Original Research Article

Utilization of Microencapsulated Thyme Essential Oil for Aroma Treatment of Wool Fabric

ABSTRACT

Background: With rising global trends and changing lifestyles in terms of fashion, beauty as well as healthcare, awareness of consumers has enforced evolution of speciality value added textiles. Essential oils which are basic ingredients of aromatherapy are microencapsulated and applied on the textiles to provide therapeutic effect and long lasting aromas. The present study was carried out to prepare thyme essential oil microcapsules using complex coacervation technique. The prepared microcapsules were applied on wool fabric using pad-dry-cure method by optimizing various variables of aroma treatment.

Methods: Thyme essential oil was used on the basis of its aromatic and therapeutic properties. Complex coacervation technique of microencapsulation was used for preparation of thyme oil microcapsules. The padding bath components and treatment variables were optimized on the basis of presence of microcapsules on wool fabric as observed under stereo zoom microscope, aroma durability to washing and improvement in properties of treated fabric in terms of bending length, flexural rigidity and crease recovery angle. The aroma treatment was given on wool fabric using pad-dry-cure method.

Result: Optimized variables for aroma treatment were 60 g/l microcapsule gel, 2 g/l softener and 10 g/l binder concentration, 1:20 material to liquor ratio, 35°C temperature and 30 minutes treatment time as at these conditions more number of microcapsules, longer wash durability and better fabric properties in terms of bending length, flexural rigidity and crease recovery angle were observed. Aroma treated wool fabric were dried at 70ºC temperature for 4 minutes and cured at 100°C temperature for 60 seconds.

Conclusions: The thyme essential oil have many reported therapeutic properties therefore microencapsulated thyme essential oil treated wool fabric can be used for apparel, home and healthcare textiles. Higher concentration of microcapsule gel and lower concentrations of softener and binder promoted deposition of maximum number of microcapsules on wool fabric. Complex coacervation technique of microencapsulation for preparation of thyme essential oil microcapsules

and pad-dry-cure method to impart durable aroma treatment on wool are needed to acquire long term sustained finish.

Key words: Thyme essential oil microcapsules, wool fabric, optimization, pad-dry-cure method, aroma treatment

INTRODUCTION

A consumer oriented 21st century challenges garment and fabric manufacturers to come up with revolutions which result from the technological improvement, not only to help in strengthening the existing product but also to diversify and flourish in new areas. New textile technologies have empowered the application of new ingredient on the fabric to provide its functional benefits to the end product (West and Annett-Hitchcock, 2018 and Eyupoglu *et al.*, 2021). Functional finishes from the natural substrates comprises of those substances that are obtained from plants and animals possess many advantages such as non-toxic, non-irritant, biodegradable, cost effective, easy availability etc. Natural oils such as essential oils are being promoted to be used for finishing application due to their good efficacy without any harmful effects (Naikwadi *et al.*, 2017 and Sayed *et al.*, 2022).

Fragrances in form of essential oils and aromatic compounds, when applied on textile materials, give the textile a pleasant odour that gives the wearer maximum beneficial effects. This process is known as aroma finish. The fragrance applied by use of essential oil not only provides a pleasant smell but also the beneficial effect of aromatherapy. Aromatherapy does not cure conditions but help the body to find a natural way to cure itself and improves immune response (Kumar *et al.*, 2021). Aromatic oily liquids called essential or volatile oils are obtained from plant materials. Essential oils extracted from different parts of the same plant may have completely different scents and properties. There are various essential oils used in aromatherapy, for moisturizing, refreshing and other wellness effects (Ahmad *et al.* 2018 and Hamid *et al.*, 2023).

The thyme essential oil is a combination of monoterpenec. The main substance of this oil are phenol isomer carvacrol and have active biological action such as antifungal, antibacterial, antioxidant activity, antitabagism and antispasmodic. Thyme is commonly used as a culinary herb and for different medicinal purposes. Nowadays, thyme present a wide range of functional possibilities in pharmacy, food and cosmetic industry. The interest in the formulation of pharmaceuticals, nutraceuticals and cosmeceuticals based on thyme is due to the treatment of disorders affecting the respiratory, nervous and cardiovascular systems. Thyme essential oil treated fabric creates the microclimate for the wearer and control release of essential oil through friction and movement of body that will play significant role in health and wellness of the wearer (Salehi *et al.* 2019 and Silva *et al.*, 2021).

Textile materials are treated with pleasant odour producing essential oils and aromatic compounds to impart aroma finish so that the wearer gets some valuable effects. Due to their highly volatile nature, these are ineffective to utilize for profitable applications in textile. But microencapsulation technology locks essential oils with fibre in a stable manner. Microencapsulation is a process by which individual particles of an active agent can be stored within a shell, surrounded or coated with a continuous film of polymeric material to produce particles in the micrometre to millimetre range, for protection and/or later release. The unique advantage of microencapsulation lies in that the core material is completely coated and isolated from external environment. Microencapsulation would not affect the properties of core materials, provided that proper shell material and preparing method are chosen (Zhao *et al.*, 2019).

As close friends of human, textiles can make aromatherapy easy wherever these are needed. Among all the natural origin fibres, wool plays a significant role in textile industry. Wool is a natural protein fibre and wool polymer is a linear keratin polymer. Its repeating unit is sulphur containing amino acid linked together with disulphide bonds (Srivastava and Srivastava, 2017). Wool is very absorbent fibre as it contains higher amorphous areas i.e. about 75-70 percent amorphous and 25-30 percent crystalline, however the scaly structure of wool makes it partially water repellent but when moisture or other substances like oil and aroma once penetrate the fibre surface, get absorbed quickly and has good retention for a longer time.

MATERIALS AND METHODS

Materials

Pure griege woven wool fabric having 59.40 ends/inch (EPI), 49.00 picks/inch (PPI), 161 g/m^2 basis weight and 0.350 mm thickness was procured from market of Ludhiana city of Punjab, India. Thyme essential oil was purchased from Emmbros Overseas Lifestyle Pvt. Ltd., Haryana, India. Wall materials i.e. gum acacia and gelatin, softener (silicon) and binder (βeta-cyclodextrin) were provided by chemical suppliers of Haryana, India. Other materials such as acetic acid, formalin, sodium hydroxide and wetting agent (Ultravon JU) were also used in the study.

Preparation of Fabric

The wool fabric was weighed initially and pre-wetting was done for 10-15 minutes. The scouring solution of 2 g/l neutral soap was prepared maintaining the material to liquor ratio 1:20 and pH 7. The fabric was added to the scouring bath and temperature of bath was raised gradually and maintained at $60^{o}C$. The wool fabric was treated for 60 minutes with occasional stirring. The scoured fabric was then rinsed with plain water and dried at room temperature.

Preparation of Thyme Oil Microcapsules

Phase separation-complex coacervation technique of microencapsulation was used for preparation of thyme essential oil microcapsules. For standardization of microencapsulation process, the ratios of essential oil, gum and gelatin, temperature and pH were optimized. The formed microcapsules were examined under inverted microscope and on the basis of size, distribution and quality of wall of capsules, different process variables were optimized. 16 g of gelatin was weighed and dissolved in 25 ml warm water and stirred using a high speed stirrer for 10 minutes. 4 g of vetiver oil was added to the solution at 45^{o}C. 16 g of gum acacia was weighed and dissolved in 25 ml warm water separately. The gum acacia solution was added to the gelatin solution and the temperature of the solution was maintained at 45^{o}C. The pH of the solution was decreased to 4.5 by adding dilute acetic acid and stirred at high speed for 20 minutes. The pH of the solution was increased to 8.5 using sodium hydroxide solution to form microcapsule gel. For stabilization, 1 ml of 17 percent alcoholic formalin was added to the formed capsules.

Standardization of Aroma Treatment for Wool Fabric

For aroma treatment, thyme essential oil microcapsules were applied on wool fabric using pad-dry-cure method. The padding bath components (microcapsule gel, softener and binder) and other treatment variables i.e. material to liquor ratio, treatment temperature and time, drying temperature and time, curing temperature and time were optimized on the basis of presence of microcapsules on wool fabric as observed under stereo zoom microscope, aroma durability to washing and improvement in properties of treated fabric in terms of bending length, flexural rigidity and crease recovery angle. The aroma treatment was given to wool fabric using optimized concentrations and conditions of pad-dry-cure method of finish application.

Optimization of padding bath components

The padding bath was prepared using microcapsule gel, softener and binder. The concentration of padding bath components were optimized on the basis of presence of microcapsules on the fabric as analyzed under stereo zoom microscope.

i. Optimization of microcapsule gel concentration: For determination of optimum concentration of microcapsule gel, four padding bath of different concentrations of microcapsule gel i.e. 30, 40, 50 and 60 g/l were prepared. For giving aroma treatment to wool fabric through pad-dry-cure method, the samples were immersed in the solutions of four different concentrations of microcapsule gel with 5 g/l binder and 1 g/l softener at MLR 1:20 maintaining a temperature of 35^{o}C for 30 minutes with occasional stirring. Afterwards, the fabric was placed on the trough of the padding mangle with padding solution and passed through the squeezing rollers of the padding mangle at pneumatic pressure of 2 kg/cm_2 with two dips and nips having 80-90 percent expression. As the fabric left the padding mangle, it was subsequently dried at 80°C for 5 minutes and cured at 110°C for 1 minute (Thilagavathi *et al.*, 2007 and Kumari, 2015).

ii. Optimization of softener concentration: Four different concentrations of softener i.e. 1, 2, 3 and 4 g/l were taken to optimize the concentration of softener with optimized concentration of microcapsule gel keeping all other variables constant. Padding, drying and curing was carried out and optimized concentration of softener was selected.

iii. Optimization of binder concentration: For optimization of concentration of binder, four different concentrations of binder i.e. 5, 10, 15, and 20 g/l were taken with optimized concentrations of microcapsule gel and softener while all other variables were kept constant. Padding, drying and curing was carried out and optimization of binder concentration was done.

Optimization of material to liquor ratio

To determine optimum material to liquor ratio (MLR) of padding bath, four different material to liquor ratios i.e. 1:20, 1:30, 1:40 and 1:50 were taken using optimum concentrations of microcapsule gel, softener and binder while other variables of pad-dry-cure method were kept constant. The optimum M:L ratio was selected on the basis of presence of microcapsules, wash durability and improvement in properties of treated fabric i.e. bending length, flexural rigidity and crease recovery angle.

Optimization of treatment temperature

The aroma treatment was given to wool fabric at four different temperatures i.e. 25, 35, 45 and 55° C with optimized concentrations (microcapsule gel, softener and binder) and conditions (M:L ratio) while other variables were kept constant. The padding, drying and curing of the fabric was carried out and the temperature exhibiting best results was selected as optimum treatment temperature.

Optimization of treatment time

The treatments were carried out for four different time durations i.e. 20, 30, 40 and 50 minutes using optimized concentrations of microcapsule gel, softener and binder keeping optimized M:L ratio and treatment temperature. On the basis of presence of microcapsules, wash durability and improvement in fabric properties in terms of bending length, flexural rigidity and crease recovery angle, treatment time was optimized for aroma treatment of wool fabric.

Optimization of drying temperature

Drying of treated fabric samples was carried out at four different temperatures i.e. 60, 70, 80 and 90°C for 5 minutes and subsequently cured at 110° C for 1 minute. The drying temperature giving best results was selected as optimum drying temperature.

Optimization of drying time

To determine optimum drying time, fabric samples were treated using optimum concentrations of padding bath components, M:L ratio, treatment temperature and treatment time. The drying of treated samples was carried out for four different time durations i.e. 2, 3, 4 and 5 minutes at optimum drying temperature keeping curing temperature and time constant and optimization of drying time was done.

Optimization of curing temperature

Drying of treated samples was carried out at optimum drying temperature and time and curing treatment was carried out at four different temperature ranges i.e. 100, 110, 120 and 130°C keeping curing time constant and optimization of curing temperature was done.

Optimization of curing time

After application of aroma treatment, the padded samples were dried at optimum temperature and time and cured at optimum temperature for four different durations of curing time i.e. 30, 60, 90 and 120 seconds. On the basis of presence of microcapsules, wash durability and improved properties of aroma treated fabric in terms of bending length, flexural rigidity and crease recovery angle, curing time was optimized.

RESULTS AND DISCUSSION

Optimization of Padding Bath Components

For aroma treatment of wool fabric, padding bath was prepared using microcapsule gel of thyme essential oil, softener and binder. The concentrations of padding bath components i.e. microcapsule gel, softener and binder were optimized on the basis of presence of microcapsules on the treated wool fabric, good aroma retention to washing and improvement in properties of treated fabric.

Optimization of microcapsule gel concentration

The data in the Table 1 and microscopic assessment of the aroma treated fabric (Image 1) indicate that when 50 and 60 g/l concentrations of microcapsule gel were used, many microcapsules were present on surface of the fabric and their wash durability lasted till 20 wash cycles. At 50 g/l concentration of microcapsule gel, bending length (3.25 cm) and flexural rigidity (15.29 mg-cm) were observed more and degree of crease recovery angle was less (114.00^{o}) as analyzed and compared with 60 g/l concentration of microcapsule gel which had decreased bending length (3.22 cm) and flexural rigidity (14.63 mg-cm) and increased crease recovery angle (114.99^{o}). At other concentrations, presence of few to average number of microcapsules was seen on the fabric surface with low aroma retention. It is obvious from the table that more number of microcapsules were present at 60 g/l concentration of microcapsule gel with good wash durability, improvement in softness and good resistance to creasing. Therefore 60 g/l concentration of microcapsule gel was chosen as the optimum concentration for preparation of the padding bath. Thite and Gudiyawar (2020) also used the ratio 50:50 of microcapsule gel and water for preparing the padding bath for application of *tulsi*, lemongrass and citronella essential oil on woven cotton fabric. Similar results were reported by Rana *et. al.* (2017) and Lim and Setthayanond (2019).

Optimization of softener concentration:

It is obvious from the Table 2 and microscopic evaluation (Image 2) of the thyme essential oil treated wool fabric that 2 and 3 g/l concentrations of microcapsule gel showed presence of many microcapsules on the fabric surface with wash durability of aroma treatment lasted till 20 wash cycles. It was found that 2 g/l concentration exhibited improvement in softness as indicated by decreased average bending length (3.21 cm) and flexural rigidity (14.79 mg cm). Also increased crease recovery angle, 116.83^{o} was recorded at 2 g/l concentration of softener as compared to 3 g/l concentration which had increased average bending length (3.23 cm), flexural rigidity (14.88 mg-cm) and decreased crease recovery angle (114.99^{o}). In 1 and 4 g/l concentrations of softener, few to average number of microcapsules were present on the treated fabric with poor wash durability. Thus, 2 g/l concentration of the softener was selected as optimum concentration for further experimental work as it showed presence of many microcapsules with good aroma retention and improved properties of treated wool fabric. Bhatt (2012) suggested that some amount of softener must be added to padding bath when aroma treatment to fabric was given using microencapsulated lemongrass essential oil to control the stiffness. The results of the study are also in agreement with Rana *et. al.* (2017).

Optimization of binder concentration

It is evident from the Table 3 and microscopic visualization (Image 3) of treated wool fabric that too many microcapsules were observed on the fabric surface at 10 g/l binder concentration and wash durability lasted till 25 wash cycles with 3.22 cm average bending length and 14.63 mg-cm flexural rigidity which was less and 115.66^{o} crease recovery angle which was more as compared to other concentrations of binder i.e. 5, 15 and 20 g/l. With increase in binder concentration, it was observed that more number of microcapsules were present on the surface of fabric but that was also responsible for the stiffness. It is apparent from the table that higher number of microcapsules, good wash durability, improved softness and good resistance to creasing was found at 10 g/l concentration of binder, hence this was taken as optimum binder (Beta-cyclodextrin) concentration for application of aroma treatment on wool fabric. These findings are in consistent with Adamowicz (2015) that the role of binder is to fix the capsules onto the fabric and to hold them in place during wear and washing as it can be chemically bonded or permanently fixed to fabrics. Kumari (2015) also used 15 g/l binder concentration in padding bath because at this concentration more number of microcapsules were deposited on the fabric with good wash durability lasting upto 20 wash cycles.

Optimization of material to liquor ratio

The data in Table 4 and microscopic analysis of aroma treated wool fabric (Image 4) reveal that at 1:20 M:L ratio, presence of too many microcapsules on the fabric surface was observed and wash durability lasted till 25 wash cycles. It was found 1:20 M:L ratio showed improvement in fabric properties as indicated by decreased average bending length (3.33 cm) and flexural rigidity (15.91 mg-cm). Also increase in crease recovery angle (114.00^{o}) was noted as compared to other material to liquor ratios of treatment bath i.e. 1:30, 1:40 and 1:50. Therefore, on the basis of presence of too many microcapsules on the fabric, good aroma retention and improved fabric properties i.e. bending length, flexural rigidity and crease recovery angle, 1:20 M:L ratio was selected and used for carrying out further research work. The results of the present study are in agreement with Bhatt (2012) and Kumari (2015) that the maximum number of microcapsules were present on the fabric at MLR 1:20 with good wash durability and with increase in MLR, deposition of number of microcapsules and wash durability of aroma treatment decreased. Similar findings were reported by Krishnaveni (2021) and El-Molla *et al.* (2022).

Optimization of treatment temperature

It is apparent from the Table 5 and microscopic assessment (Image 5) of treated fabrics that at 35 and 45ºC treatment temperatures, too many to many microcapsules were present on the fabric, wash durability reduced from 25 to 20 wash cycles with increased average bending length from 3.15

to 3.41 cm, flexural rigidity from 14.72 to 16.99 mg-cm and decreased crease recovery angle from 116.00º to 115.66º. It was further observed that when the treatment temperatures was increased to 55º C, presence of only few microcapsules on the fabric surface with low wash durability was observed. Hence, for carrying out further padding process, 35ºC treatment temperature was optimized as it displayed presence of more number of microcapsules with good aroma retention and improved fabric properties in terms of softness and resistance to creasing.

Optimization of treatment time

The data shown in the Table 6 and microscopic evaluation of aroma treated wool fabric (Image 6) indicate that at 20 and 30 minutes treatment duration, too many microcapsules were present on the fabric, wash durability lasted till 30 wash cycles. But at 30 minutes treatment time, average bending length (3.03 cm) and flexural rigidity (13.03 mg-cm) of the treated fabric was less and crease recovery angle (115.33_{0}) was more as compared with the fabric treated for 20 minutes having 3.24 cm average bending length and 15.56 mg-cm flexural rigidity with 115.00^{o} crease recovery angle. Treatment times 40 and 50 minutes showed presence of onlyaverage to few number microcapsules on fabric surface with low wash durability, increased average bending length, flexural rigidity and decreased crease recovery angle. Thus, on the basis of presence of microcapsules, wash durability and improvement in fabric properties, 30 minutes duration was chosen as optimum time for aroma treatment of wool fabric with microencapsulated thyme essential oil.

Geethadevi and Maheshwari (2018) treated bamboo and tencel fabrics with palmarosa, petitgrain, tea tree, thyme and lavender essential oils for 15 minutes to apply essential oils through pad-dry-cry method. Yuvasri *et al.* (2020) applied microcapsules of lemon grass, thyme and lavender essential oils on pure mercerized cotton fabric through pad-dry-cure method by immersing the fabric samples in microcapsule gel solution for 30 minutes. Naikwadi *et al.* (2023) used vetiver root extract for the finishing of the organic cotton fabric by pad-dry-cure method and treatment temperature was kept at 44^{o}C.

Optimization of drying temperature:

It is clear from the Table 7 and through visualization (Image 7) of thyme oil treated fabric samples under stereo zoom microscope that too many microcapsules were present at 70°C drying temperature with wash durability lasting till 30 wash cycles having 3.18 cm average bending length, 14.61 mg-cm flexural rigidity and 113.50° crease recovery angle. At 60 and 80°C temperatures, many microcapsules were seen on the fabric and wash durability lasted upto 25 wash cycles. At 80°C temperature 3.43 cm average bending length, 17.22 mg-cm flexural rigidity and 112.00° crease recovery angle was noticed whereas 3.38 cm average bending length, 15.60 mg-cm flexural rigidity with 112.66° crease recovery angle was observed at 60°C drying temperature. However, at 90°C drying temperature, only few microcapsules were observed with decreased wash durability (upto 15 wash cycles) and crease recovery angle (111.33°) and increased average bending length (3.46 cm) and flexural rigidity (17.41 mg-cm). It is thus concluded that at 70°C drying temperature, soft fabric was obtained with more number of microcapsules as compared to other time durations. Therefore, 70°C was taken as optimum temperature for drying of aroma treated fabric.

Optimization of drying time

It can be inferred from Table 8 and microscopic analysis (Image 8) of aroma treated fabric that drying times 2 and 3 minutes exhibited presence of many microcapsules on the surface of the fabric with wash durability that lasted till 25 wash cycles having 3.32 and 3.43 cm average bending length and 16.21 and 16.89 mg-cm flexural rigidity with 110.86 and 110.83° crease recovery angle, respectively. At 4 minutes drying time, too many microcapsules were seen on the fabric surface with 3.15 cm average bending length, 14.26 mg-cm flexural rigidity and 113.33° crease recovery angle with wash durability lasting upto 30 washes. Whereas, at 5 minutes drying time, average number of microcapsules were found present on the fabric with wash durability lasting till 15 wash cycles having increased average bending length (3.41 cm) and flexural rigidity (16.81 mg-cm) and decreased crease recovery angle (109.83°). It is deduced from data in the table that higher number of microcapsules, good wash durability, improved softness and good resistance to creasing was found at 4 minutes drying time. So, this time duration was selected as optimum drying time for aroma treatment of wool fabric.

Sathianarayanan *et al.* (2019) applied microencapsulated *tulsi* leaf and pomegranate extract onto the cotton fabric and dried it at 80^{o}C for 5 minutes. The results of the study are supported by the findings of Krishnaveni (2019); Thite and Gudiyawar (2020) and Rana (2021).

Optimization of curing temperature

The perusal of the Table 9 indicates that microencapsulated thyme essential oil treated fabrics (Image 9) had average bending length of 3.12, 3.32, 3.35 and 3.39 cm, flexural rigidity of 13.78, 15.85, 16.03 and 17.99 mg-cm and crease recovery angle of 115.16, 111.83, 111.33, 110.66 degree when cured at 100, 110, 120 and 130°C, respectively. It is further deduced from the table and microscopic visualization of the microcapsules that too many microcapsules were present on the fabric at temperature 100°C having wash durability lasting upto 30 washes with decreased average bending length, flexural rigidity and increased crease recovery angle. Thus, upon comparison of results of different curing temperatures on different parameters i.e. microscopic evaluation of the treated fabrics for presence of microcapsules, wash durability of aroma, bending length, flexural rigidity and crease recovery angle, 100°C temperature was optimized for curing of aroma treated wool fabric.

Optimization of curing time:

The data in the Table 10 and microscopic images (Image 10) of aroma treated wool fabrics indicate that at curing times 30 and 60 seconds, too many microcapsules were present having wash durability of aroma lasting upto 30 wash cycles whereas when curing time increased from 90 to 120 seconds, presence of microcapsules was few to very few with wash durability that lasted from 20 to

15 wash cycles. At 60 seconds curing time, average bending length (3.06 cm) and flexural rigidity (13.70 mg-cm) of aroma treated fabric were less while the crease recovery angle (116.66^{o}) was observed as more as compared to the other aroma treated fabrics which were cured for 30, 90 and 120 seconds. Hence, 60 seconds was chosen as optimum time for curing of thyme essential oil treated wool fabric as better results in terms of enhanced fabric properties with higher number of durable aroma capsules were obtained at this curing duration.

Bhatt *et al.* (2016) applied lemongrass microcapsules onto the cotton fabric by padding process and curing of treated fabric was done at 80^{o}C for 60 seconds. It was observed that with increase in curing temperature and time, the walls of microcapsules got ruptured. The results are also in agreement with Sayed *et al.* (2022).

CONCLUSIONS

The optimized variables for aroma treatment were found to be 60 g/l microcapsule gel, 2 g/l softener and 10 g/l binder concentration, 1:20 material to liquor ratio, 35°C temperature and 30 minutes treatment time as at these conditions more number of microcapsules, longer wash durability and better fabric properties in terms of bending length, flexural rigidity and crease recovery angle were observed. Aroma treated wool fabric when dried at 70ºC temperature for 4 minutes and cured at 100°C temperature for 60 seconds exhibited too many microcapsules on the fabric surface with good wash durability, improvement in softness and good resistance to creasing, hence optimized for drying and curing of microencapsulated thyme essential oil treated wool fabric. The wool fabric being highly hygroscopic in nature is considered very suitable fabric for development of aroma textiles. Microencapsulation is found very promising technique that provide long-lasting aroma finish by controlling the release rate of microencapsulated thyme essential oil on wool fabric.

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Table 1: Optimization of microcapsule gel concentration

Concentration of microcapsules gel (g/l)	Parameters											Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)		
		5	10	15	20	25	30					
30	Few	√	√	×	×	×	×	3.32	16.11	112.33		IV
40	Average	√	√	√	×	×	×	3.24	15.33	112.49		III

50	Many	√	√	√	√	×	×	3.25	15.29	114.00	II
60	**Many**	√	√	√	√	×	×	**3.22**	**14.63**	**114.99**	**I**

Table 2: Optimization of softener concentration

Concentration of softener (g/l)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
01	Few	√	√	×	×	×	×	3.26	15.46	113.66	IV
02	**Many**	√	√	√	√	×	×	**3.21**	**14.79**	**116.83**	**I**
03	Many	√	√	√	√	×	×	3.23	14.88	114.99	II
04	Average	√	√	√	×	×	×	3.26	15.16	112.99	III

Table 3: Optimization of binder concentration

Concentration of binder (g/l)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
05	Average	√	√	√	×	×	×	3.34	16.38	112.66	III
10	**Too many**	√	√	√	√	√	×	**3.22**	**14.63**	**115.66**	**I**
15	Many	√	√	√	√	×	×	3.27	15.51	115.33	II
20	Many	√	√	√	√	×	×	3.35	16.40	110.00	IV

Table 4: Optimization of MLR of aroma treatment

MLR	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
1:20	**Too many**	√	√	√	√	√	×	**3.33**	**15.91**	**114.00**	**I**
1:30	Many	√	√	√	√	×	×	3.45	16.14	112.99	II
1:40	Few	√	√	√	×	×	×	3.52	16.17	110.33	III
1:50	Few	√	√	√	×	×	×	3.64	16.48	109.66	IV

Table 5: Optimization of temperature of aroma treatment

Treatment temperature (^{o}C)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
25	Average	√	√	√	×	×	×	3.37	16.68	114.66	III

35	**Too many**	√	√	√	√	√	×	**3.15**	**14.72**	**116.00**	**I**
45	Many	√	√	√	√	×	×	3.41	16.99	115.66	II
55	Few	√	√	×	×	×	×	3.47	17.74	114.16	IV

Table 6: Optimization of time of aroma treatment

Treatment time (minutes)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycle)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
20	Too Many	√	√	√	√	√	√	3.24	15.56	115.00	II
30	**Too Many**	√	√	√	√	√	√	**3.03**	**13.03**	**115.33**	**I**
40	Average	√	√	√	√	×	×	3.39	16.69	114.83	III
50	Few	√	√	√	×	×	×	3.37	16.85	112.49	IV

Table 7: Optimization of drying temperature for aroma treatment

Drying temperature (^{o}C)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
60	Many	√	√	√	√	√	×	3.38	15.60	112.66	II
70	**Too Many**	√	√	√	√	√	√	**3.18**	**14.61**	**113.50**	**I**
80	Many	√	√	√	√	√	×	3.43	17.22	112.00	III
90	Few	√	√	√	×	×	×	3.46	17.41	111.33	IV

Table 8: Optimization of drying time for aroma treatment

Drying time (minutes)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
02	Many	√	√	√	√	√	×	3.32	16.21	110.86	II
03	Many	√	√	√	√	√	×	3.43	16.89	110.83	III
04	**Too many**	√	√	√	√	√	√	**3.15**	**14.26**	**113.33**	**I**
05	Average	√	√	√	×	×	×	3.41	16.81	109.83	IV

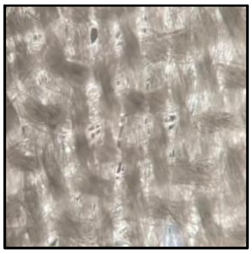
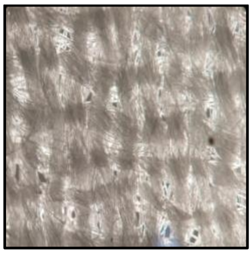
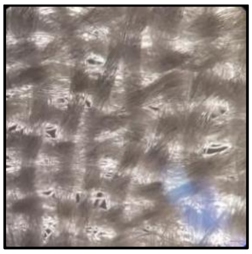
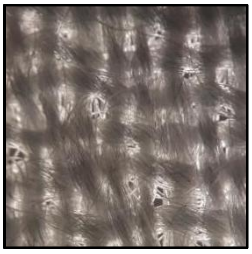
Table 9: Optimization of curing temperature for aroma treatment

Curing temperature	Parameters					Ranks
	Presence of microcapsules	Wash durability (Wash cycles)	Average bending	Flexural rigidity	Average crease	

(^{o}C)	on fabric	5	10	15	20	25	30	length (cm)	(mg-cm)	recovery (Degree)	
100	**Too Many**	√	√	√	√	√	√	**3.12**	**13.78**	**115.16**	**I**
110	Many	√	√	√	√	√	×	3.32	15.85	111.83	II
120	Few	√	√	√	×	×	×	3.35	16.03	111.33	III
130	Very few	√	√	×	×	×	×	3.39	17.99	110.66	IV

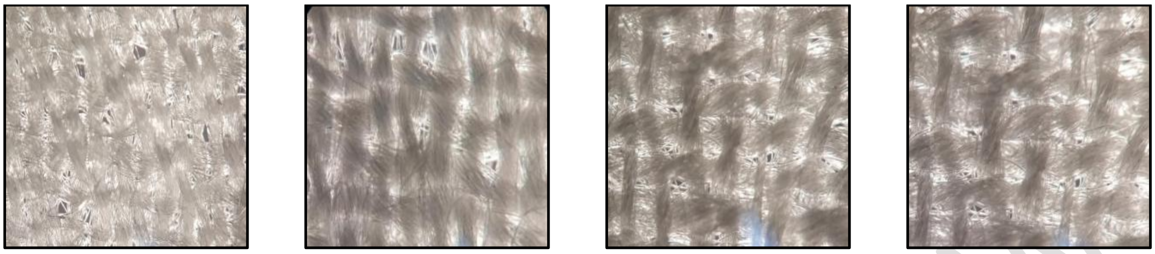
Table 10: Optimization of curing time for aroma treatment

Curing time (seconds)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycle)						Average bending length (cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
30	Too many	√	√	√	√	√	√	3.25	15.27	112.83	II
60	**Too many**	√	√	√	√	√	√	**3.06**	**13.70**	**116.66**	**I**
90	Few	√	√	√	√	×	×	3.23	15.29	112.33	III
120	Very few	√	√	√	×	×	×	3.28	15.67	111.16	IV

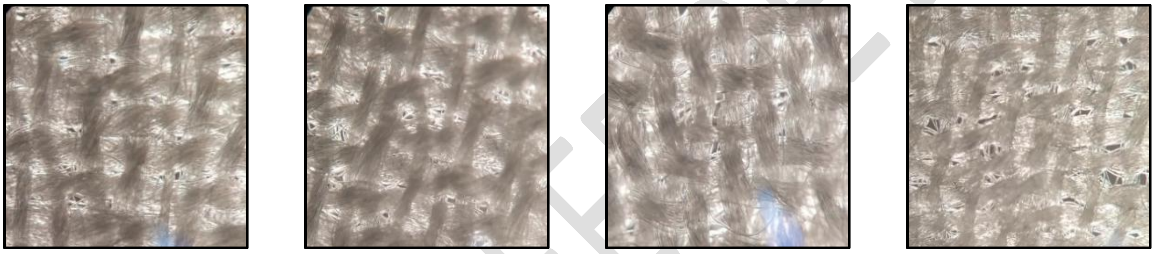
30 g/l (Rank- IV) 40 g/l (Rank- III) 50 g/l (Rank- II) 60 g/l (Rank- I)

Image 1: Stereo zoom microscopic images of treated fabric at different concentrations of microcapsule gel



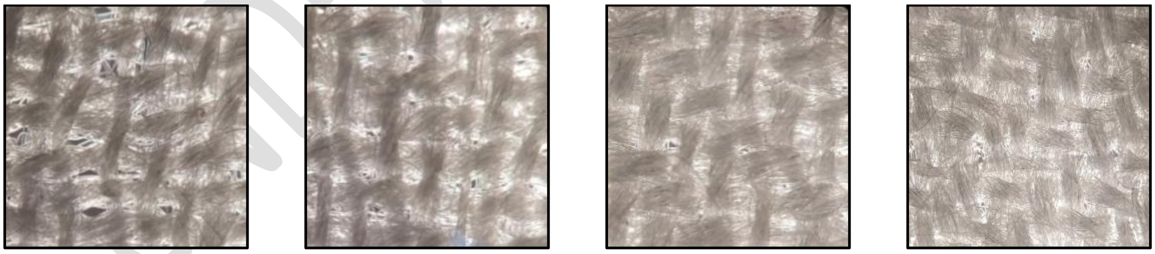
1.0 g/l (Rank- IV) 2.0 g/l (Rank- I) 3.0 g/l (Rank- II) 4.0 g/l (Rank- III)

Image 2: Stereo zoom microscopic images of treated fabric at different concentrations of softener



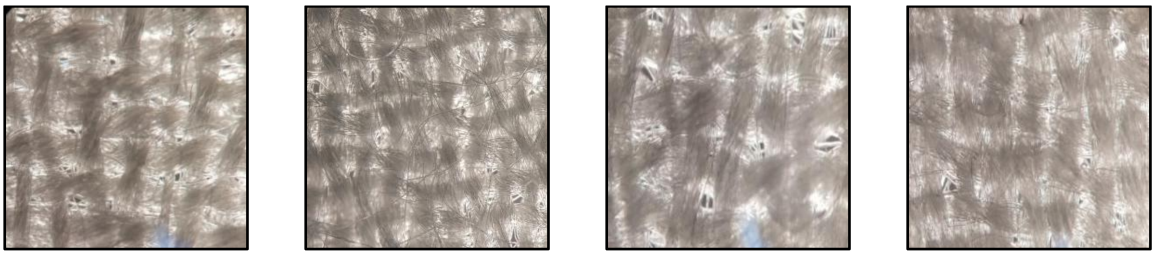
5 g/l (Rank- III) 10 g/l (Rank- I) 15 g/l (Rank- II) 20 g/l (Rank- IV)

Image 3: Stereo zoom microscopic images of treated fabric at different concentrations of binder



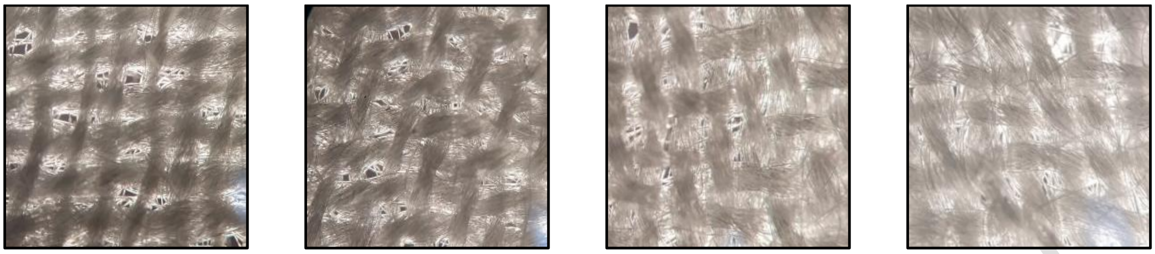
1:20 (Rank- I) 1:30 (Rank- II) 1:40 (Rank- III) 1:50 (Rank- IV)

Image 4: Stereo zoom microscopic images of treated fabric at different MLR



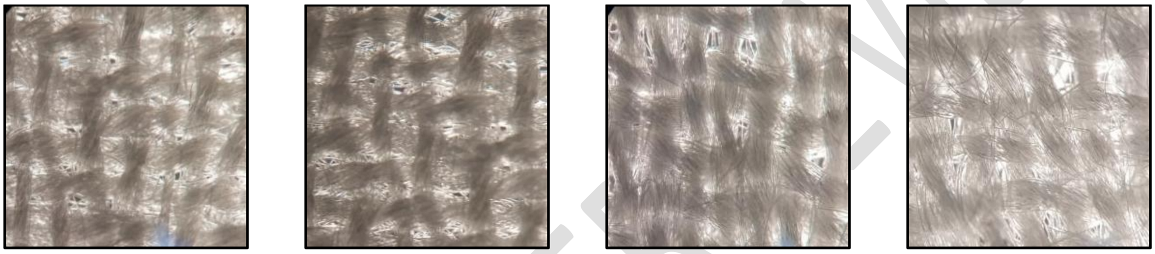
25°C (Rank- III) 35°C (Rank- I) 45°C (Rank- II) 55°C (Rank- IV)

Image 5: Stereo zoom microscopic images of treated fabric at different treatment temperatures



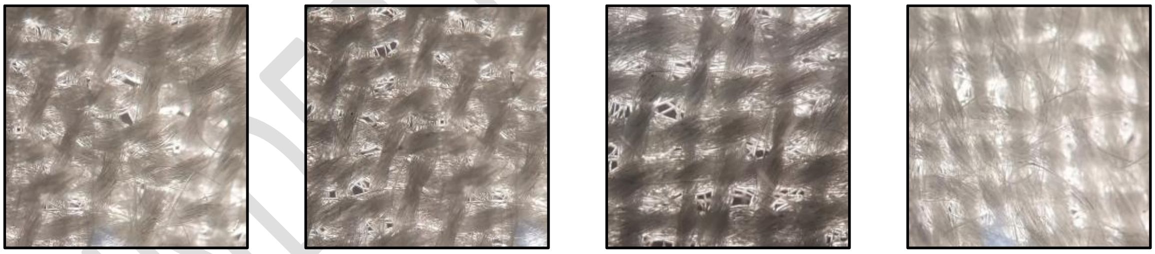
20 min (Rank- II) 30 min (Rank- I) 40 min (Rank- III) 50 min (Rank- IV)

Image 6: Stereo zoom microscopic images of treated fabric at different treatment times



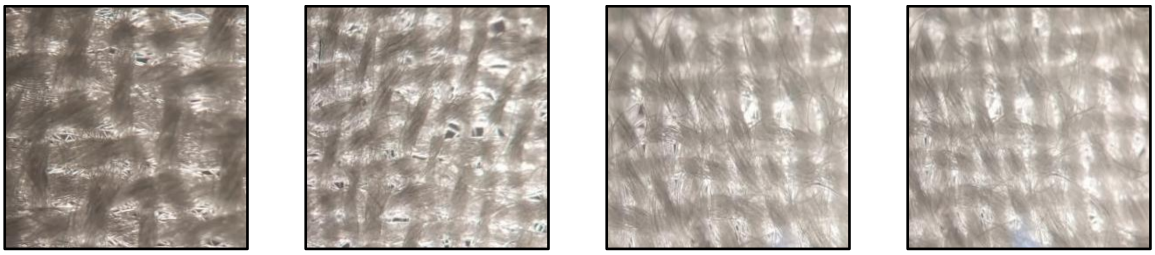
60°C (Rank- II) 70°C (Rank- I) 80°C (Rank- III) 90°C (Rank- IV)

Image 7: Stereo zoom microscopic images of treated fabric at different drying temperatures



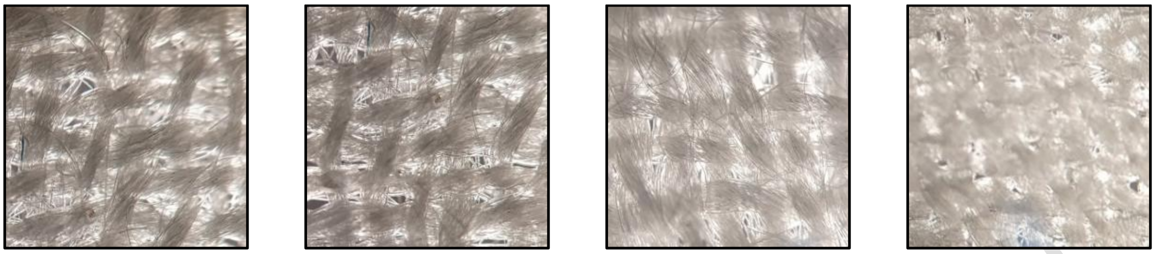
2 min (Rank- II) 3 min (Rank- III) 4 min (Rank- I) 5 min (Rank- IV)

Image 8: Stereo zoom microscopic images of treated fabric at different drying times



100°C (Rank- I) 110°C (Rank- II) 120°C (Rank- III) 130°C (Rank- IV)

Image 9: Stereo zoom microscopic images of treated fabric at different curing temperatures



30 sec (Rank- II) 60 sec (Rank- I) 90 sec (Rank- III) 120 sec (Rank- IV)

Image 10: Stereo zoom microscopic images of treated fabric at different curing times