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The Sustainable Colouration of Merino Wool Yarns with Herbs

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Abstract

The Textile industry is the second largest polluter in the world. The European green deal has placed the textile industry at the top priority for establishing sustainability standards for the global benefit to the environment and human health alike. The ESG and CSR are at the core of the sustainability agenda this propels the instigated research towards sustainability in textiles. The research herein experiments with the colouration of merino wool yarns with herbal colours namely tulsi, green tea, and manjistha. The maximum L value of 70.00 denoted light shade obtained with green tea also K/S of 8.87, a* value of 5.58, and b* value of 31.97 was obtained with green tea.*

The ATR-FTIR identified densest of phytochemicals in raw tulsi herb in specific the strong C=O stretch of α, β-unsaturated esters were noted at 1729.79 cm-1 and its treated merino wool yarns exhibited a strong C-O stretch of alcohols, carboxylic acids, esters, and ethers at 1232.72 cm-1 wavenumbers. The oxidation-reduction potential (ORP) value of the spent solution after processing the merino wool yarns with herbs in research was transformed from a negative value of -53.4 mV for original water to a positive value of 96.1mV for leftover manjistha root solution, 90.7 mV for leftover green tea solution, and 62.3 mV for a leftover tulsi solution, hence sustainable. Likewise, the dissolved oxygen (DO) of the surplus solutions remained in the acceptable range with the values of 111.0 %, 103.3%, and 95.6 % for leftover solutions of manjistha root, tulsi, and green tea, respectively hence ecological. Life cycle analysis is recommended for the future.

Key words: Merino Wool Yarns, Herbal Colours, Plant-Based Colours, Sustainable Textiles, Eco-Smart Textiles

Introduction

The Changing Markets Foundation (CMF) reports, backed by the Clean Clothes Campaign, Plastic Soup Foundation, and No plastic in My Sea NGOs investigations, promulgates on the fossil fashion that dangerously depends on cheap synthetic fibres causing ecological disasters. It reinforces The European Green Deal's one trillion projects to establish climate-neutral Europe by 2050, wherein the textile industry is at the heart of a new circular economy action plan. Herein it is suggested to implement natural renewable circular materials in eco-design. Likewise, encourage natural fibres to reduce microfibres treats from synthetics. Levying a high tax on fossil-based raw materials to channel manufactures towards alternative renewable materials. The European Green Deal would compel manufacturers to present Life Cycle Assessment (LCA) and provide end-of-life ecological treatment for each product. It also supports the sustainability framework that highlights the reuse, recycles and repair of materials. It completely contempt the fast fashion and recommends substituting it with a sustainably slow circular model from start to finish. Hence, the instigated research that implements natural renewable raw materials and ecological processing methods for resilient future fashion factories [1].

Therefore, in Germany, scientists have turned to isolate chitosan from waste crab shells, insects, and funghi for water-repellent textile finish and disdain the use of fluorocarbon-based oil and water repellent finishes to reinforce the circular economy agenda of the textile industry [2]. Likewise, Zhang et al conducted a study wherein the weft-knitted single jersey wool fabric was treated with Chinese gallnut colourant, the optimum extraction was gained at 2 hours of working at 90°C with a 1:30 material to liquor ratio. Also, the optimum dyeing was attained at 98°C at 200% dye liquor concentration, 2.5% mordant concentration at pH 8. The wash, rub and perspiration fastness properties had a greyscale rating of 3 at the minimum. The coloured wool fabric exhibited antibacterial activity against Staphylococcus aureus and Escherichia coli of 99.90% and 96.55% respectively. The entire work was concluded to be cost-effective. However, no account of mordants was provided nor the ecological efficiency or functional groups were detailed [3]. In the same vein, three types of wool from Polish Merino, Żelaźnieńska, and Polish Lowland sheep were coloured with golden tickseed. Fascinating colours were obtained with all three types of wool, the L*a*b* values of one type of wool are as follows, refer to Table 1 [4].

Table 1: The colour values and colours as obtained on Polish lowland sheep wool with Golden tickseed.

Mordant	L*	a*	b*	Colour	Pantone
Raw wool	76.13	0.5	16.62	Golden cream	13-0919 TCX
No mordant	51.72	19.38	46.94	Golden yellow	15-0953 TCX
Alum	55.31	15.34	50.14	Nugget gold	16-0952 TCX
Sodium carbonate	35.84	31.8	26.67	Rusty red	16-1449 TCX
Citric acid	68.71	-1	57.86	Maize	13-0746 TCX
Copper sulphate	36.65	20.12	27.73	Light brown	18-1160 TCX
Iron sulphate	40.17	5.14	27.73	Olive brown	17-0840 TCX

However, the fastness properties remain to be evaluated. A noteworthy alert was raised by Dalena White towards a misleading sustainability rating system wherein fossil-based synthetic fibres are not penalized for being non-renewable and non-biodegradable similarly the natural fibres namely wool and cotton are not allotted positive scoring for being renewable and bio-degradable. Microplastic generation is not rated negatively. Furthermore, the natural fibres that are the antidote to fast fashion are fully costed for the environmental impacts. The European Union has aimed the textile sector on priority for establishing sustainability standards however it is highly essential to improve the European commission rating rules [5].

Interestingly, the Woolmark licensee Tintoria di Quarenga has created a natural dyeing process called NATURALE that implements more than 200 natural materials to create a broad array of colours suitable for colouring wool (The Woolmark Company, n.d.). The resultant products are thoroughly tested for quality and approved under the Woolmark Certification Program. Wool is 100% natural and renewable, refer to Figure 1. Every year sheep generates a new fleece therefore wool is 100 % a natural animal fibre and renewable. Concurrently wool can be reused and recycled hence being sustainable [6].

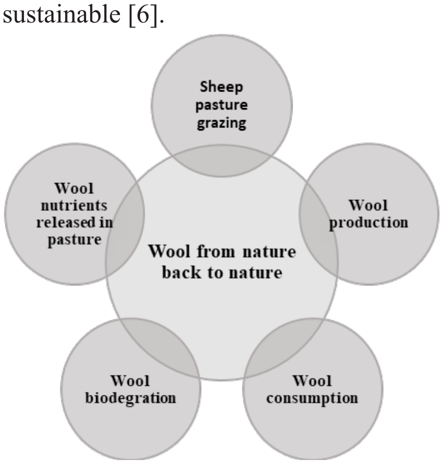


Figure 1: Illustrating 100 % wool biodegradability (The Woolmark Company, 2019).

The benchmark tools namely SAC and the Made-By, utilized for measuring wool's environmental footprints implement the partial Life Cycle Assessment Technique (LCA) wherein micro-plastic pollution of waterways and solid waste generation is not included. Therefore, the Woolmark Company research studies are rigorously promulgating the environmental credentials of wool to the concerned agencies [8]. Wool fibres are breathable. The natural crimp of the wool fibre keeps the wearer warm and dry. Wool is naturally breathable fibre, therefore less sweat. Sweat itself has no odour however in contact with skin, environmental dirt and moisture provide the correct environment for bacterial colonization hence the odour. Conclusively wearing breathable wool gives less sweat and less body odour [9]. Wool socks are preferred to synthetic socks after wearing and post washing due to lack of odour [10].

Even more, with regards to the carbon footprint of wool, the wool industry is working to reduce global greenhouse gas impact across wool garments' whole life cycle from cradle to grave, refer to Figure 2 [11]. Few examples of measures taken are listed below [12].

1. Research and development to mitigate methane.
2. Sheep rearing farms could enhance soil fertility for nutritious pasters and enhanced carbon storage. The emissions may perhaps be circumvented by planting more trees.
3. The carbon footprint per kilo of wool might be reduced by increasing lamb and wool production per sheep.
4. By processing wool with a renewable source of energy would control carbon emissions.
5. Wool consumers ought to recycle and reuse wool products to combat GHG emissions from wool.

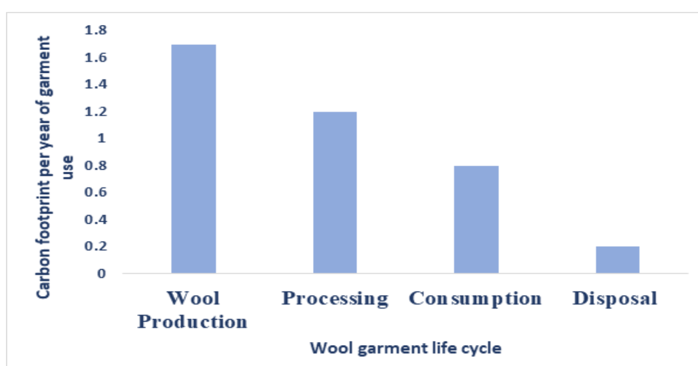


Figure 2: GHG emission from wool garments per year over the entire life cycle (The Woolmark Company, 2017).

There is a various genus of wild herbs and grasses available in spare, refer to Figure 3 a and b. These reserves from the forest were recently investigated by Griffiths, the author mordanted grey and white wool skeins with mordant alum and cream of tartar.

Table 2 shows the wild herbs utilized for treating wool and the colours acquired with it [13].

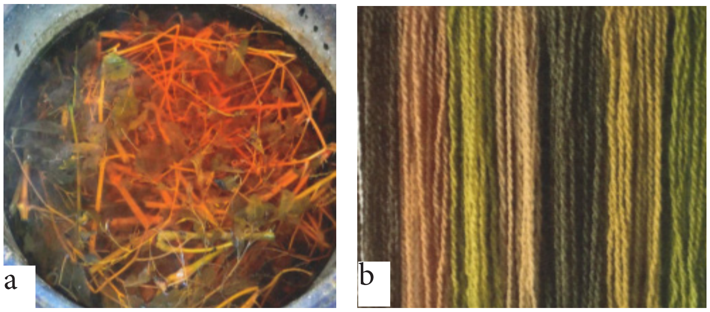


Figure 3: a) Jewelweed dyebath and b) wool skeins coloured with natural dyes (Griffiths, 2020)

Table 2: Colours were obtained on wool skeins with wild weeds, shrubs, and grasses (Griffiths, 2020).

Wild Weeds, Shrubs & Grasses	Grey Wool	White Wool
Solidago (Goldenrod)	Olive Grey	Golden Yellow
Andropogon Gerardii (Big Bluestem Grass)	Yellow	Yellow
Persicaria Tinctoria (Indigo)	Citrine Green	Citrine Green
Impatiens Capensis (Orange Jewelweed)	Pink	Pink

The natural colouration is an antique art that could enormously promote sustainability nevertheless of mass production. Concurrently, the concept of Sustainability is at its forefront worldwide. The sustainability agenda is gaining core value in each aspect of our life likewise for every research and development and future fashion factory. Sustainability incorporates, Environmental, Social, and Governance (ESG) & Corporate Social Responsibility (CSR) as succinctly explained in Figure 4 [14].

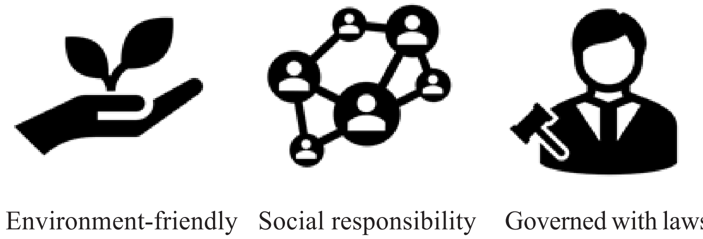


Figure 4: ESG and CSR are at the core of the sustainability agenda (Picton & Nicola, 2021).

Common sense would be to realize that sustainability is here to stay it is not a fashion fad. Ayurvedic colours and natural textiles comply with ESG and CSR for the survival of future fashion cottage industries hence the originated research.

Materials and Methods

Materials

The ready-to-colour merino wool yarns were sourced from the Laughing hens, Uk, refer to Figure 5. The herbs in the research study namely tulsi and manjistha were sourced from the Sheetal Ayurved Bhandar, India, and the green tea was sourced from (Twinings) ASDA, UK. They are summarised in Table 3.

Figure 5: Original merino wool yarns

Table 3: Herbs in research and their potential functionalities on natural textile substrate.

Botanical name	Common name	Functional in textiles
Ocimum tenuiflorum	Tulsi, vrndavani, vrnda, visvapujita, puspasara, nandini, krsna-jivani, visva-pavani, tulasi.	Antibacterial, Antifungal
Rubia cordifolia	Manjistha root, Indian madder, Bengal madder, Munjeet madder wort, Aromatic madder, Dyer's madder, Alizarin	Anti-inflammatory & improves skin health, wound healing
Camellia sinensis	Green tea, Dragon well, Chinese green tea, Sencha, Tencha	Anti-bacterial & improves skin health

Methods

Extraction and colouration

The herbs namely tulsi, green tea, and manjistha were infused in the warm water of 60°C overnight. Thereafter, the merino wool yarns were stepped in the extract solution at room temperature of 20°C overnight. No solvent slow process was adopted.

Evaluation of Colour values as per data colour 600

Data colour 600, a dual-beam spectrometer was utilized for colour measurement. The device has an SP2000 monochromator with dual 256 LEDs and a high-resolution holographic grid. The source of light in it is D65, it covers the spectral range from 360 nm to 700 nm and has a photometric range of 0 to 200%.

K/S value is the direct measure of the colour yield. The Kubelka-Munk equation as demonstrated in Equation 1,

$$K/S = (1 - R)2 / 2R$$

denotes the relationship between the colour solution concentration and the reflectance of the coloured fabric by relating reflectance to the absorption and scattering of the light. K and S are therefore defined as the absorbance and scattering coefficients of the dyed materials at specified wavenumbers and R is the percentage reflectance value of the dyed sample at λ_{max}.

The CIE Lab colour scheme offers a standard colour scale to calculate the colour values. It is a colour scheme with three dimensions L*, a*, and b*. L* represents the lightness/darkness of a colour. When L* equals 0, it is black and 100 is white. The colour channels a* and b* represent true neutral grey values at a* = 0 and b* = 0. a* represents redness/greenness of colour, with green at negative a* values and red at positive a* values. b* indicates yellowness/blueness of colour, with blue at negative b* values and yellow at positive b* values.

Fastness tests methods

A Wash fastness test was performed on SDL-ATLAS, M229 Rotawash, refer to Figure 6 a and b for external and internal view respectively, following BS EN ISO 105- C06:2010, however, the use of detergent was eliminated for ecological outcomes. The addition of synthetic detergent also brings about changes in the original colour (agglomeration) and functional properties of the resultant herbal fabrics, hence eliminated. Lightfastness test was conducted on Turfade, serial number 200/18/1053 as per BS EN ISO 105-B02:2014: Colourfastness to artificial light: Xenon arc fading lamp test, refer to Figure 7 a and b for external and internal view respectively.

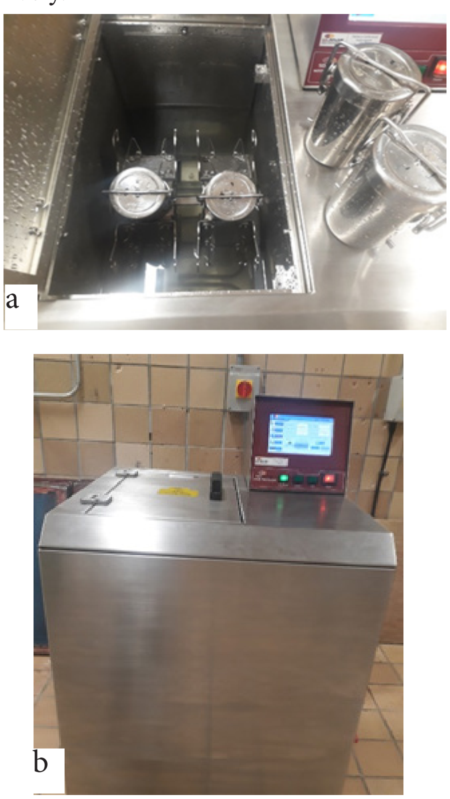


Figure 6: Rotawash, M229 for wash fastness test performance of the merino wool yarns treated with herbs. (a) Rotawash, M229 External view with digital controls (b) Rotawash, M229 Internal view with jars and water bath

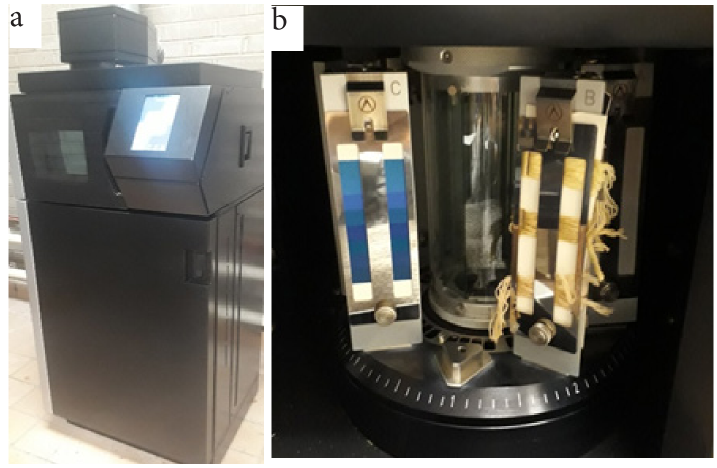


Figure 7: Turfade light fastness instrument, a) Main Instrument b) Internal component with Blue Wool Standard card, coloured yarns samples mounted on card and light source.

Natural bio-material analysis on Attenuated Total Reflectance – Fourier Transform Infrared Spectroscopy (ATR-FTIR)

Thermo Scientific™, Nicolet™ iS™ 5 FTIR Spectrometer was applied for probing the constituent profile of raw herbal leaves. In infrared spectroscopy (IR), IR radiations are passed through a sample, some of the IR radiations are absorbed by the sample and some of it is transmitted through the sample. The resulting spectrum represents the molecular absorption and transmission or reflection, creating a molecular fingerprint of the sample. Fourier Transform Infrared spectrophotometers (FTIR) are mainly used to measure light absorption of so-called mid-infrared light, in the range of wavenumber between 4,000 and 400 cm^{-1} (wavelengths from 2.5 to 25 µm), to identify and quantify various materials.

Attenuated Total Reflection (ATR) type of FTIR was implemented in this research for analyzing cotton fabrics without requiring complex preparation as required in the KBr pellet method. A Thermo Scientific™, Nicolet™ iS™ 5 ATR-FTIR consists of a diamond accessory that operates by measuring the changes that occur in an internally reflected IR beam when the beam meets a sample [15]. Figure.8 succinctly illustrates the working principle of the ATR-FTIR.

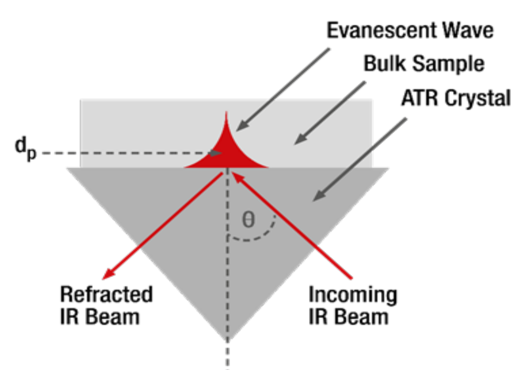


Figure 8: Mechanisms of ATR-FTIR working with the diamond crystal (Bradley, n.d.).

The ATR-FTIR technique was utilized for acknowledging the presence of predominant functional groups in each of the raw herbs, biomordanted cotton fabric samples, and coloured cotton fabric samples [16]. The spectroscopy tables and IR window as given in Figure 9 were utilized for interpreting the ATR-FTIR spectroscopy fingerprints for each of the herbs and treated cotton fabrics in the research.

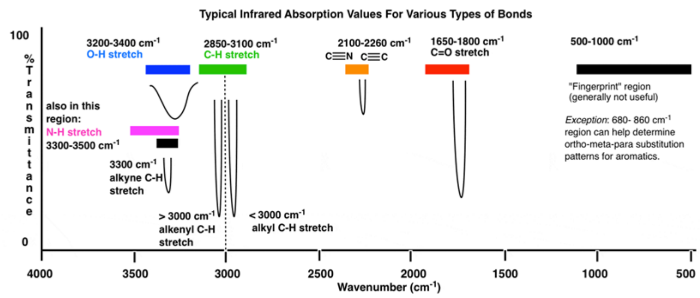


Figure 9: IR window for ATR-FTIR peak analysis [17].

Dissolved oxygen (DO), oxidation-reduction potential (ORP) and pH examination of the spent herbal solutions

The ecological compatibility of the material and methods implemented in the research were evaluated based on three parameters namely, Dissolved Oxygen (DO), Oxidation-Reduction Potential (ORP), and Potential of Hydrogen (pH).

Dissolved Oxygen (DO) level

The dissolved oxygen (DO) level of the spent solution after herbal colouration was measured with a dissolved oxygen meter Hanna, HI 9146 microprocessor. Just like animals and humans living on land, animals that live in water need oxygen to survive. Oxygen from the atmosphere dissolves in river and lake water, and it is this oxygen that fish and other aquatic animals use to breathe. Table 4 shows the dissolved oxygen requirement of marine fish.

Table 4: Dissolved oxygen level requirement of marine fish.

Fish survival	Dissolved oxygen (mg/l) level
All fish die	0-4
Very few fish live	4-6.5
Big fish live, Small fish die	6.5-9.5
All fish live	9.5-12

Oxidation-reduction potential (ORP)

The surplus water after completing the mordanting and colouration process was analyzed using Hanna, HI 8424 pH/mV/°C portable pH meter/ORP (oxidation-reduction potential) meter. The ORP is measured in millivolts (mV). The higher the ORP at the end of the process the cleaner the water. When the ORP value is high, there is a lot of oxygen present in the water. ORP sensor works by measuring the amount of dissolved oxygen [18]. A positive (+) ORP means the solution is an oxidizing agent. A negative (-) ORP reading means the solution is a reducing agent [19].

Drinking water should have a rating of least -50 millivolts, however, filtered water can have ORP values ranging from 357 to -25. Normal tap water, bottled water, rainwater, and so forth, have a positive ORP generally between 200 and 400 mV, and even as high as 500-600 mV depending on location [19].

Potential hydrogen (pH)

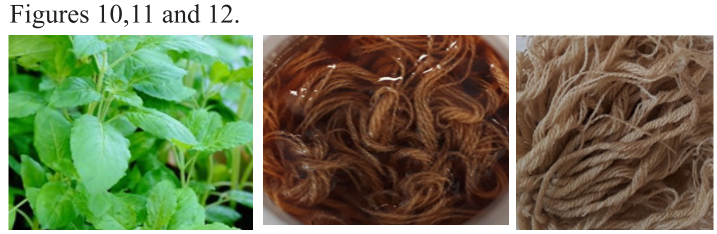
The pH scale indicates the hydrogen concentration which determines the nature of a solution, whether the solution is alkaline or acidic, or neutral. It is measured by the pH scale, and its index value is related to the ratio of positive hydrogen ions (H+) and negative ions (OH-) [19]. The solution is called neutral when the concentration of OH- and H+ ions are equal, pH value = 7. The solution is called acidic when the concentration of H+ ions is higher than OH- ions. The solution is called alkaline when the concentration of OH- ions is higher than H+ ions.

Water with a pH value of 6.5 to 8.5 is considered safe for drinking, meaning the water is neither acidic nor alkaline enough to be harmful to the human body. When the pH value drops to below 6.5 or rises above 8.5, water becomes toxic, causing various health issues like eye and skin irritation, diarrhoea, nausea, gastrointestinal upset, etc. (Environment and Natural Resources, n.d.) (Aqua health products, 2020). The surplus bath after processing the cotton fabric samples with biomaterials was tested for DO, ORP, and pH levels to quantify its recyclability and disposability.

Results

Colours obtained

The merino wool yarns were sustainably processed with tulsi, manjistha, and green tea leaves obtaining the colours as shown in Figures 10,11 and 12.



Tulsi Extract Dried yarns

Figure 10: The merino wool yarns are treated with tulsi leaves herb.

Manjistha root Extract Dried yarns

Figure 11: The merino wool yarns are treated with Manjistha root herb.

Green tea leaves Extract Dried

Figure 12: The merino wool yarns are treated with Green tea leaves herb.

The dried tulsi leaves, manjistha root, and dried green tea leave yield leaf brown, pale red, and cream colours respectively as per visual observation in daylight. The moderate extracts of herbs were obtained ecologically by a simple and clean method with no polluting solvents implemented.

Colour values

The colour values as obtained on the merino wool yarns treated with tulsi, manjistha, and green tea leaves are given in Table 5.

Table 5: Colours values were obtained on Merino wool yarns with herbs in research.

Herbs	K/S	L*	a*	b*
Tulsi	13.88	61.15	5.56	31.51
Manjistha	19.93	53.89	26.26	44.01
Green tea	8.87	70.00	5.58	31.97

The K/S of 19.93, 13.88, and 8.87 was gained on merino wool yarns treated with tulsi, manjistha, and green tea leaves, respectively. The maximum lightness value of 70.00 was acquired with green tea leaves followed by tulsi at 61.15 and lastly, manjistha with the value of 53.89 gained on the treated merino wool yarns. The maximum positive a* values of 26.26 and maximum positive b* value of 44.01 was acquired on merino wool yarns treated with manjistha. Overall, the values indicate the light red-yellow shade of colours obtained on the herbs treated merino wool yarns.

Fastness properties

The fastness properties were evaluated of the merino wool yarns treated with herbs in research as shown in Table 6.

Table 6: The fastness ratings were obtained for merino wool yarns treated with tulsi, manjistha, and green tea herbs.

Herbs	Lightfastness	Wash fastness	
		Staining	Colour change
Tulsi	4	4/5	4
Manjistha	2	4/5	4/5
Green tea	2	4/5	4/5

The good to very good wash fastness ratings were obtained on the greyscale for merino wool yarns treated with tulsi, manjistha root, and green tea leaves. The lightfastness was fair for merino wool yarns treated with tulsi and poor for yarns treated with manjistha and green tea herbs. Therefore, shade drying would be recommended.

ATR-FTIR

The ATR-FTIR analysis of the raw herbs namely tulsi, manjistha, and green tea leaves are shown in Figure 13. The raw tulsi exhibited a moderate peak of C-Br stretch of alkyl halides at 521.80 cm^{-1} of wavenumber and moderate C-N stretch of aliphatic amines at 1015.61 cm^{-1}. From the wavenumbers, 1504.20 up to 1555.33 cm^{-1} strong N-O asymmetric stretches of nitro compounds and moderate C-C stretch (in-ring) of aromatics were noted in raw tulsi. The moderate N-H bend, -C=C- a stretch of 1° and strong C=O stretch of amine, alkenes and α, β- unsaturated aldehydes, ketones respectively were noted from 1612.57 up to 1694.26 cm^{-1} of wavenumbers. The strong C=O stretch of α, β-unsaturated esters was noted at 1729.79 cm^{-1}. At 2849.40 cm^{-1} cm wavenumbers, moderate O-H stretch of carboxylic acids was noted. At 3281.98 cm-1 up to 3337.69 cm^{-1} wavenumbers moderate N-H stretch of 1°, 2° amines, amides were noted. Lastly, at 3624.77 cm^{-1} wavenumber strong and sharp O-H stretch, free hydroxyl functional groups of alcohols and phenols were identified in raw tulsi herb. In all the tulsi herb is dense in phytochemicals with varied functional groups.

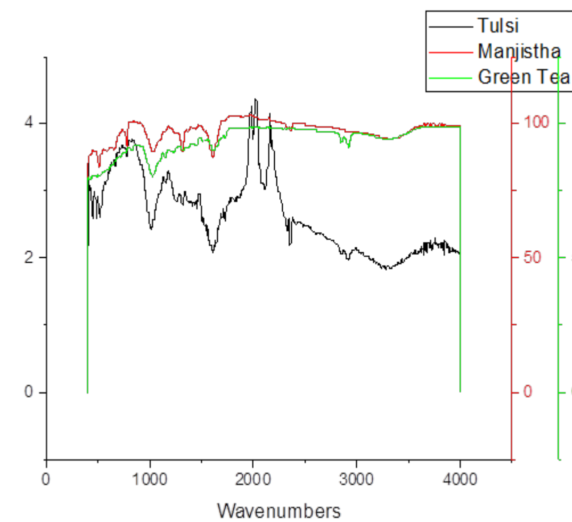


Figure 13: ATR-FTIR spectrum of raw herbs namely tulsi, manjistha, and green tea herbs

The raw manjistha roots herb exhibited a moderate C-Br stretch of alkyl halides at 589.85 cm^{-1} wavenumbers. At 77.56 cm^{-1} wavenumber strong C-H 'oop' of aromatics was noted. Likewise, at 1029.95 cm^{-1} wavenumber moderate C-N stretch of aliphatic amines was noted. The strong C-O stretch of alcohols, carboxylic acids, esters, and ethers was noted at 1314.99 cm^{-1} wavenumber. Hence, the raw manjistha herb demonstrated strong peaks of several functional groups as detailed. Similarly, the raw green tea herb demonstrated moderate C-Br alkyl halides at 520.76 cm^{-1} and 547.91 cm^{-1} of wavenumbers. The strong peak of the C-O stretch of alcohols, carboxylic acids, esters, ethers was noted at 1028.29 cm^{-1} wavenumber. The moderate C-N stretch of aliphatic amines was noted at 1144.86 cm^{-1} of wavenumber. The ATR-FTIR analysis of merino wool yarns treated with tulsi, manjistha, and green tea is shown in Figure 14.

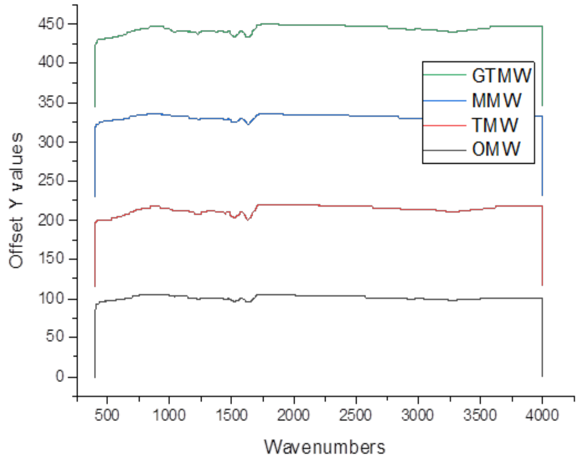


Figure 14: The ATR-FTIR spectrum of merino wool yarns treated with herbs in research.

The original merino wool and merino wool treated with tulsi, manjistha, and green tea herbs all exhibited moderate N-H bend of 1° amine at 1629.33 cm^{-1} of wavenumber. The strong N-O asymmetric stretch of nitro compounds was observed on merino wool yarns treated with tulsi, manjistha, and green tea at 1514.11 cm^{-1} of wavenumber. Also, the merino wool yarns treated with tulsi exhibited a strong C-O stretch of alcohols, carboxylic acids, esters, and ethers at 1232.72 cm^{-1} wavenumbers. Lastly, the merino wool yarns treated with manjistha showed a strong N-O asymmetric stretch of nitro compounds at 1527.67 cm^{-1} of wavenumber. Overall, the treated merino wool yarns exhibited traces of functional groups present in raw herbs in specific N-O of nitro compounds and C-O of alcohols, carboxylic acids, esters, and ethers.

DO, OPR and pH

The dissolved oxygen (DO), oxidation-reduction potential (ORP), and pH of the surplus solution after processing the merino wool yarns with tulsi, manjistha, and green tea herbs were noted as summarised in Table 7.

Table 7: The DO, ORP, and pH of the surplus solution were left after processing the yarns with herbs.

Herbs	pH	ORP (mV)	DO (%)
Water	7.84	-53.4	8.20
Tulsi	5.97	62.3	103.3
Manjistha	5.21	96.1	111.0
Green tea	5.39	90.7	95.6

It is essential to note that the ORP value of the water utilized in research had moved from a negative ORP value of the original water towards a positive ORP value after the completion of the processing. This indicates that the herbs in research are liberating oxygen hence sustainable. The maximum ORP values are obtained with a manjistha root of 96.1. Likewise, the DO remains in an acceptable range for all the surplus baths in research hence ecological with highest for manjistha at 111%. The ORP and DO are conducive for both the environment and human health. The pH needs to be neutralized with organic calcium carbonate for safe disposal or recycling. Overall, the ecological results would imply sustainability in the textile industry.

Conclusions

Together, the following conclusions are made.

1. The low energy and water demand process are hence sustainable. Also, no polluting solvents were implemented in research, plain distilled water was the only solvent implemented for research experimentation. The simple and clean process is hence sustainable.
2. The colour values obtained indicate light red-yellow shades of colours obtained with herbs in research. The maximum K/S values were gained with manjistha of 19.93 and maximum a* values of 26.26.
3. The wash fastness of good to very good was obtained on merino wool yarns with all the herbs namely tulsi, manjistha, and green tea herbs.
4. The raw tulsi herb demonstrated the presence of the densest functional groups namely the strong C=O stretch of amine, alkenes, and α, β- unsaturated aldehydes, ketones respectively were noted from 1612.57 up to 1694.26 cm^{-1} of wavenumbers. Also, the merino wool yarns treated with tulsi exhibited a strong C-O stretch of alcohols, carboxylic acids, esters, and ethers at 1232.72 cm^{-1} wavenumbers the same was not observed on the raw merino wool yarns.
5. The ORP changed from negative -53.4 mV of original water to positive of all the surplus solutions left after the processing of merino wool yarns with herbs with a maximum ORP value acquired of 96.1 mV with manjistha. Likewise, the maximum DO value of 111.0 % of the spent solution was also gained with manjistha roots herbs. Overall, the ecological outcomes were derived that would propel sustainability in future fashion factories.

Future work

It is a challenge for the textile sector to meet ESG and CSR to achieve net-zero carbon emission by 2050. A good thing would be for the "We Humans" to consider ourselves a bit less important and prioritize others' happiness by showing concern for those suffering in the "Manufacturing world" and must realize that there is no "Planet B". A clear, mandatory, and ambitious set of appropriate actions are required to transform the textile sector towards sustainability hence the research and its ecological outcomes are a drop in an ocean though. As a future course of research and development life cycle analysis and clinical investigations on the potential therapeutic benefits of herbal fabrics to the wearer are recommended.

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