artisans for manufacturing of shawls. It provides good source of employment and income to the local artisans. Medium wool (24-30μ fibre diameter) is consumed in the production of local non-apparel products such as overcoats, mat and khash (coarse cotton bed sheet). Carpet grade wool is produced in the northwestern semi-arid and arid regions of the country. Majority of coarse wool is produced in the southern states. The high proportion of medullated fibre, least crimp and poor pliability in coarse wool make it unsuitable for yarn manufacturing. Therefore, it is utilized for manufacturing of handmade namda, machine made coarse felt or locally made products such as blankets (barrack), for instance, kambli in Karnataka. Recently, efforts have been made to utilize the coarse wool for diversified applications (Gopi et al., 2010). Quality improvement of coarse wool in terms of reduction in fibre diameter and increasing proportion of medullated fibre, removal of kempy fibre through the modified carding machine has been made. These techniques have made possible to utilize coarse wool in carpet making and realizing better price (Raja et al., 2013).

A. Decentralized Sector

Wool and woollen textile are a rural-based and export-oriented industry, where organized, decentralized and rural sectors complement each other. The decentralized woollen sector plays a pivot role in meeting the clothing needs of the country and also provides employment to millions of people. It produces a wide variety of khadi product, carpet, namada and blanket with intricate designs. This sector can successfully compete in the global market and contributes significantly to the foreign exchange earnings.

i. Carpet sector: India has an ancient tradition of carpet weaving. Carpet industry started flourishing in the country from 16th century onwards. Today, India is the largest producer and exporter of hand knotted carpet in terms of value as well as volume. In fact, 90% of the carpets manufactured in India are exported. Indian carpets are known worldwide for their excellent design, fascinating colours and quality. The wool produced in the northwestern region of the country is most suitable for carpet manufacturing. It gives better pile coverage, handle and resiliency to carpet (Onder and Berkalp, 2001; Shakyawar et al., 2006). It has 15% by count or 35% by weight hetro-typical medullated fibres with 30μ fibre diameter and 3-4 inches fibre length. Carpet compressibility, resiliency and durability are mainly governed by the fibre composition of the carpet pile and its constructional parameters i.e. pile height and pile density. Increase in pile density from 900 to 1275 g/m^2 for constant pile height of 10 mm, improves the durability factor from 215 to 277. However, the compressibility increases from 46 to 51% with pile height from 8 to 10mm and decreases from 46 to 43% with high pile density of 1032 and 1615 g/m^2. Carpet resiliency decreases with pile height (Anon, 2015). An increase in pile height improves the compressibility of the carpet, but there is no change in its elastic recovery. The high pile density improves the pile's elastic recovery, reduces the thickness variation and increases the stability factor (Mirzalili and Sharzehee, 2005). Moghassem and Gharehaghaji (2008) found that compression and matting of the pile yarn decreased and its elastic recovery increased with the increase in knot density. Increase in pile height caused an increase in the degree of variation for carpet. Whereas, the pile fibre composition viz., the proportion of medullated fibres to an extent improves compression properties but adversely affects the durability of carpet. The carpet hand value (CHV) increases with the increase in knots up to 2300 knots/dm^2 and increase in pile height up to 12 mm and then starts decreasing (Shakyawar et al., 2006).

There is significant relationship between fibre diameter and carpet abrasion. Abrasion loss of carpet shows positive correlation with a fibre diameter (R^2=0.34) and medullation (R^2=0.46) (Shakyawar et al., 2008). A software for predicting abrasion loss and CHV of hand-knotted carpet with the help of C language has been developed. The software can predict abrasion loss and CHV within the range of error ± σ value. The abrasion behaviour (number of revolutions required to reach carpet backing) for carpet made from Romney sheep wool showed better abrasion resistance than carpet made from Drysdale and British Mountain sheep wool (Ince and Ryder, 1984). According to gross dimensional properties, Magra sheep wool (34.5 μ fibre diameter and 45% medullation) is the best carpet wool in the country (Kumar et al., 2013). Carpet made from Magra wool (autumn clip) has the highest resiliency (39%), optimum fibre abrasion loss (69 mg) for first 1000 cycles and a pile contraction of 9.92% with the highest pile recovery (95.5%) after dynamic loading of 1000 impacts. The carpet is a costly home textile and thus, the selection of wool fibre and constructional parameters of carpet should be optimized to achieve higher durability and functional properties.

Cheaper carpet yarn can be produced from coarse wool (>40 μ fibre diameter) by the strategic positioning of different fibres across the cross section of the yarn. Attempts were made to develop multi-layer yarn structure by strategically positioning the wool fibres of different fibre diameter, medullation and bending rigidity to improve the bending rigidity of yarns. The three layers engineered yarn gave 66% higher bending rigidity than yarn prepared for woollen spinning system (Ishtiaque et al., 2015a). Ishtiaque et al. (2015b) concluded that with multi-layered yarn structures, it is possible to strategically place high bending rigidity fibre and manipulate the radial packing density of yarns to increase the compression and performance properties of carpet. Ishtiaque et al. (2015c) reported 9.6% improvement in resiliency of the carpet made from engineered yarn. The carpet texture retention under dynamic loading (% thickness loss) was significantly increased. Ishtiaque et al. (2015d) also observed that carpet made of multi-component- engineered yarns in comparison to carpet from woollen and worsted spun yarns prepared from homogeneous wool mix made of Chokla, Magra and Malpura (40:50:10) gave higher value of carpet durability factor (300 vs 275 and 295), tuft withdrawal force (1.26 vs 1.15 and 1.22 kg), thermal insulation (1.003 vs 1.03 and 1.11 tog) and lower brunt area (249 vs 317 and 306 mm^2 during tablet test for carpet flammability. It could be inferred from the study that the positioning of Malpura wool (10%) in the core of the yarn improves resiliency (8-10%), compressibility (6-7%) and durability (10-15%) of the carpet. Carpet washing is an important finishing process to remove loose fibre, any surface debris picked off or singeing residues. Normal wash carpets showed higher CHV than the herbal and antique wash carpet due to little pile damage (Shakyawar et al., 2006)

ii. ***Namda and Handicraft sector***: Namdas are felted mat made from wool. Namdas were probably introduced in Pakistan as saddle blankets by the Aryans from Central Asia during the Iron Age. This particular technique remains traditional to Turkistan, the subcontinent, as well as Tabriz in Iran, near western Central Asia (Bheda, 2012). The decorative style of namdas including chain stitch embroidery is a characteristic of Kashmir and reflects eastern Central Asian influence. Namdas were also imported into the sub-continent by way of Leh in Kashmir during the 19th century (Hamid, 1989). Felted products are an integral part of nomadic life in the north and Central Asian steppes and probably the technique was first discovered in Central Asia (Kadam et al., 2014b). Tonk is the only centre for namda making in Rajasthan and uses coarse wool that are mainly obtained from nearby sheep rearing places like Malpura. They used a carding machine to prepare the fleece, but until recently, the painja - a wooden tool resembling a large bowl, was used to beat and fluffy wool. Textile manufacturers have started using automated machines and cheap synthetics for the manufacture of floor covering and offering their products at a cheaper cost (Bheda, 2012). In addition to that, namda product has issues like fibre shedding during use and repetitive designs. A new computer-aided designs and use of resins for binding are developed (Raja et al., 2014).

Blending of Angora fibre with sheep wool provides extra white and soft feel to namdas. Felt prepared from wool-rabbit fibre blends were found to be smooth, soft and warm as compared with wool felt (Shakyawar et al., 2007). Shakyawar et al. (2012) reported that the felting ability of coarse wool can be modified by mixing 40% medium fine wool. Raja et al. (2013) further reported a 24% increase in the felting ability of coarse wool by mixing 40% medium fine wool fibre. Raja et al. (2014) have made an attempt to optimize the fibre blend for namda making to reduce the fibre shedding. Medium quality felt could be prepared from wool - camel hair blends with natural colours (Patni et al., 2006). Traditional use of felts can be redefined by converting them into diversified handicraft products. Hand embroidery and free hand painting can also be done on undyed or dyed felts. In addition, natural dyeing of felts with colours obtained from onion, walnut, saffron, madder and henna adds a great value to the product. Similarly, a natural dye based-process was developed for dyeing namda for imparting moth resistance. Kumar et al. (2016) reported that extract obtained from neem leaves and barks have good efficacy as anti-moth on woolen fabric.Different innovative designs and products have been developed from felts, viz., wall hangings, toys, household articles etc. (Shakyawar et al., 2014). Economic analysis showed that namda handicrafts provide a profit margin of 25-60%.

iii. ***Woollen khadi***: It plays an important role in Indian economy by providing a large scale employment in rural areas. Earlier, woollen khadi products were made from indigenous wool and traditionally used by people. With a change in lifestyle, today it is a fashion. The use of indigenous wool has gradually replaced by importing Australian Merino wool in Khadi products. It has become a common practice to use the imported Australian wool top for making yarn with Amber Charkha for making apparels. Fine wool of 22-25 μ is used for making shawl in handloom sector, same wool is also used in the Khadi sector (Kumar, 2011).The spinning ability of crossbred fine wool has been studied on Charkha (Meena et al 2018a). It was found that crossbred sheep of Himachal Pradesh, Jammu and Kashmir and Merino wool of Jammu and Kashmir can be spun in 24 Nm and the blending of Australian Merino: Jammu and Kashmir crossbred wool in 50:50 and 75:25 can be spun into yarns of 32 Nm. The tenacity and elongation of fabric made of different blends of Jammu and Kashmir crossbred and Australian Merino wool showed an increasing trend with increase in proportion of Australian Merino wool fibre. Initial modulus decreases with increase in Australian wool in the blend. The fabric friction showed decreasing trend with increase in proportion of Australian Merino wool in the wool-cotton fabric (Meena et al., 2018b).

Consumer demands for wool and its blends with cotton have increased in recent years for the products like dresses, suits and skirts. In blends, wool contributes warmth, resilience and drape ability while cotton adds its strength. The popularity of these blends is due to their light weight, good strength, drape ability, easy washing ability together with low cost, but there are losses in handling, drape and crease recovery. Lupton and Khan (1984) developed two grades (62s and 80s) of 50.8 mm (maximum fibre length 2.00”) cut-top wool from intimately mixed with cotton and polyester fibres at varying blend levels. Subsequently, yarns (6.9 Tex, 16/1Nc) were ring-spun using the short staple system of mechanical processing and standard crepe fabrics were manufactured from each. Blended worsted yarns were manufactured from equal proportions of wool and cotton for knitwear, dress wear, underwear, children's clothing, light weight shirtings, pajamas, clothes and blankets. The cotton-Merino wool blends are used for light weight sweaters. Wool-cotton blend fabrics or cool wool are not expected to replace all wool apparel, but extend the use of wool in apparel in a non-traditional niche such as Sunbelt customers. In Indian climatic conditions, during pre- and post-winter seasons, use of cotton-wool blended fabric is most suitable for apparel. Sharma et al. (2015) studied cotton: wool blended hand knitted fabrics. Indian crossbred wool (Rambouillet x Chokla) was blended with cotton in three different ratios (10:90, 20:80 and 30:70) and yarns were prepared on hand spinning system. Knitted fabrics of 100% cotton and cotton-wool (90:10, 80:20 and 70:30) blends showed warp relaxation shrinkage of knitted fabrics. Weft formability was I too low, it might cause poor seam performance and difficulties in inserting sleeves. As warp and weft bending rigidity was high, molding might be difficult. ***S***harma et al. (2016) further studied on objective assessment of designing of cotton-wool blended knitted khadi apparels. The acceptability of design khadi garments was assessed on the basis of colour combination, uniqueness in design, aesthetic appeal. They found that all the khadi garments were accepted by the respondents. The weighted mean score was found between good and excellent. It has been proved that cotton-wool blended knitwears can be constructed with khadi village industry.

iv. ***Quilt from coarse wool***: Quilts were introduced into the market as an alternative to blankets. They are also called as duvets. Quilt consists of two layers of fabrics filled with fibre material in the middle. It is well known that wool products are warmer and are more comfortable due to their breathing ability behaviour compared to synthetic fibre. A comparison was made with participants sleeping under wool-filled quilts and polyester quilts and observed that participants using wool quilt found to have favourable next-to-skin microclimate (International Wool Secretariat, 1986). The technical advantage of wool quilts is its water vapour transport and water absorbing properties. The saturation water content of wool fibres was observed to be in the order of 38% at high relative humidity (Li et al., 1992). The synthetic fibres are having less regain value and are largely insensitive to relative humidity. The water vapour absorption / desorption as a function of relative humidity creates the buffering capability of wool and other natural fibres. Another property responsible for the differences among bedding products constructed of wool and other fills is their exothermic heat of sorption. Wool fibres absorb water vapour during the transition from a low to a higher relative humidity environment and release heat due to heat of absorption phenomena. Naylor et al. (2017) demonstrated that the amount of heat released is directly proportional to the quantity of wool present in the wool products. A quilt containing 1 kg of filling, the wool-filled product will produce approximately an additional 300 kJ of heat under the transient conditions compared to polyester filled quilts.

A processing technique has been developed at ICAR-Central Sheep and Wool Research Institute (CSWRI), Avikanagar for the preparation of light weight razai (quilt) using coarse wool (Malpura sheep wool). This new coarse wool razai looks similar to Jaipur razai and has a total weight of 975 g in size of 7 x 5 ft. Normally Jaipur razai is prepared by filling of cotton or in some cases polyester fibre. The disadvantage of cotton is that it is expensive by 2.5 times of wool and polyester has the problem of environmental pollution during its manufacture as well as after disposal. In the preparation of the quilt, first a sheet of coarse wool web was prepared and then it is laid inside a cotton cloth and then stitched manually. Coarse wool is having high stiffness and hence it protrudes through the interlacement gaps of warp and weft and creates hairiness in the end products. Closely woven compact fabric is used to reduce the protrusion fibres through fabric surface. The thermal insulation value of coarse wool quilt was assessed using thermal conductivity apparatus and it was found to have Tog value of 3.23. This shows that the prepared quilt can protect the users from cold during normal winter (Anon, 2018).

Efforts have been made to reduce the problem of high coarseness and medullation, specially the high proportion of kempy fibres by processing coarse wool through a cotton cord with modified speed ratio. The principle of differential surface speed has been used to remove kempy and hairy fibres. The study showed that the hetero, hairy and kemp fibres proportions of coarse wool were reduced to 24, 35 and 23%, respectively, whereas 26% reduction in total medullation by carding action. In another study, coarse wool was processed on the woollen breaker card which reduced kempy fibres by 70% and overall medullation by 34%. It increased fibre fineness by 31% (Shakyawar et al., 2012). Jurinskaya et al. (2014) processed Kazakistan coarse and medium wool on the specialized woollen card with three passages. It increased the fineness and quality of the product. In another study, coarse wool fibres were pulled on carding machine and fine downy fibres with diameter 21-24 µ were obtained and used as a filling for quilts (Otynshiyev and Jurinskaya, 2013).

v. ***Woollen blankets***: Wool is the preferred raw material for preparation of eco-friendly blankets. Blankets can be prepared by non-woven and woven processes. The conventional wool blanket is warmer and lighter in weight compared to cotton and acrylic blankets and it was observed that the increase in relative humidity caused a decrease in thermal resistance. Studies conducted on wool / acrylic and wool/ polypropylene blend blankets had shown that wool /acrylic blended blanket had better thermal insulation value (Das et al., 2001). The thickness and bulk of blankets had positive correlations with fibre diameter and medullation while tenacity and thermal conductivity of blankets had negative correlation with fibre diameter and medullation (Gupta et al., 1998). Further warp- and weft-way breaking strengths of blanket fabrics decreased with an increase in the proportion of medullated fibres (Gupta et al., 1987). Woollen blankets are made from coarse wool (45.8 µ fibre diameter) on charka and pit loom in Coimbatore district of Tamil Nadu. It has a harsh feel and can be improved by adding fine wool (Raja et al., 2008). Deccani wool blankets also give the harsh feel; it can be improved by softening treatment to improve the drape, crease recovery and bending length. Silicone softeners give better results than non-ionic and cationic softeners (Manjulatha and Mahale, 2017).

Optimization of indigenous wool mixes for blanket manufacturing was carried out by selecting one fine wool sheep - Bharat Merino and two medium coarse wool sheep – Chokla and Avikalin (Shanmugam et al., 2018). Yarns of 4.0 Nm were prepared from Bharat Merino, Chokla and Avikalin after scouring and carding of raw wool. Six types of blankets were prepared with ends/inch of 22 and picks/ inch of 19 with a weight of 525 g/m². A maximum breaking load of 318 N was observed for Chokla blanket followed by Bharat Merino / Chokla blanket at 292 N. The thermal insulation value of blankets ranged from 2.68 to 3.88 Tog. The blend ratio of fine wool and coarse wool was optimized at 60:40. The resultant yarn of 3.5 Nm on the woollen spinning system was 30% finer than the hand spun kambli. It was also stronger and softer than the latter one and thus made them suitable for quality blankets (Raja et al., 2013).Studies were conducted to know the effect of laundering on non-woven and woven blankets of wool/ acrylic blend, 100% acrylic, 100% cotton and 100% polyester. The study indicated that non-woven blankets had better dimensional stability characteristics (Epps, 1996). It was also indicated that laundering alters fabric structural characteristics and thermal transmittance of both woven and non-woven blankets.

vi. ***Diversified uses of coarse wool***: Wool has acoustical properties, particularly in their ability to reduce airborne sound, control surface noise and isolate impact sounds. The porosity of fibre enables the sound waves to penetrate into the fibrous structure and dissipate. Acoustic ceiling panels absorb sound but cannot reduce surface noise or isolate impact. Thus, coarse wool structures may be developed. The low thermal conductivity of wool and its natural crimp (which restricts convection) provides a high level of thermal comfort and provide warmth in cold climate. Besides this, woollen products never give a damp or clammy feel since they can absorb, store and diffuse the moisture into the atmosphere. It also helps to maintain low humidity at the skin surface. Dust mites thrive in hot and humid environments. Coarse wool needs to be given surface treatments to exploit it in such applications. Causer et al. (1995) and Meade (1998) have shown that wool is an ideal substrate for interior textiles and carpets because wool has some peculiar properties. It has the lowest propensity for flame spread, produces much lower levels of smoke, can remove formaldehyde, nitrogen dioxide and sulphur dioxide from the air more rapidly and effectively. Further, it does not release these gases, even when heated, and may continue to purify indoor air up to 30 years. This long-term benefit is due to the acid-combining potential of wool. Wool Research Association (WRA) of India has developed composites from coarse Indian wool such as a door panel, electric insulation mats, electric boards, false ceiling etc. (Udakhe and Kherdekar, 2011).

B. Wet Processing in Decentralized Sector

Wet processing in the woollen textile industry, mainly consists of pre-treatment, dyeing and finishing. The main objective of the preparatory process is to make the woollen ready for further subsequent processing by removing the unnecessary impurities.

i. ***Scouring of wool***: Application of ultrasonic energy is reported in scouring of wool in recent years. Hurren et al. (2006) examined the application of ultrasonic agitation in conventional non-ionic detergent wool scouring. They reported that ultrasonic agitation significantly improved the removal of grease from the wool fibre. Lower detergent concentrations could be used with ultrasonic agitation and still achieve the same level of scouring as conventional scouring. Lower scouring temperatures of 50°C are feasible with ultrasonic agitation for 22 μ fibres. Ultrasonic agitation produces virtually no fibre entanglement during scouring. Kadam et al. (2013) used ultrasound energy for effective removal of grease at lower chemical concentration, temperature and time. The results show that the removal of grease to appreciable limit can be achieved with the 25% reduction of conventional chemical, with the aid of ultrasound energy. Pan et al. (2018) recommended ultrasonic pre-treatment of raw wool scouring and fabric scouring for achieving an efficient dye uptake.

ii. ***Dyeing of woollens***

a. Synthetic dyes: The dyeing of wool and woollen in decentralized sector is mainly carried out by using acid, metal complex and reactive dyes. Recent advancements have been made in the development of low temperature dyeing techniques for wool and woolen products. Paul et al. (2008) used acetic acid - benzyl alcohol micro emulsion system to solubilize a water-insoluble antimicrobial natural dye for wool dyeing. The results depict that the dye exhaustion on the fabric took place at low temperatures (<60°C) with the liberation of the dye solubilized in the oil droplets of the micro emulsions. Guzel and Akgerman (2000) dyed wool fibre with mordant dyes dissolved in supercritical carbon dioxide. Wool fibre were mordanted by the metal using conventional techniques and dyed at 60-80°C and 150-230 atmospheric pressure. Chen et al. (2016) pre-treated wool with dimethyl sulfoxide and analyzed its dyeing behaviour in non-aqueous green solvents. The study showed that compared with aqueous dyeing, solvent dyeing was found to give 30% higher covalent fixation, which translated to better colour fastness at higher colour depth. Islam et al. (2017) used ultrasonic irradiation to reduce dyeing times and temperatures whilst increasing dye migration and fastness. The results show that, ultrasonic irradiation during the dyeing of wool caused an increase in the dye exhaustion rate for acid dye. Both wash and rub fastness were improved for ultrasonically-dyed fibre with dyeing temperatures of 70 and 80°C and were found suitable for the low-temperature dyeing of wool. For low-temperature dyeing, Pan et al. (2018) pre-treated the wool with ultrasonic irradiation and observed significant increase in dye uptake and colour strength on the fabric ultra-sonication at 40 kHz, followed by that at 80 kHz and the conventionally treated sample, in both acid and reactive dyeing. In acid dyeing, a 20% increase in dye uptake was achieved at 70°C upon applying ultrasonic pretreatment at 40 kHz. With the assistance of a levelling agent, 80% dye uptake of the fabric treated with ultrasonic at 40 kHz was measured at 70ºCin reactive dyeing. Rybicki et al. (2000) concluded that enzymatic-chitosan pre-treatment assures the good dyeing ability of wool fabrics by reactive dyestuffs. Mendhe et al. (2016) investigated the effect of plasma treatment and reported that the hydrophilicity and dye uptake of the fabric are enhanced significantly.

b. ***Natural dyes***: Whilst in the decentralized sector, synthetic dyes contribute much, some of the cottage industries are employing natural dyes for making the products. These natural dye products have very good demand in the export market. In comparison with cellulosic fibre like cotton, wool is having a better dyeing ability for natural dyes (Sharma, 2013). Mathur and Gupta (2003) reported the dyeing of Bharat Merino wool with turmeric in the presence of natural mordant extracted from banana flower petaloids as well as metallic chromium mordant under identical conditions. The study showed that 3.5% natural mordant and 1.5% chromium produce similar colour fastness, reflectance, colour shade and K/S values. In another study, Mathur et al. (2003) found that the dyeing of wool yarn using natural colourants extracted from the bark of neem (*Azadirachta indica*) at pH 4.5, colourant concentration - 0.05 g/g of wool, treatment time - 60 min and treatment temperature - 97.5ºC) gave very good light and wash fastness properties without deteriorating the quality of wool. Ammayappan and Shakyawar (2016) reported that cochineal dye pre-mordanted with Fe^{2+}, Sn^{2+}, and Al^{3+} gave greyish, reddish, and purplish chrome colours, respectively; however, cochineal dye without mordant produced bluish purple colour on woollen yarn. When two mordants are applied, the final colours depend on the properties of the dominant mordant.They further observed that dyed yarns showed moderate to very good washing fastness and moderate to excellent light fastness properties. Lim et al. (2001) obtained a full range of colours on wool using palmatin, red wood and natural indigo dyes with metallic mordant like tin, copper, tin, iron, nickel, chrome and alum. They further obtained that two component natural dyes showed good miscibility in dye bath in combination to dyeing of palmatin/red wood and palmatin/natural indigo. Kamel et al. (2011) also studied the dyeing behaviour of wool fabric with a mixture of natural dyes from *Terminalia arjuna* fruits and madder with different ratios (80:20, 70:30 and 50:50). The results indicated that dyeing with a combination of mordant improved the washing and light fastness from moderate to very good fastness properties. Pandey et al. (2017) used the skin of roasted peanut, an agro processing waste for the dyeing of wool. The colour uptake of wool was found to be better than cotton. The dyed fabrics possessed good to very good fastness properties with an ultraviolet protection factor up to 65.

c. ***Functional finishing on woollens***: Wool fabrics are subjected to washing or prolonged mechanical action, the fibres become entangled and locked together, causing the woollen fabric to shrink.

Pretreatments of loose wool, sliver/ top stage, knitted garment or woven fabric are carried out to prevent such shrinkage. The treatments are permanent and will enable the garments to withstand machine washing and tumble drying without shrinking. Silicone such as polydimethyl siloxane, alkoxy silane or amino alkoxysilane may be used for polymer application (Dekha and Chauhan, 2005). The chlorination of woollens is reported as effective for the prevention of shrinkage. Cardamoneet al. (2004) reported that alkaline hydrogen peroxide (H_2O_2) systems, including dicyandiamide, gluconic acid and triton x surfactant, used alone or followed by enzyme treatments, are effective to surface smoothing of the fibres and yields a relative area shrinkage of 2.95%. Another effective H_2O_2 system, using the same pretreatment, but followed by an enzymatic treatment with additives-polyacrylamide to restrict enzyme activity to the fibre surface and sodium sulfite to reduce disulfide linkages-yields 1.16% area shrinkage. Rybicki et al. (2000) concluded that enzymatic pre-treatment had notable influence on shrink-proofing properties and only a small amount of chitosan is necessary for stabilization of wool shrink-proofing quality. A novel, effective and commercially viable antimicrobial treatment for wool was developed by Yuan et al. (2011) using a peroxy monosulsulphate / sulphite pretreatment and the biocide polyhexamethylene biguanide (PHMB). The finishing conferred strong antimicrobial activity to the fabrics and at the same time reduced felting shrinkage after laundering to an acceptable level.

The larvae of *Tineola bisselliella* and *Anthrenus verbasci* are cause a severe attack to woollens, which is one of the major threats to wool fabric (Nazari et al., 2013). The majority of the synthetic organo-halogen and other commercial chemical formulations are effective in the prevention of moth attack, but most of them are toxic to human. ICAR-CSWRI has performed a good number of studies for the prevention of moth attack using eco-friendly chemicals. Raja et al. (2014) reported the use of silver oak, madder and henna extract for the prevention of moth attack on namda. Silver oak and madder treated woollen fabrics were found to have good resistance to moth attacks; however henna was found to be poor resistant. The fabric without treatment had severe moth attack and the weight loss was 10%. Shakyawar et al. (2015) attempted to develop natural dye-based anti-moth formulation for woollens using the extract of silver oak, walnut husk and pomegranate rinds. They found that natural dyes, having > 40% tannin content showed better anti-moth properties. Kumar et al. (2016) studied the properties of neem bark and leaves extract for the colouration and anti-moth properties on woollen fabric in the presence of metallic mordant viz., aluminum, stannum and iron. The anti-moth efficacy of neem bark was found to be better than neem leaves. The mordant processing with Sn metal further enhanced the anti-moth properties. Jose et al. (2018) imparted anti-moth property to a woollen fabric using nano-kaolinite, an aluminium silicate mineral based of natural origin. Moth proofing performance of nano-kaolinite coated wool fabric against *A. verbasciare* was investigated and found that 1.0% concentration of nano-kaolinite treatment results to moth mortality rate to 70% with less than 2.0% fabric weight loss. It was further observed that Eulan performed better than a nano-kaolinite in terms of anti-moth efficacy.

C. Waste Management in Decentralized Woolen Industry

i. ***Waste wool management:*** Indian woollen in decentralized sector generates various kinds of waste such as wool hard waste - recycled yarn waste, shoddy waste, scoured wool waste, greasy wool, soft waste, burr waste etc. Substantial amounts of solid waste - wool waste, yarn cones and packaging - are generated which account for a significant proportion of operating costs. Wool waste in the carding and spinning sector amounts to 7-14% of wool consumption and in the weaving and finishing sector to 5-9% (Sule and Bardhan, 2001). Wool waste in the knitwear sector ranges from 5 to20%. Wool waste arising in the felt manufacturing sector varies from almost zero for industries producing cheap felts from reclaimed materials to >20% of wool consumption quality felts producing industries (Shakyawar et al., 2018).

Wool waste generated from processing industries is of no use for them and dumped on the ground. These wool wastes are voluminous and disposal is a big concern. This waste wool has been used in agriculture as a source of fertilizer and to retain soil moisture for a long time (Kadam et al., 2014a). Gorecki and Gorecki (2010) reported that waste sheep wool is a valuable fertilizer and reduced the soil salinity and nitrogen content. Zheljazkov et al. (2009) reported that wool wastes could be used as a nutrient source and growth medium constituent for container-grown plants. Wool contains high quantities of nitrogen, sulphur and carbon. It is a rich source of important nutrients which are necessary for plant growth (McNeil et al., 2007). When wool breaks down partially by alkaline hydrolysis due to its enriched source of nutrients it can act as a slow release fertilizer (Gousterova et al., 2003).

The use of waste wool in agricultural crops showed 30% higher yield for tomato and pepper crop (Zheljazkov, 2005; Gorecki and Gorecki, 2010). Barley plant growth, green fodder and grain yield were markedly improved by using coarse wool in agriculture. The improvements in cluster bean crop of kharif season have been also observed (Kadam et al., 2013). In the ICAR-CSWRI, bulk waste wool collected from Bikaner woollen mills and decomposed the waste wool, sheep manure and crop residues in 30:50:20 ratio. The compost manure is found useful for indoor and outdoor ornamental plants in pots in multistory buildings, malls, corporate offices, airports.

ii. ***Water effluent management***: Another source of waste is unused dye stuff after dyeing of woollen products. Woollen textile industry consumes significant amount of dyestuffs. During the colouration process, a large amount of the synthetic dye does not bind and lost in the waste stream (Patel and Vashi, 2010). About 10-15% dyes are released into the environment during the dyeing process, making the effluent highly coloured and aesthetically unpleasant. The effluent from textile industries thus carries a large number of dyes and other additives which are added during the colouring process (Ratna and Padhi, 2012). Generally effluent from textile processing units does not conform to the stipulated norms. Therefore, water pollution due to discharge of liquid effluents from textile processing units on sewers, ponds, rivers or on irrigated land pose serious threat to the environment. They also undergo degradation to form products that are highly toxic and carcinogenic.

Conclusion

India's presence in the international market of woollen textiles and products is attributed to traditional skills, presence of the entire value chain and skilled manpower availability. The focus should be given for innovations in the use of Indian wool for value-added woollen products. By blending of coarse wool with fine wool or blending with silk, nylon or other fibres, new market could be created as it enhances the feel of the yarn. The preparation of card sliver in decentralized unit and subsequent hand spinning of woollen yarns for multiple applications can generate rural employment. New product such as wool-based denims will also help in increasing consumption of

Indian wool. Although, most of the Indian wool is non-apparel grade, it can cater to the need of technical textile applications which is still untapped. The coarse wool may be explored as a material for insulation, acoustical, construction, bulletproofing, automobile, agriculture and paper industries. Thus, coarse wool will certainly be a source of raw material for a wide range of products in smart cities.

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