

A Preliminary Exploration of Merino Wool–Milkweed Floss/Fibre (CLOCell™) blended Knits for Lightweight, Thermal Comfort and Sustainable Winterwear

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Abstract:

Background: The presented article is a preliminary investigation that explores the thermal comfort attributes and sustainability potential of knitted winterwear made from novel blend of merino wool and milkweed floss/fibre. Merino wool is acclaimed for its softness, elasticity and warmth, while milkweed floss offers breathability, lightweight superior thermal insulation, biodegradability and social impact potential. Milkweed, a native perennial shrub with minimal input resource requirements, produces extremely lightweight, hollow seed hair cellulosic floss known for its inherent insulating capabilities.

Materials and Methods: Merino wool sourced from M/s Ganga Acrowools Ltd. and Milkweed floss (CLOCell™) trademarked fibre of Northern India Textile Research Association (NITRA) were used to develop the blends. Merino wool was used in the scoured, bleached, carbonized and acid dyed state. While, Milkweed was used in its raw undyed state.

Results: When integrated with merino wool, milkweed demonstrates promising thermal performance while offering a bio-based alternative to conventional synthetic blends. Initial evaluations of the developed blend indicate favourable properties including light weight, breathability, moisture regulation and increased thermal insulation. The study presents insights into an innovative merino wool-milkweed floss blend that delivers greater warmth than wool while being lighter and softer, establishing a foundation for the advancement of sustainable thermal textile solutions. The integrative blending of milkweed floss with merino wool holds significant potential to reduce India's dependence on imported Merino wool and synthetic fibres like polyester and acrylic.

Conclusion: The developed fabric from milkweed/merino blended yarn was light weight, breathable and increased thermal insulation. Unconventional blends of natural protein and prized cellulosic fibres like milkweed offer sustainable and novel solutions to petrochemical based garments.

Key Words: Milkweed floss/fibre, merino wool, thermal comfort, sustainable, knitting, clo- value.

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I. Introduction

Wool is a highly effective natural protein fiber, possessing the unique scale like structure that makes it prized for superior thermal insulation and comfort along with breathability and moisture management. It retains warmth while damp and regulates body temperature across diverse temperatures and climates. The natural crimp of wool fibre makes it trap air (best insulator), creating insulating pockets with reduced conductivity. This structure enhances loft and thermal resistance, making wool ideal for cold-weather applications. Wool fibre exhibits low thermal conductivity that ranges from 0.035 to 0.045 W/m·K, comparable to synthetic insulators like polyester and polyurethane foams¹. Besides, wool also has the unique property of moisture management (moisture absorption- desorption behaviour). It can absorb up to 30% of its weight in moisture without feeling wet, maintaining insulation even in humid or damp conditions. Wool is a naturally renewable fiber that decomposes without releasing microplastics in the environment unlike its common alternatives, viz. acrylic and polyester². Wool is graded on the basis of its fineness, which ranges from ultrafine like Merino to coarse like carpet wool, yak wool, gaddi wool (15 microns to 100 microns). Merino wool (15 µm) is the ultrafine superior quality of wool known for its superior thermal insulation and moisture management characteristics that makes the wearer stay in comfortable state³.

I.I Merino Wool

Merino wool is sourced from Merino sheep, primarily raised in Spain, South Africa, Australia and New Zealand⁴ and is valued for its softness, breathability, and thermal regulation⁵. Literature represents merino wool as ideal for sports clothing and other high performance applications requiring thermal insulation and moisture management. A study conducted by North Carolina State University demonstrated that Merino wool offers superior thermal comfort and performance during intermittent, high-activity sports such as cycling, rock climbing, hiking, and golf. This advantage is attributed to a property known as dynamic breathability/ moisture-air exchange responsiveness —the ability of Merino wool garments to respond effectively to fluctuating physical demands by dissipating heat and moisture during exertion, while retaining warmth during periods of rest. In contrast to conventional synthetic fabrics, Merino wool sustains thermal equilibrium across varying activity levels. It helps alleviate the discomfort of after-chill, a common issue in outdoor sports, thereby supporting energy conservation and sustained comfort. As the human body continuously strives to maintain a skin temperature of approximately 35°C during stop-start activities, Merino wool reduces the physiological burden by naturally regulating microclimate conditions⁶. Merino wool is biodegradable in soil and water. However, producing merino wool garments requires high water and land use as sheep farming requires significant water, land, and feed resources. Methane emissions from livestock also contribute to its massive environmental footprint⁷.

Milkweed Floss/Fibre (CLOCell™)

Milkweed floss/fibre is the cellulose rich natural seed hair fibre cultivated and processed by NITRA and trademarked as CLOCell™. Milkweed (*Calotropis gigantea/procera*) is a hardy, swamp-adapted plant that thrives in marginal soils with minimal water and resource input, making it an ecologically resilient plant source for sustainable fiber sourcing. Milkweed (*Calotropis gigantea/procera*) plant bears pods/fruits that burst on maturity and release soft, lightweight, silky cellulosic floss attached to its seeds. Milkweed floss characterized by its fine, lightweight, low-density, and naturally hollow structure, exhibits exceptional thermal resistance. The hollow fibers effectively trap air, enhancing insulation against temperature fluctuations, while their low density (0.8 g/cc) contributes to superior fill power⁸. Milkweed floss is the only natural cellulosic fibre that offers thermal insulation property. Milkweed floss also exhibits high comfort characteristics due to its fine, lightweight structure and soft hand feel, making it suitable for applications requiring gentle contact with skin and enhanced wearer comfort⁹. Milkweed floss grows indigenously unlike Merino that is imported to India for superior quality winter wear. Milkweed floss being a fine and light weight fibre has a smooth and lustrous appearance that makes an aesthetically appealing choice apart from its thermal insulation property¹⁰.

In a previous study knitted fabric was reported to have been developed by blending Milkweed floss with Cotton and Polyester in different blend proportions respectively. The Milkweed blended and knitted fabrics were found to have higher Ultraviolet Protection Factor (UPF) and thermal insulation than cotton and polyester fabrics⁸. However, no study has been reported till date on blending of Milkweed with Merino with the aim to increase thermal insulation and reduce cost of using 100% Merino. In this initial exploratory study, conjoint property of both milkweed and merino was studied in terms of winterwear application. Merino- Milkweed blended woollen yarns and knitted fabrics were developed at M/s Ganga Acrowools Limited, Ludhiana, Punjab. The developed fabrics were then studied for performance attributes, viz. thermal resistance (clo-value), water vapour resistance ($m^2.Pa/W$), water vapour permeability index.

II. Material And Methods

Merino wool sourced from M/s Ganga Acrowools Ltd. and Milkweed floss (CLOCell™) trademarked fibre of Northern India Textile Research Association (NITRA) were used to develop the blends. Merino wool was used in the scoured, bleached, carbonized and acid dyed state. While, Milkweed was used in its raw undyed state. The fibre properties of Merino wool and Milkweed floss used in manufacturing of the blended yarn were tested and are produced in Table no 1.

Table no 1: Comparative Properties of Merino wool and Milkweed floss/fibre

Property/ Characteristic	Merino Wool	Milkweed Floss/Fibre (CLOCell™)
Fibre length, mm (ASTM D 5867)	83 mm	28- 32mm
Fibre fineness, microns (ASTM D 1577)	17- 28 microns	18- 25 microns
Fibre density, g/cc (ISO 1183)	1.30 g/cc	0.89 g/cc
Tensile strength, g/tex (ASTM D 3822)	15- 22	25-31
Elongation at break, % (ASTM D 3822)	25- 30	11- 18

II.I Yarn spinning

Merino wool (80%) and Milkweed floss (20%) blended yarn was produced and compared with 100% Merino yarn at an initial exploratory trial at the facility of M/s Ganga Acrowools Limited by semi worsted system. The blend components were first hand mixed, followed by blow room feeding for homogeneous blending. Thereafter, material was processed through card, gill boxes and ring frame machines.

Knitting and fabric testing

The blended yarn was developed into knitted woollen fabric by double jersey rib stitch. For comparative evaluation of various performance qualities of the blended fabric a control fabric of 100% merino wool was also developed keeping the machine construction parameters constant. The developed fabrics were tested for areal density (g/m^2), thermal resistance (clo-value), water vapour resistance ($\text{m}^2\cdot\text{Pa/W}$) and water vapour permeability index.

III. Results

Characterization of fibre properties

Merino wool sourced from M/s Ganga Acrowools Ltd. and Milkweed floss/fibre (CLOCell™) trademarked fibre of Northern India Textile Research Association (NITRA) were evaluated for comparative fibre properties before blending (Table 1). Merino wool is a long staple fiber and milkweed floss has a short staple length. Merino wool's slightly longer length and elongation aids in yarn strength and spinnability. Both fibres exhibit comparable fineness values, supporting their suitability for blending. While the crimped structure of Merino wool imparts elasticity and resilience, the hollow lumen of milkweed fibres enhances lightweight insulation. Milkweed floss shows higher tensile strength but lower elongation, whereas wool balances moderate strength with excellent elasticity (Table 1). Merino and Milkweed complement and contribute to the properties desirable in the blended yarn.

Yarn spinning

As an exploratory preliminary study, a blend of Merino wool and Milkweed floss/fibre (80/20) was developed and compared with 100% Merino yarn. The blend components (merino and milkweed) were first hand mixed and then fed into the blow room to achieve a homogeneous blend. The blended fibre mix was further processed through card, gill boxes and ring frame machines. Yarns were tested for performance parameters like twist per inch, yarn count, count strength product, elongation, unevenness and hairiness (Table no. 2).

Table no 2: Mechanical properties of the developed yarns

Physical property	100% Merino wool yarn	80/20 Merino wool/Milkweed floss blended yarn
Twist per Inch (TPI)	3.60	3.60
Count, Ne	2.40	2.40
Count strength product	4097	3351
Elongation, %	35.56	28.59
Unevenness, U%	6.78	6.89
Hairiness (h)	14,109	14,000

The incorporation of milkweed floss/fibre into Merino wool did not necessitate any change in spinning twist, and the yarn count remained consistent. This indicates that the blend of milkweed with merino does not contribute to coarseness in the blended yarn structure. However, due to the lower elongation percentage of the milkweed floss (i.e. 11- 18%), the count strength product (CSP) showed a slight decline compared to 100% Merino wool yarn. The blend yarn has lower tensile strength and elasticity relative to the hollow structure and low resiliency of milkweed floss. However, the reduced CSP did not limit development of yarn and fabric. On the other hand, hairiness and unevenness remain virtually unaffected, demonstrating that the blend retains good spinnability and surface quality.

Fabric Testing

The knitted fabric developed from 100% Merino was heavier than the 80% Merino- 20% Milkweed blended fabric (Table no 3).

Table no 3: Characterization of the developed knitted fabrics

Properties	Test method	100% Merino Wool fabric	80% Merino Wool+20% Milkweed fabric	Assessment
Areal Density, g/m²	IS 1964	701	601	Merino wool-milkweed blended fabric is lighter than 100% wool fabric as milkweed fibre is lighter than wool.
Blend, %	AATCC 20A	100% Wool	Wool: 80.22% Milkweed: 19.78%	Negligible wastage of milkweed noticed during blending.
Thermal Insulation, clo-value	ISO 11092	1.17	1.30	Merino wool-milkweed blended fabric is warmer than 100% wool fabric.
Water vapour resistance, m².Pa/W	ISO 11092	15.17	13.94	Merino wool-milkweed blended fabric is less resistant to water vapour than 100% wool fabric. This means sweat can pass through blended fabric faster than from 100% wool fabric.
Water vapour permeability index	ISO 11092	4.63	5.60	A water vapour permeability index is significant because it measures how easily water vapour can pass through a material, which is crucial for assessing the breathability and comfort of fabrics, especially in clothing, as it directly impacts how well sweat can evaporate from the body, thus affecting thermal comfort levels; a higher index indicates greater permeability and better breathability. Merino wool-milkweed blended fabric has a higher water vapour permeability index than 100% wool fabric, making it more breathable and comfortable.

Softness	Manual method	-	-	Merino wool-milkweed blended fabric is softer than 100% merino wool fabric.
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IV. Discussion

Milkweed blended fabric exhibited high thermal insulation (clo- value) due to the hollow structure of milkweed (more than 70% hollow) and low density. Due to low density more no. of fibres pack and take space in blend. Higher no. of milkweed floss increases the clo- value of the fabric. The results establish that inclusion of milkweed floss in blend increases the clo- value of the resultant final product. A similar trend was also reported by Parmar et al., 2015 on blending milkweed with cotton and polyester. Blending merino with milkweed decreases water vapour resistance, a low value depicts fabric is more breathable and suitable for active winter wear. Thus, the fabric produced is thermally insulating as well as offers comfortable and good moisture management property, well suited for athleisure, sports clothing, etc. The blending of merino with just 20% milkweed results in a fabric with better water vapour permeability, making it a comfortable choice of fabric for temperate climates. On blending with milkweed floss, the areal density drops indicating a lighter fabric without compromising insulation and breathability.

V. Conclusion

The study highlights the following conclusions for the developed 80/20 merino- milkweed blended fabric over the 100% merino fabric:

- **Weight:** The merino wool-milkweed blended fabric is lighter than 100% wool fabric because milkweed fibre is lighter than wool.
- **Thermal Properties:** The merino wool-milkweed blended fabric is warmer than 100% wool fabric, milkweed floss exhibits thermal insulation property in the blended fabric.
- **Water Vapour Resistance:** The merino wool-milkweed blended fabric is less resistant to water vapour compared to 100% merino wool fabric. This indicates that sweat can pass through the blended fabric faster than through 100% wool fabric.
- **Water Vapour Permeability Index:** The merino wool-milkweed blended fabric has a higher water vapour permeability index than 100% wool fabric, making it more breathable and comfortable.
- **Softness:** The merino wool-milkweed blended fabric is softer than 100% wool fabric.

The developed novel 80/20 Merino/ Milkweed blend is proposed for eco-luxury textiles (scarves, shawls, sweaters, mufflers, baby blankets, winter wear) where softness, comfort, warmth, luxurious look and sustainability are desired. Further to this exploratory study, a detailed experimental plan is considered for future exploration to study different blends of Milkweed floss with merino and other varieties of indigenously available wool grades like gaddi wool, angora, yak, camel wool, etc. Simultaneously, effect of different knits may be considered to evaluate the property of the blended fabric.

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