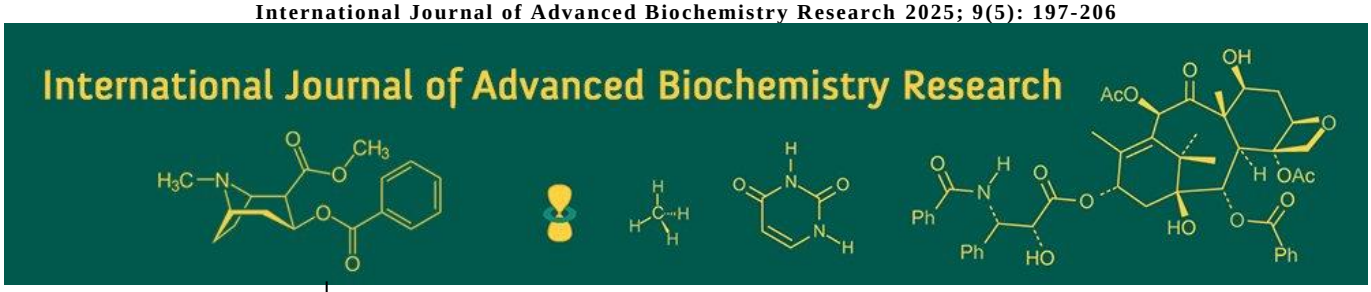

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Multifunctional wool fabric treated with microencapsulated thyme essential oil: A sustainable approach

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Abstract
The present study focused on developing wool fabric infused with microencapsulated thyme essential oil. Scanning electron microscopy (SEM) analysis of the treated wool fabric demonstrated the presence of numerous uniformly sized spherical microcapsules on its surface, while Fourier-transform infrared spectroscopy (FTIR) indicated the existence of various functional groups likely responsible for the alterations in characteristics. The treatment with microencapsulated thyme essential oil enhanced most of the physical, mechanical, and performance properties of the wool fabric. The aroma-infused wool fabric exhibited significant effectiveness against moths, resulting in a weight reduction of 8.10 percent and a moth mortality rate of 50 percent. Additionally, the aroma-infused fabric displayed antibacterial properties, decreasing bacterial growth against *Staphylococcus aureus* and *Escherichia coli* by 71.20 percent and 67.71 percent, respectively. Scoured wool fabric exhibited a strong UPF value of 30.25, which increased to 42.31 after undergoing aroma treatment. Fabric samples that were treated with microencapsulated thyme essential oil demonstrated impressive aroma retention and intensity when subjected to various factors such as washing, abrasion, ironing, and sun-drying. Therefore, microencapsulated thyme essential oil serves as an effective means to provide a durable fragrance finish to wool fabric, creating textiles that have multiple functions, including antimoth, antibacterial, and UV protection properties, without adversely affecting the physical characteristics of the wool fabric.

Keywords: Thyme oil, microencapsulation, wool fabric, aroma finishing, physical and functional properties, aroma durability

1. Introduction
The demands, requirements, and anticipations of consumers for a healthier and more enjoyable lifestyle are growing daily, particularly in the fashion industry. Thanks to the development of new eco-friendly technologies, the increasing health and hygiene preferences of consumers can be addressed without compromising safety, human health, or environmental integrity (Sanjay and Malpani, 2013; Thite and Gudiyawar, 2015) [19, 30]. Buyers typically expect a significant level of comfort while wearing, and finishing plays a critical role in achieving that. In a narrow definition, finishing represents the concluding stage of the fabric production process, providing the final chance to deliver features that customers appreciate. Functional finishes made from natural materials include components sourced from plants and animals, offering various benefits such as being non-toxic, non-irritating, biodegradable, economically viable, and easily accessible. Natural oils, especially essential oils, are being promoted for finishing purposes due to their effectiveness and lack of negative effects (Naikwadi *et al.*, 2017; Sayed *et al.*, 2017) [15, 21].
The finishing technique known as aroma or fragrance finishing is considered a developing area that has influenced the textile sector by enhancing product value through the regulated release of different aroma into fabrics, leading to the production of fragranced textiles. The fragrance derived from essential oils not only provides a delightful aroma but also brings the positive effects associated with aromatherapy (Kumar *et al.*, 2012) [10]. Essential oils are volatile, natural, and intricate compounds characterized by their strong fragrance, sourced from various parts of aromatic plants, such as flowers, leaves, stems, fruits, and roots. The term 'essential' refers to the fact that it holds the unique scent or essence of the plant from

which it is extracted (Salehi *et al.*, 2018) [18].

Thyme oil is one of the essential oils with various functions and can be utilized as an eco-friendly finishing agent to enhance fabric performance. Derived from the *Thymus vulgaris* L. plant, thyme oil possesses a range of qualities such as fragrance, antiseptic, antioxidative, antibacterial, antifungal, antiviral, antispasmodic, and antitussive properties, and it has been employed in traditional medicine to address numerous health issues. The name thyme comes from the Greek word 'thumus', which translates to smell. *Thymus vulgaris* is a blooming plant belonging to the mint family *Lamiaceae*, commonly referred to as *Ajwain*. Fabric treated with thyme essential oil creates a microclimate for the wearer and regulates the release of essential oil through friction and bodily movement, significantly impacting the health and well-being of the individual wearing it (Senem *et al.*, 2018) [22].

The integration of fragrant essential oils into textiles increases their appeal for fashion consumers who are focused on both aesthetics and the therapeutic and health-related advantages. Nonetheless, the ongoing challenge of scent retention in fabrics over time and through multiple washes poses a significant issue for both researchers and consumers (Wang *et al.*, 2009) [32]. Consequently, microencapsulation has emerged as a promising approach to address this problem. Microencapsulation involves the encapsulation of active and volatile substances, resulting in micro or nano-sized capsules. This method may help safeguard the core elements from external factors while also offering innovative applications and controlled release characteristics (Zhao *et al.*, 2019) [33].

Essential oils can penetrate the skin, allowing aroma textiles to deliver these oils through the surface of human skin with a unique scent. Textiles, being familiar companions to humans, can support aromatherapy wherever it is needed. Various materials, including fibers, textiles, non-fabrics, and garments, can be utilized to experience the therapeutic and emotional advantages of fragrance oil-treated fabrics. Different fabrics absorb oils and aromas in various manners, and protein fibers are considered excellent mediums for transferring and retaining fragrances for longer durations. Wool, a natural protein fiber, has a polymer structure comprising salt linkages and hydrogen bonds. Hydrogen bonds are relatively weak connections formed between hydrogen and nitrogen atoms, which can be disrupted by water or other substances like fragrance oil, allowing them to penetrate the fiber's polymer structure. Wool exhibits hygroscopic properties and contains a greater number of amorphous regions. Although the scaly structure of wool largely repels water, when water or other substances such as oil and fragrance contact the fiber's surface, they are quickly absorbed and held for an extended time (Silva *et al.*, 2014) [23]. In response, the present research aimed to utilize the fragrant and healing characteristics of thyme essential oil on wool fabric, with the intention of assessing the impact of microencapsulated vetiver essential oil on the treated wool's properties and exploring the longevity of the aromatic treatment on the fabric.

2. Experimental

2.1 Materials

A pure griege woven wool fabric with a count of 59 ends per inch (EPI), 49 picks per inch (PPI), a basis weight of 161 g/m^2, and a thickness of 0.35 mm was obtained from market in Ludhiana, Punjab, India. Thyme essential oil was sourced from Emmbros Overseas Lifestyle Pvt. Ltd. located in Haryana, India. Wall components (gum acacia and gelatin), a softer (silicon), and a binder (βeta-cyclodextrin) were supplied by chemical vendors in Haryana, India. The investigation utilized acetic acid, formalin, sodium hydroxide, and a wetting agent known as Ultravon JU.

2.2 Preparation of Fabric

The wool fabric was scoured with a neutral wetting agent (2 g/l) at 60 °C for an hour, maintaining a material to liquor ratio of 1:20 and a pH of 7, while being stirred occasionally. The scoured fabric acted as a control and reference point. The physical and functional properties of the scoured wool fabric were assessed and compared with those of the aroma-treated wool fabric (Singh *et al.*, 2002) [25].

2.3 Preparation of Vetiver Oil Microcapsules

Microcapsules were produced using the complex coacervation method. Various experiments were conducted to optimize the parameters for gel formation in the microcapsules, such as the ratios of essential oil, gum, and gelatin, as well as temperature and pH, to achieve the desired results. The microencapsulation process was refined based on a visual assessment of three features under an inverted microscope: the size of the microcapsules, the uniformity of their size and distribution, and the quality of the microcapsule walls. A total of 16 g of gelatin was measured, dissolved in 25 ml of warm water, and mixed for 10 minutes with a high-speed stirrer. The solution was combined with 4 g of vetiver oil at a temperature of 45 °C. Separately, 16 g of gum acacia was weighed and dissolved in 25 ml of warm water. This gum acacia solution was mixed into the gelatin solution while maintaining the temperature at 45 °C. After adding dilute acetic acid and stirring vigorously for 20 minutes, the solution's pH was adjusted down to 4.5. To create the microcapsule gel, sodium hydroxide was added to increase the pH of the solution to 8.5. Finally, to stabilize the microcapsules, 1 ml of 17 percent alcoholic formalin was applied to the capsules produced (Kumari *et al.*, 2018) [11]. The microcapsules were then applied on the wool fabric.

2.4 Application of Microcapsules on Wool Fabric

Research was conducted to establish a standardized protocol for applying microencapsulated vetiver oil to wool fabric using the pad-dry-cure technique. Various concentrations and parameters were adjusted based on the observation of microcapsules on the fabric, viewed through a stereo zoom microscope, which led to enhanced wash durability and improvements in properties like bending length, flexural rigidity, and crease recovery angle. Initially, the scoured wool fabric was treated with a padding solution containing optimum levels of microcapsule gel, softener, and binder, specifically 60, 2, and 10 g/l, respectively, while keeping a material to liquor ratio of 1:20. Subsequently, the fabric underwent fragrance treatment for an ideal duration of 30 minutes at a temperature of 35 °C. The treated cloth was then processed between the rollers of the padding mangle under a pneumatic pressure of 2 kg/cm², undergoing two dips and nips to achieve an expressivity of 80-90 percent. Finally, the fabric was dried at a temperature of 70 °C for 4 minutes before being cured at 100 °C for 60 seconds (Thilagavathi *et al.*, 2007; Kumari, 2015) [29, 12].

2.5 Characterization

A Philips XL-30 Scanning Electron Microscope (SEM) was utilized to examine the morphology of the treated cloth at an accelerating voltage of 10 kV. The resolution was set at 20 µm, and the magnification varied between 800 and 1000X. Fabric samples that had been treated, with a diameter of 10 mm, were secured on a circular metallic sample holder that remained inside the SEM apparatus for observation at different magnifications. Images were captured during this process. The enlarged photographs confirmed the presence of microcapsules on the wool fabric. Micrographs of both scoured and aroma-treated fabrics were analyzed to identify the presence of microcapsules and to observe the surface morphological features. Fourier Transform Infrared Spectroscopy (FTIR) was employed to analyze the interactions and chemical absorption in the scoured and aroma-treated fibers. The fabrics were ground into a powder and then placed into the FTIR instrument. The transmittance spectrum was recorded across the range of 800 to 3800 cm^{-1}. The FTIR analysis disclosed the presence of various functional groups in the scoured and aroma-treated wool fibers.

2.6 Testing of Physical Properties

The preliminary properties of scoured and aroma-treated wool fabrics were assessed using three factors: fabric count, weight, and thickness. The fabric count of the wool was measured following the ASTM-D123 test procedure with a pick glass and a pointer. The weight for one square meter of fabric was calculated using the ASTM-D3776-90 method, which involves multiplying the weight of the specimen in grams by 100. A digital thickness gauge was employed to assess the thickness of the fabrics according to the ASTM-D 1777-60 standard. Mechanical properties such as bending length, flexural rigidity, tensile strength, and elongation were evaluated. The bending length and flexural rigidity of the fabrics were assessed using a stiffness tester based on the ASTM-D 1388-64 testing method. Flexural rigidity was calculated using Equations 1 and 2.

Flexural rigidity in warp and weft direction (G_1 and G_2) = $W \times C^2 mg - cm$ (1)

Where, W is the weight per unit area of the fabric in milligrams per square centimeter; C is the mean bending length for the respective direction.

Overall Flexural rigidity $(G) = \sqrt{G_1 \times G_2}$ (2)

A Digital Tensile Strength Tester was utilized to assess the tensile strength and elongation of both scoured and treated wool fabrics, following the IS: 4169 standard test procedure. The performance properties that were evaluated included moisture regain, wickability, water absorbency, crease recovery angle, and air permeability. Moisture regain was assessed using the BS1051:1960 testing method. The wickability was measured in accordance with the AATCC 1945 standard testing method. To determine the water absorbency of the scoured and treated fabrics, a drop test was conducted. The Crease Recovery Tester evaluated the fabric's crease recovery performance utilizing the BS3086:1972 testing method. Fabric air permeability was examined using an Air Permeability Tester that adhered to the Kawa bata KES-F8-API testing method, referenced by ASTM D737. The average of five readings was calculated for each feature, which were then statistically analyzed using the paired t-test.

2.7 Testing of Functional properties

The properties of wool fabrics that have been scoured and given aroma treatment were investigated for their effectiveness against moths. Samples measuring 1.5×5 cm were taken from both types of textiles and placed in separate poly petri dishes containing 10 adult carpet beetle moths. These petri dishes were kept in an incubator for 15 days at temperatures between 30-35 °C and relative humidity levels of 50-65 percent. After the incubation period, the living and deceased moths were counted. Subsequently, the moths were removed, and the fabric samples were washed and conditioned for a duration of 24 hours (Kumar *et al.*, 2015) [19]. Additionally, the fabrics were evaluated for their antibacterial properties using a standardized quantitative method, the AATCC Test Method 100. Measurements for the zone of inhibition, Colony Forming Units (CFU), and the percentage reduction in bacterial count were recorded. The Ultraviolet Protection Factor (UPF) of both scoured and treated fabrics was assessed using the SDL UV penetration and protection measurement system (Compsec M 350 UV-Visible Spectrometer) along with the UVR TRANSMISSION AATCC-183:2004 test method. The UV protection classification was determined based on the UPF values outlined in the Australian/New Zealand Standards AS/NZS4399 (1996).

2.8 Assessment of Aroma Durability

2.8.1 Retention of Aroma

The aroma treated wool fabrics were assessed qualitatively for aroma retention by a panel of 25 experts using olfactory analysis after being subjected to various factors, including washing, abrasion, ironing, and sun-drying. Each expert took a 3x3 cm section of the treated fabric and evaluated it for aroma. Prior to the evaluation, the samples were hung outside in a room for an hour to allow fragrance evaporation to slow down. To maintain fairness in the assessment, experts were prohibited from entering the stabilization room, and the samples were presented to them. For fragrance detection, a sample was placed on a desk, and the expert used their fingernail to mark an 'X' on the sample, breaking some capsules to release the scent for smelling the swatch. The feedback was documented as 'Yes' or 'No' (Kumari, 2015) [12].

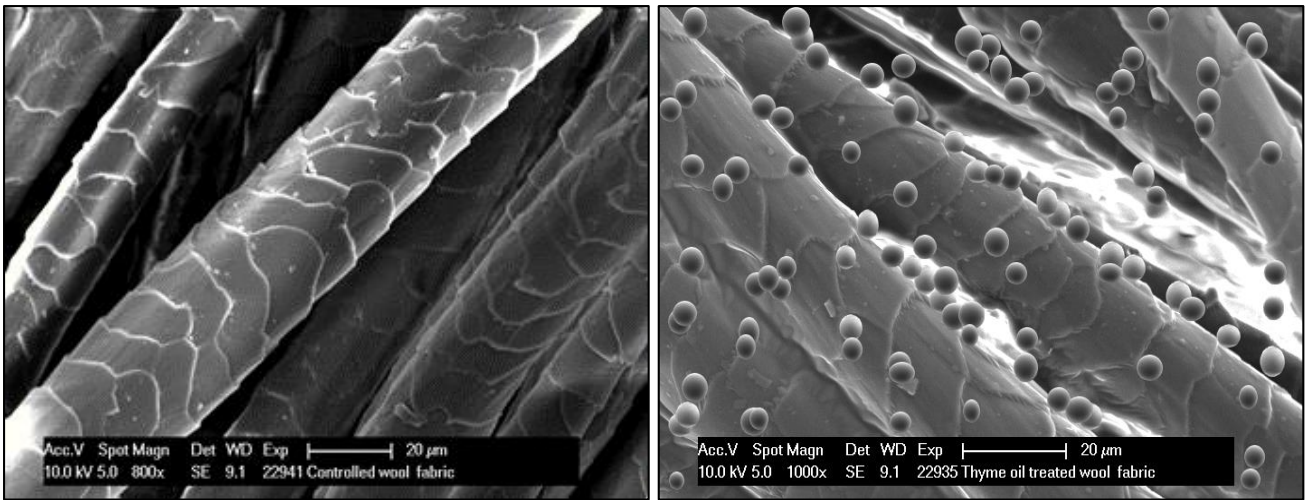
2.8.2 Intensity of Aroma

The fabrics that were treated were also assessed for their aroma intensity. Sensory evaluation by 25 experts was used to determine the change in aroma intensity. This assessment utilized a five-point scale, with ratings ranging from very strong (5) to strong (4), moderate (3), mild (2), and faint (1). To analyze how these conditions influenced aroma performance, the aroma was tested following different washing cycles (5, 10, 15, 20, 25, and 30), abrasion cycles (10, 50, and 100), ironing durations (1, 5, and 10), and sun-drying periods (1, 2, and 3 hours). The experimental results were analyzed using frequencies, percentages, and weighted mean scores (WMS).

3. Results and Discussion

3.1 Scanning Electron Microscopic Analysis of Aroma Treated Wool Fabric

The scoured and aroma treated wool fabrics aroma were analyzed using a scanning electron microscope (SEM) to observe any alterations in surface morphology due to the application of thyme essential oil. Figure 1 illustrates that many spherical microcapsules of uniform size were attached to the wool fabric, which were believed to encapsulate thyme essential oil within their structure. The results are in line with the studies of Petrulyte *et al.* (2017) [16], Sannapapamma *et al.* (2018) [20], Lim and Setthayanond (2019) [13] and Stan *et al.* (2019) [26] that numerous microcapsules of spherical shape and size were found deposited on the surface of aroma treated wool fabric.



(a) (b)

Fig 1: SEM images of wool fabric (a) scoured and (b) treated

3.2 Fourier Transform Infrared Spectroscopy Analysis of Aroma Treated Wool Fabric

The spectral analysis of scoured and aroma-treated fabrics revealed the existence of various functional groups, such as primary amine, alkyl aryl ether, methine, nitro compound, cyclic alkene/amide, methine, and alcohol/amine. Additionally, it was noted that there was a minor shift in the peaks of functional groups from 1066 to 1022 cm-1, 1235 to 1259 cm-1, 1451 to 1448 cm-1, 1517 to 1518 cm-1, 1628 to 1625 cm-1, 2936 to 2962 cm-1, and 3281 to 3278 cm-1 in the aroma-treated fabrics, which was believed to contribute to the changes in properties observed in Fig. 2. Biswas *et al.* (2015) [6] also carried out FTIR analysis of untreated and aroma treated jute fabrics for their comparative analysis. It was noticed that there was a slight shift in band/peaks of functional groups untreated to aroma treated jute fabric.

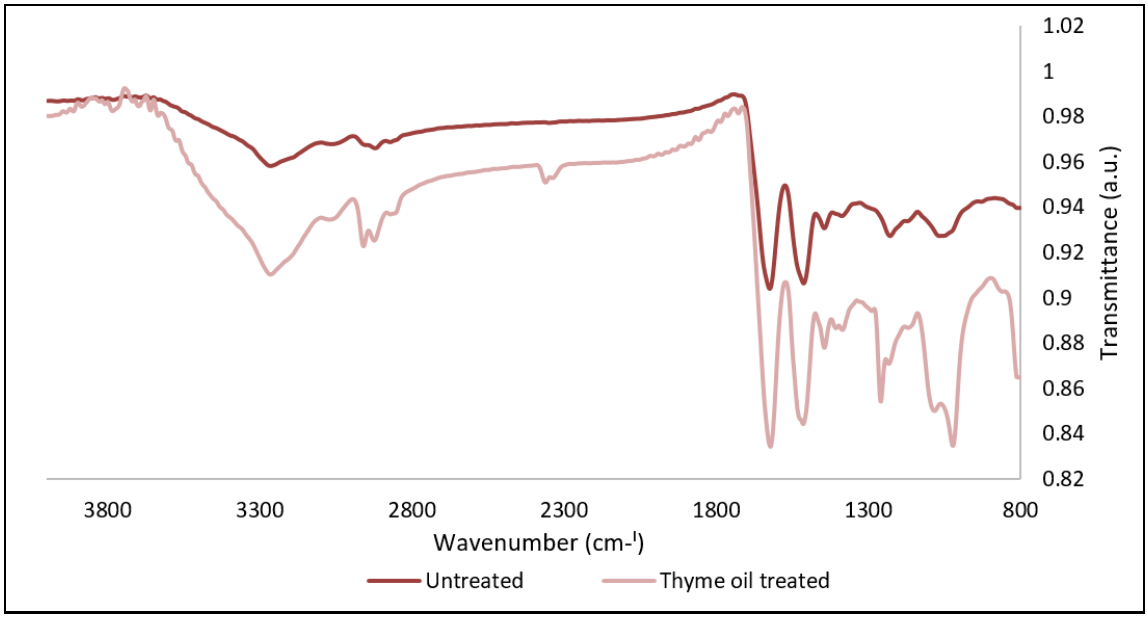


Fig 2: FTIR spectra of wool fabric

3.3 Effect of Aroma Treatment on Preliminary and Mechanical Properties of Wool Fabric

Table 1 displays the preliminary properties of scoured and aroma-treated wool fabrics. The scoured fabric features 55×45 ends and picks per inch in both the warp and weft directions, respectively. After aroma treatment, the fabric count was increased to 65×54 ends and picks per inch in the warp and weft directions, respectively. The table further

indicates that following the aroma treatment of scoured fabric using microencapsulated thyme essential oil, the average weight and thickness of the fabric rose from 152.40 to 165.20 g/m² and from 0.456 to 0.500 mm. A statistically significant difference (p<0.05) was observed in fabric count and weight between the treated fabrics. The increase in preliminary properties may be linked to the fragrance finish application, which caused fabric shrinkage and brought the warp and weft threads closer together. It may also result from the presence of multiple microcapsules on the fabric surface, along with the incorporation of other auxiliaries like beta-cyclodextrin and silicon softener in the treatment solution. The results are in agreement with the findings of Bhatt (2012) [5], Annapoorani *et al.* (2016) [2] and Naikwadi and Sannapapamma (2018) [14] that there was a slight increase in fabric weight, count and thickness of microencapsulated fabric as compared to scoured (untreated) fabric.

Table 1: Effect of aroma treatment on preliminary and mechanical properties of wool fabric

Fabric	Weight g/m²	Count EPI and PPI		Thickness mm	Bending Length cm		Flexural rigidity mg-cm	Tensile strength kg		Elongation %	
		Warp	Weft		Warp	Weft		Warp	Weft	Warp	Weft
Scoured	152.4	55	45	0.4	4.3	2.4	17.02	27.0	20.7	25.9	22.6
Treated	165.2	65	54	0.5	4.7	2.8	23.05	36.2	30.8	35.2	29.7
t-value	5.0*	5.2*	2.8*	0.009	7.4*	6.6*	-	4.8*	2.8*	5.2*	3.0*
*Significant at 5% level of significance.											

Table 1 presents the mechanical characteristics of the fabrics. The average bending length of the scoured fabric measured 4.3 cm in the warp direction and 2.4 cm in the weft direction; however, after undergoing aroma treatment, it increased to 4.7 cm in the warp and 2.8 cm in the weft direction. A notable difference (p<0.05) was observed in the bending length of the treated fabric. The rise in bending length and flexural rigidity of the aroma-treated wool fabric may be due to the accumulation of microcapsules and binder on the fabric, which hardened the treated material. Similar findings were reported by Teli and Chavan (2015) [28] and Lim and Setthayanond (2019) [13] that after application of aroma treatment, bending length and flexural rigidity values increased that indicated slight increase in fabric stiffness.

Following the fragrance treatment, the tensile strength of the scoured fabric rose from 27.0 to 36.2 kg in the warp direction and from 20.7 to 30.8 kg in the weft direction. The elongation of the scoured wool fabric was initially 25.9 percent in the warp direction and 22.6 percent in the weft direction, but after applying thyme essential oil, it increased to 35.2 percent in the warp and 29.7 percent in the weft. The aroma treatment caused notable changes (p<0.05) in both tensile strength and elongation measurements. This may be attributed to a decrease in the projected fibers within the wool fabric, leading to a more compact cloth. Additionally, beta-cyclodextrin seemed to diminish the limitations on the segmental movement of the fibers, thereby improving tensile strength These results are in line with earlier reports of Khanna *et al.* (2015) [8] and Singh *et al.* (2017) [24] that tensile strength of fabric treated with essential oil increased as compared to untreated fabric.

3.4 Effect of Aroma Treatment on Performance Properties of Wool Fabric

Table 2 illustrates the performance characteristics of scoured and aroma-treated textiles. The moisture regain of the scoured fabric was recorded at 11.0 percent, but after being treated with microencapsulated thyme essential oil, it decreased to 9.0 percent, indicating a reduction of 8.18 percent. The table further indicates that following the thyme essential oil treatment, the wickability of the scoured fabric fell from 6.2 to 4.1 cm in the warp direction and from 6.1 to 4.0 cm in the weft direction. The water absorbency of aroma-treated fabric also declined, as evidenced by a drop test that extended the time required for water absorption from less than 51 seconds to less than 75 seconds. The duration for water absorption in the treated fabric increased by 47.05 percent. There was a statistically significant difference in wickability and water absorbency for the fragrance-treated wool fabric at the 5% level of significance. The reduction in these properties of the treated fabric can be explained by the fragrance treatment applied to the scoured fabric, which led to blocked pores due to the increased surface deposition of microcapsules. Rathinamoorthy and Thilagavathi (2013) [17] and Janarthanan and Kumar (2017) [7] also noticed decrease in these properties after aroma treatment.

Table 2 demonstrates that the crease recovery angle of scoured wool fabric measured 148.00° in the warp direction and 88.33° in the weft direction. However, after aroma treatment with microencapsulated thyme essential oil, these values decreased to 141.67° in the warp and 82.33° in the weft direction. Statistical analysis at the 5% significance level indicated that there was no notable change in the crease recovery angle in either direction for the aroma-treated wool fabric. The reduction in crease recovery angle might be attributed to the presence of numerous microcapsules adhering to the surface of the fabric, which could have increased its stiffness. The results are in line with Sukumar and Lakshmikantha (2010) [27], Kumari (2015) [12] and Naikwadi and Sannapapamma (2018) [14] that there was decrease in crease recovery of microencapsulated fabric as compared to untreated fabric.

Table 2: Effect of aroma treatment on performance properties of wool fabric

Fabric	Moisture regain %	Wickability cm		Water absorbency sec	Crease recovery angle degree		Air permeability CFM
		Warp	Weft		Warp	Weft	
Scoured	11.0	6.2	6.1	**<51**	148	88	251
Treated	09.0	4.1	4.0	<75	141	82	382
t-value	-	4.1*	4.6*	4.9*	0.04	0.07	6.2*
*Significant at 5% level of significance.							

The table shows that following treatment with thyme essential oil, the air permeability of scoured wool fabric rose from 251 to 382 CFM, reflecting a notable increase of 52.80 percent in the air permeability of the treated fabric. At the 5 percent significance level, a significant enhancement in air permeability was observed in the aroma-treated wool fabric. Thite and Gudiyawar (2015) [30] observed that air permeability of cotton fabric increased after application of microencapsulated mosquito repellent essential oils. The higher air permeability of treated cotton fabrics might be due to the hairs clinging on the yarn surface and allowing more pores area for the air to pass.

3.5 Effect of Aroma Treatment on Functional Properties of Wool Fabric

The effectiveness of wool fabric treated with microencapsulated thyme essential oil against moths was demonstrated through weight loss measurements. The wool fabric exposed to aroma treatment experienced a weight reduction of 08.1 percent, while the scoured wool fabric exhibited a weight loss of 11.8%, as indicated in Table 3. Additionally, it was observed that after 15 days of incubation, only 05 (50%) moths remained alive on the aroma-treated fabric sample, in contrast to 09 (90%) moths on the scoured fabric sample. Udakhe *et al.* (2014) [31] also inferred that the microcapsule treated samples performed better when tested along with the untreated samples as the moth preferred eating untreated samples than their treated counterpart. It can further be derived from Table 3 that when tested for antibacterial properties in terms of zone of inhibition, the scoured wool fabric showed no activity against *Staphylococcus aureus* and *Escherichia coli*, whereas the thyme essential oil treated fabric showed weak antibacterial activity, with 3.0 and 3.6 zone of inhibition for *Staphylococcus aureus* and *Escherichia coli*.

Table 3: Effect of aroma treatment on functional properties of wool fabric

Fabric	Moth mortality %	Weight loss %	*Staphylococcus aureus*			*Escherichia coli*			UPF
			Zone of inhibition (mm)	Bacterial count (CFU/ml)	Percent reduction	Zone of inhibition (mm)	Bacterial count (CFU/ml)	Percent reduction	
Scoured	10	11.8	-	31.33×10^8	-	-	35.33×10^8	-	30.25
Treated	50	08.1	3.0	1.19×10^8	71.20	3.6	3.14×10^8	67.71	42.31

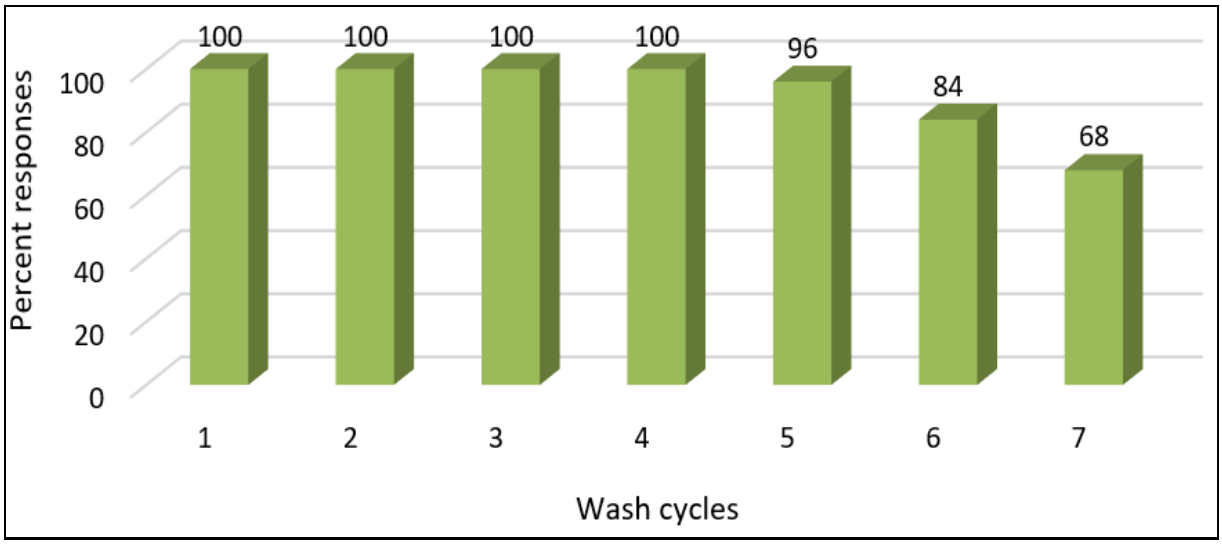
The research also indicated that the fabric that underwent treatment exhibited a reduced bacterial count compared to the scoured fabric, showing reductions of 71.20 percent for *Staphylococcus aureus* and 67.71 percent for *Escherichia coli* in bacterial growth, respectively. Similar findings were reported by Agili (2014) [1], Bansal and Kaur (2016) [3] and Senem *et al.* (2018) [22] that essential oils imparted good antibacterial activity in the treated fabric. The information presented in Table 3 indicates that scoured wool fabric achieved a UPF value of 30.25, categorizing it as providing very good protection, while the aroma-treated fabric registered a UPF value of 42.31, placing it in the excellent protection category. The increased weight and thickness of the treated fabric likely resulted in the blockage of the pores between the interstices, which may explain the improved UPF value.

3.6 Assessment of Aroma Durability

The aroma durability after exposing to different conditions i.e. washing, abrasion, ironing and sun-drying was assessed for the retention and intensity of aroma in the treated wool fabric.

3.6.1 Retention of Aroma

Figure 3(a) indicates that the aroma remained intact even after 30 washing cycles in wool fabric treated with thyme essential oil, as reported by 68 percent of respondents. This could be attributed to the protective wall of microcapsules that encases the thyme essential oil, safeguarding it from external environmental factors while also enabling a controlled release to prolong its lifespan. The aroma was observed to diminish as the number of abrasion cycles increased. It was maintained up to 10 abrasion cycles, as reported by 100 percent of respondents [Fig. 3(b)].



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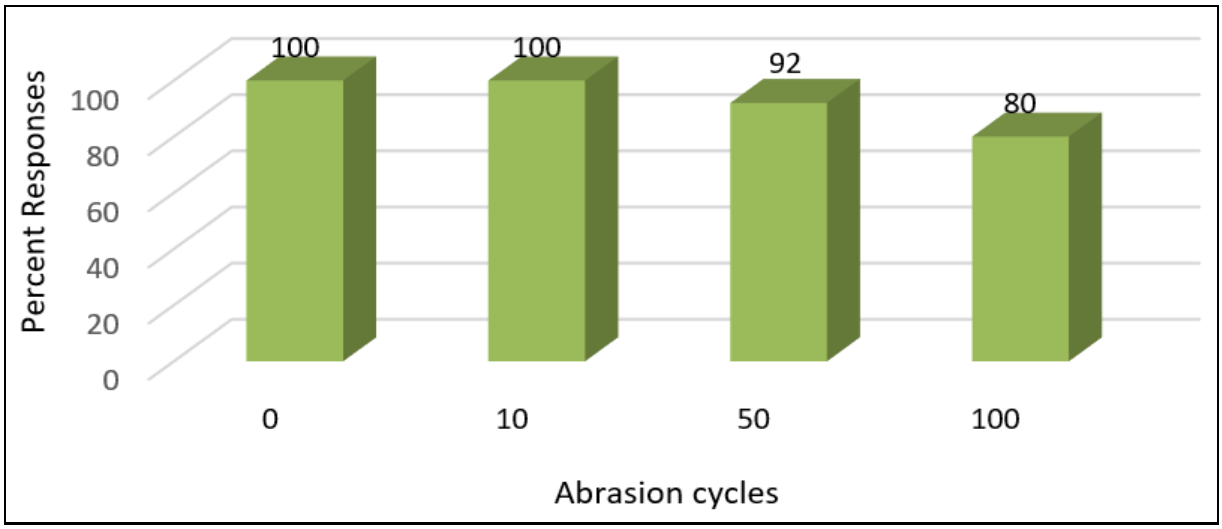

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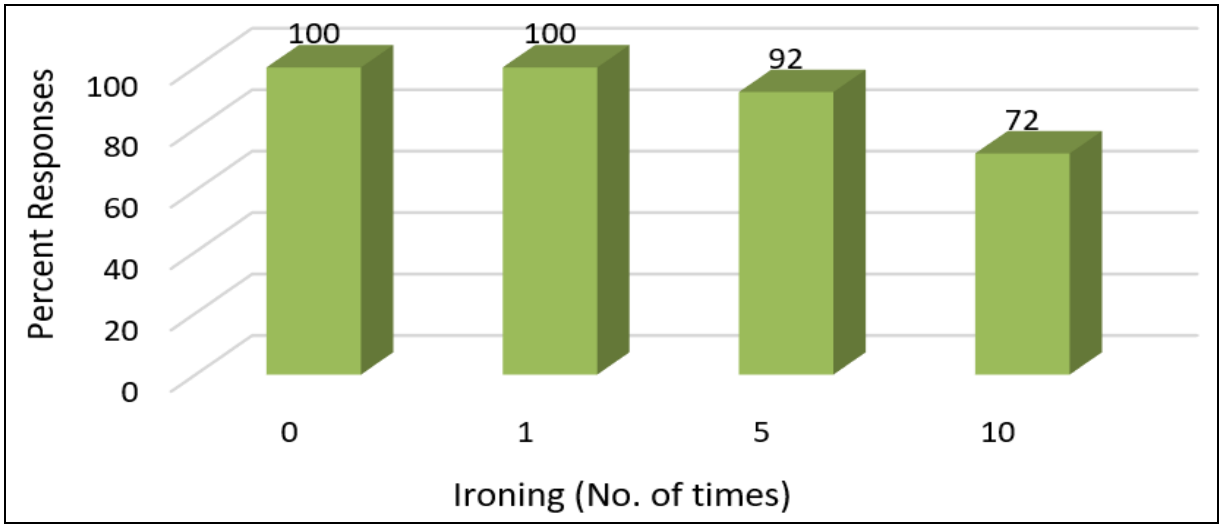

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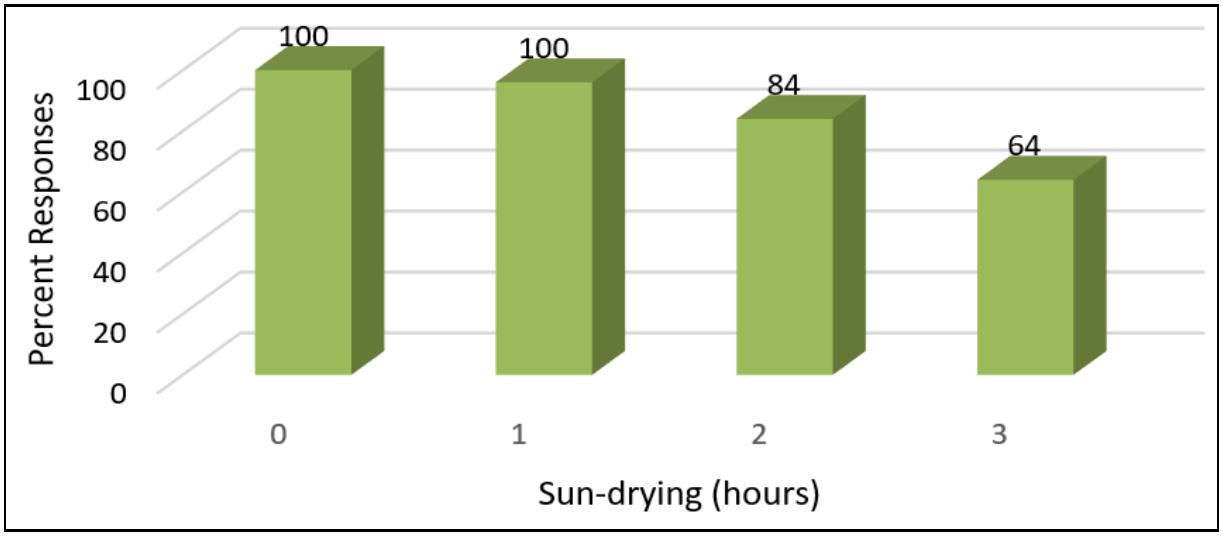


(d)

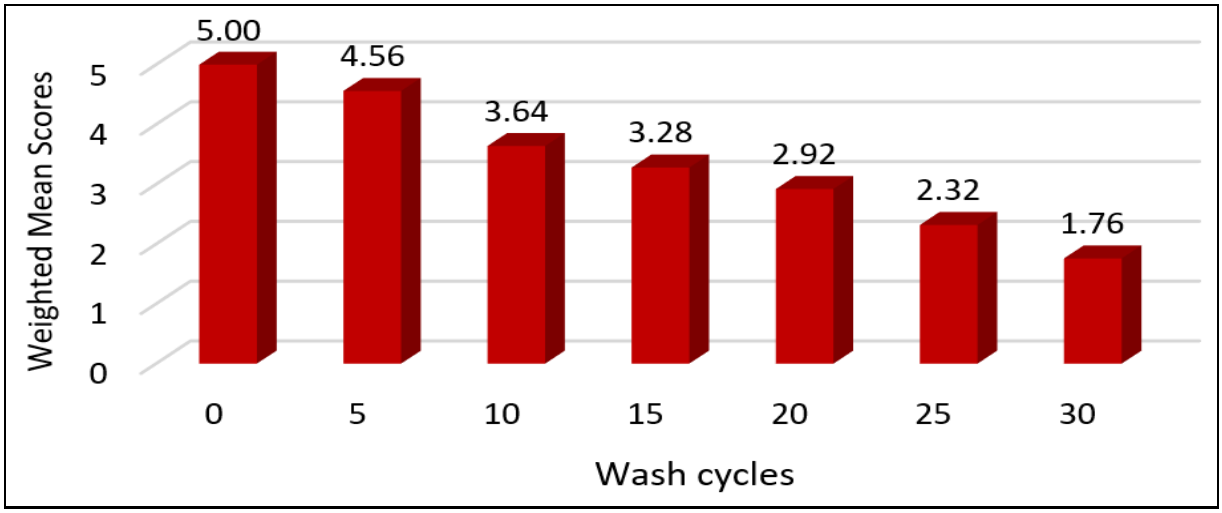
Fig 3: Retention of aroma in treated fabric after (a) washing, (b) abrasion (c), ironing and (d) sun-drying

It is additionally noted from Fig. 3(c) that as the number of ironing sessions increased from 1 to 10, the retention of aroma decreased, although 72 percent of respondents confirmed that aroma persisted in the aroma-treated wool fabric after undergoing 10 ironing cycles. It was observed that prolonging the hours of sun-drying led to a decrease in aroma retention. All respondents (100%) indicated that the aroma was preserved in the aroma-treated wool fabric after one hour of sun-drying, and 64 percent acknowledged that the aroma remained in the treated fabric after three hours of

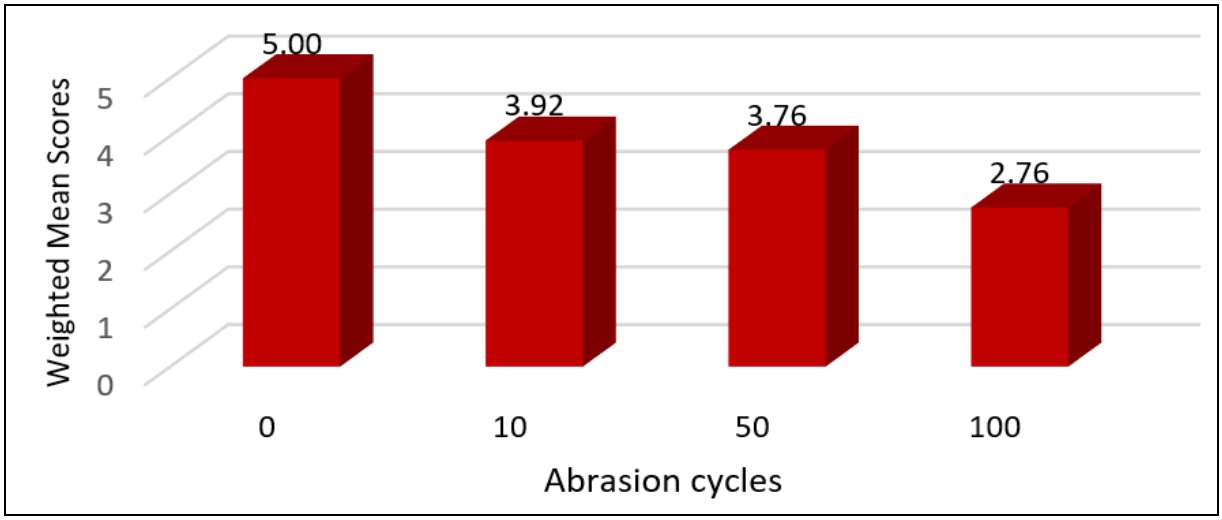
sun-drying [Fig. 3(d)]. The results are found in agreement with Bhatt *et al.* (2016) [4], Zhao *et al.* (2016) [33] and Stan *et al.* (2019) [26] that retention of aroma gradually decreased as the exposure to these agencies increased.

3.6.2 Intensity of Aroma

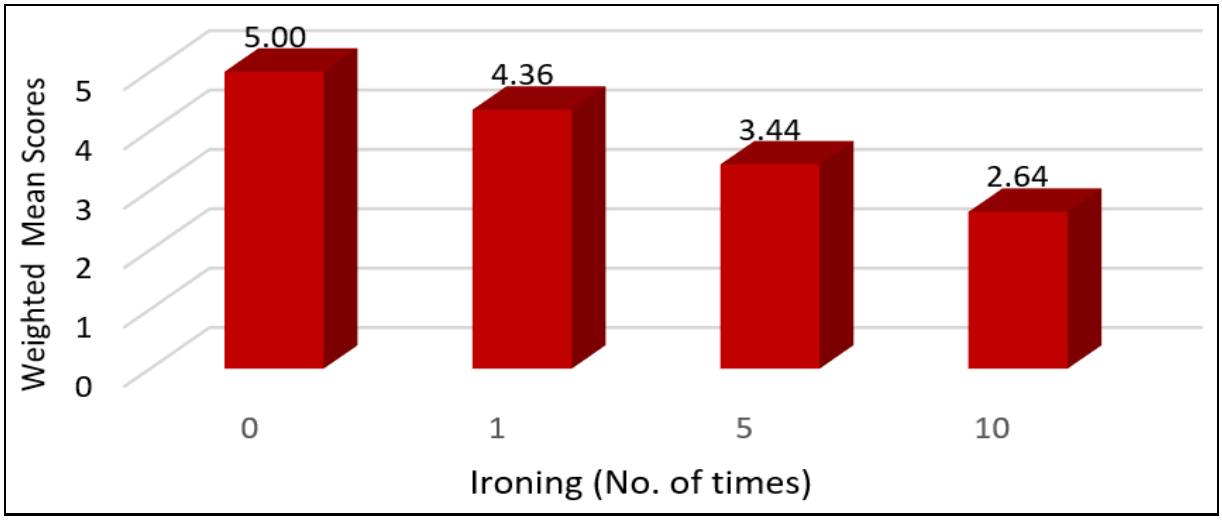
Figure 4(a) illustrates that the strength of the aroma from the treated wool fabric was quite potent after five wash cycles, then was categorized as strong, moderate, mild, and finally became faint after 10, 15, 20, 25, and 30 wash cycles. The aroma intensity in the treated wool fabric samples diminished as the number of abrasion cycles increased. After 10 and 50 abrasion cycles, the aroma intensity was assessed as strong, while it was moderate after 100 abrasion cycles [Fig. 4(b)].



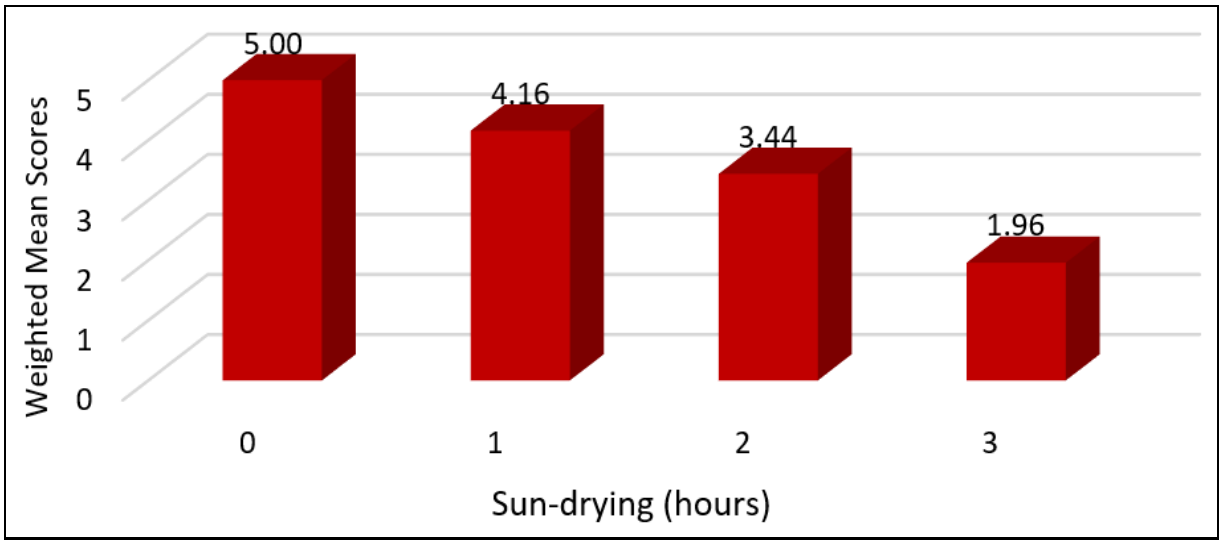
(a)



(b)



(c)



(d)

Fig 4: Intensity of aroma in treated fabric after (a) washing, (b) abrasion (c), ironing and (d) sun-drying

Figure 4(c) shows that the aroma intensity in the treated sample that had undergone one ironing session was very strong. It then transitioned to strong and moderate after five and ten ironings, respectively. It was found that exposure to sunlight led to a reduction in aroma intensity. The aroma was rated as strong in the treated fabric sample that had been sun-dried for one hour, then as moderate and eventually mild when the treated wool fabric was dried in the sun for two and three hours, respectively [Fig. 4(d)]. The results of study are supported by the findings of Biswas *et al.* (2015) [6] and Bhatt *et al.* (2016) [4] that intensity of aroma in essential oil treated samples reduced gradually as with each wash cycle few microcapsules got washed away from the treated fabric.

4. Conclusion

Wool fabric was treated with microencapsulated thyme essential oil to manage fragrance release and assess its impact on the properties of the fabric. SEM analysis indicated the presence of numerous microcapsules with spherical shapes and uniform sizes on the surface of the treated fabric. FTIR analysis showed the existence of various functional groups at different peaks in the wool fabric that had been treated. The preliminary and mechanical characteristics of the wool fabric improved after the aroma treatment. Following the aroma treatment, the air permeability of the scoured wool fabric increased, while its moisture-related properties and crease recovery angle decreased. The treated fabric displayed superior antimoth efficacy compared to the scoured wool fabric, evidenced by a weight loss of 08.1 percent and moth mortality of 50 percent. The aroma-treated fabric demonstrated significant antibacterial effectiveness against Staphylococcus aureus and Escherichia coli, with reductions in bacterial growth of 71.20 percent and 67.71 percent, respectively. Scoured wool fabric provided very good UV protection (30.25), whereas after aroma treatment, it showed excellent UV protection (42.31). The durability of the aroma, in terms of retention and intensity after exposure to various agents, was found to be very good in the treated fabrics. Therefore, wool fabric can be enhanced with microencapsulated thyme essential oil to create effective textiles that are antibacterial, antimoth, and UV protective with aroma features. Thyme essential oil is reputed to have multiple medicinal benefits, which means that wool fabric treated with microencapsulated thyme essential oil can be utilized in garments, home textiles, and healthcare applications. Given that wool fabric is highly hygroscopic, it absorbs more aroma and retains it for an extended period, making it particularly suitable for the creation of aroma textiles. Consequently, microencapsulation has been recognized as a highly effective technology for delivering a long-lasting scent finish on wool fabric by regulating the release rate of microencapsulated thyme essential oil.

5. References

1. Agili FA. Chemical composition, antioxidant and antitumor activity of *Thymus vulgaris* L. essential oil. Middle-East Journal of Scientific Research. 2014;21(10):1670-1676.
2. Annapoorani SG, Nivedha RB, Devi SY. Development of disposable baby diaper with microencapsulated natural fragrance finish. International Journal of Applied Research. 2016;2(7):685-687.
3. Bansal T, Kaur H. Benefits of essential oil. Journal of Chemical and Pharmaceutical Research. 2016;8(6):143-149.
4. Bhatt L, Singh SSJ, Rose NM. Durable aroma finish on cotton using microencapsulation technology. Journal of Cotton Research and Development. 2016;30(1):156-160.
5. Bhatt L. Microencapsulation of essential oil on cotton [MSc thesis]. Hisar: CCS Haryana Agricultural University; 2012.
6. Biswas D, Chakrabarti SK, Saha SG, Chatterjee S. Durable fragrance finishing on jute blended home-textiles by microencapsulated aroma oil. Fibres and Polymers. 2015;16(9):1882-1889.
7. Janarthanan M, Kumar MS. Novel improvement of bioactive microencapsulated textile products using brown seaweed for healthcare applications. International Journal of Clothing Science and Technology. 2017;29(2):26-32.
8. Khanna S, Sharma S, Chakraborty JN. Performance assessment of fragrance finished cotton with

cyclodextrin assisted anchoring hosts. Fashion and Textiles. 2015;2(19):1-17.
9. Kumar A, Pareek PK, Kadam VV, Shakyawar DB. Anti-moth efficacy of neem (*Azadirachta indica* A. Juss.) on woollen fabric. Indian Journal of Traditional Knowledge. 2015;15(2):272-277.
10. Kumar DV, Boopathi N, Karthick N, Ramesh P. Aesthetic finish for home textile materials. International Journal of Textile Sciences. 2012;1(3):5-9.
11. Kumari P, Rose NM, Singh SSJ. Microencapsulation: Use of geranium oil for aroma finishing of woven cotton fabric. Indian Journal of Health and Wellbeing. 2018;9(3):45-53.
12. Kumari P. Development of aroma textiles using essential oils [PhD thesis]. Hisar: CCS Haryana Agricultural University; 2015.
13. Lim P, Setthayanond J. Factors affecting release of microencapsulated essential oils from finished silk fabric for automotive and aroma textile products. International Journal of Engineering and Advanced Technology. 2019;8(3):501-504.
14. Naikwadi S, Sannapapamma KJ. Effect of treatment and method of application on mechanical properties of vetiver finished organic cotton fabrics. Journal of Farm Science. 2018;31(2):183-187.
15. Naikwadi S, Sannapapamma KJ, Venugopal CK. Optimization of vetiver root extract for textile finishing. International Journal of Current Microbiology and Applied Science. 2017;6(10):2009-2022.
16. Petrulyte S, Plascinskiene D, Petrulis D. Impregnation of microencapsulated aroma oil on ramie blended terry textile and its bending rigidity. Fibres and Textiles in Eastern Europe. 2017;25(124):95-101.
17. Rathinamoorthy R, Thilagavathi G. Antimicrobial and in-vitro drug release studies of microencapsulated *Terminalia chebula* extract finished fabric. International Journal of PharmTech Research. 2013;5(3):894-905.
18. Salehi B, Mishra AP, Shukla I, Rad MS, Contreras MDM, Carretero AS, *et al*. Thymol, thyme and other plant sources: Health and potential uses. Phytotherapy Research. 2018;2(1):1-19.
19. Sanjay R, Malpani. Antibacterial treatment on cotton fabric from neem oil, aloe vera and tulsi. International Journal of Advance Research in Science and Engineering. 2013;2(7):35-43.
20. Sannapapamma KJ, Lokanath HM, Naikwadi S. Antimicrobial and aroma finishing of organic cotton knits using vetiver oil microcapsules for health care textiles. International Journal of Materials and Textile Engineering. 2018;12(2):82-93.
21. Sayed U, Sharma K, Parte S. Application of essential oils for finishing of textile substrates. Journal of Textile Engineering and Fashion Technology. 2017;1(2):42-47.
22. Senem K, Guldemet B, Figan O, Atac U. Preparation of thyme oil loaded microcapsules for textile applications. International Journal of New Technology and Research. 2018;4(3):1-8.
23. Silva PTD, Fries LLM, Menezes CRD, Holkem AT, Schwan CL, Wigmann ÉF, *et al*. Microencapsulation: Concepts, mechanisms, methods and some applications in food technology. Ciencia Rural. 2014;44(7):1-8.
24. Singh N, Yadav M, Khanna S, Sahu O. Sustainable fragrance cum antimicrobial finishing on cotton: Indigenous essential oil. Sustainable Chemistry and Pharmacy. 2017;5(1):22-29.
25. Singh SSJ, Pruthi N, Yadav S, Gaba G. Annual report of All India Coordinated Research Project in Home Science (ICAR), Department of Clothing and Textiles, CCS Haryana Agricultural University, Haryana. 2002. p. 7.
26. Stan MS, Chirila L, Popescu A, Radulescu DM, Radulescu DE, Dinischiotu A. Essential oil microcapsules immobilized on textiles and certain induced effects. Materials. 2019;12(12):1-15.
27. Sukumar N, Lakshmikantha CB. Methods of encapsulation and their evaluation of the natural aromatic oils in textile material. Indian Journal of Applied Sciences. 2010;56(11):56-69.
28. Teli MD, Chavan PP. Encapsulation of aroma and its application on cotton to impart mosquito repellency. Asian Dyer. 2015;12(3):45-49.
29. Thilagavathi G, Bala SK, Kannaian T. Microencapsulation of herbal extracts for microbial resistance in healthcare textiles. Indian Journal of Fibre and Textile Research. 2007;32(9):351-354.
30. Thite AG, Gudiyawar MY. Development of microencapsulated ecofriendly mosquito repellent cotton finished fabric by natural repellent oils. International Journal of Science Technology and Management. 2015;4(11):166-174.
31. Udakhe J, Shrivastava N, Honade S. Fragrance release and moth repellent activity of natural essential oils. Colourage. 2014;11(2):33-38.
32. Wang MJ, Zheng WQ, Zhu H, Zhou Y. Preparation and characterization of natural fragrant microcapsules. Journal of Fiber Bioengineering and Informatics. 2009;1(4):293-298.
33. Zhao H, Fei X, Cao L, Zhang B, Liu X. The fabrication of fragrance microcapsules and their sustained and broken release behavior. Materials. 2019;12(3):1-14.