A Unique Approach for Functionalization of Cotton Substrate with Sustainable Bio-based Vanillin for Multifunctional Effects

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ABSTRACT

Exploration of novel bio-based materials for value addition of textile substrates is a desirable research trend. In this context, vanillin (4-hydroxy-3-methoxybenzaldehyde), a bio-based material (obtained from vanilla pod) having multifunctional properties, can be a well-suited candidate. In the present article, both the vanillin alone and vanillin-copper (vanillin-Cu) complexes have been incorporated into cotton textiles separately using a high temperature-high pressure (HT-HP) dyeing machine and the quantity of copper has been successfully optimized to demonstrate enhanced properties. The vanillin-treated fabric has shown very good all-round properties like ultraviolet protection factor (UPF), color value (K/S value), and antibacterial activity (AM) in the presence of copper salt. However, only vanillin itself has rendered as such no UPF value but demonstrated 70% antimicrobial activity against *E. coli* (Gram-negative) bacteria and during washing operation small molecules of vanillin get leached out of fabric (as represented by significant loss in properties). This is the first time that the functional properties of vanillin and vanillin-Cu complex have directly been explored on cotton textile wherein significantly enhanced properties have been achieved on vanillin-Cu complex-treated fabric (i.e. 99% AM, a good UPF factor of 78, K/S value of 11.55, and even 25% antioxidant activity).

KEYWORDS

Vanillin; copper; cellulosic textiles; antimicrobial; Ultra-Violet protection (UPF); multifunctional

| 关键词 | 香草醛; 铜; 纤维素纺织品; 抗菌; 紫外线防护; 多功能 |

摘要

探索新型生物基材料以增加纺织品基材的价值是一个理想的研究趋势。在这种情况下，香草醛（4-羟基-3-甲氧基苯甲醛），一种具有多功能性质的生物基材料（从香荚兰中获得），可以是非常合适的候选物。在本文中，使用高温高压（HT-HP）染色机将单独的香草醛和香草醛-铜（香草醛铜）复合物分别掺入棉织物中，并成功地优化了铜的量，以证明其性能增强。香兰素处理的织物在铜盐存在下表现出非常好的综合性能，如紫外线保护因子（UPF）、色值（K/S值）和抗菌活性（AM）。然而，只有香兰素本身没有UPF值，但对大肠杆菌（革兰氏阴性）细菌具有约70%的抗菌活性。在洗涤过程中，香兰素从织物中渗出（表现为性能的显著损失）。这是第一次在棉织物上直接探索香草醛和香草醛铜络合物的功能特性，其中香草醛-铜络合物处理织物的性能得到显著提高（即约99%的AM，良好的UPF因子为78，K/S值为11.55，甚至25%的抗氧化活性）。

Introduction

Cotton textile is known for its extraordinary comfort properties since a long time. But cotton textiles having cellulosic backbone are prone to microbial growth and do not possess desirable ultraviolet protection, making the products unhygienic and limiting their usage as functional textile. Natural materials have been explored for multifunctional agent to impart various properties such as flame retardancy, antimicrobial...
activity since a long time but suffers problem of high add on (requires much amount of the natural material for getting the desirable properties), reproducibility in action, etc. (Basak and Ali 2018; Shukla et al. 2019). Vanillin has not yet been explored in textile sector as a novel multifunctional agent; however, it has exponentially been explored in pharmaceutical, food and beverage, and fragrance industries. p-vanillin and ortho-vanillin have only been explored as carrier in textiles to ease the dyeing of polyester (PET) fabric, and it has been found that ortho vanillin (o-vanillin) has shown better result over para vanillin (p-vanillin) in terms of color strength (K/S) to synthetic textiles. However, p-vanillin is much safer than ortho vanillin as reported in literature (Gressier et al. 2019; Pasquet et al. 2013). Very recently vanillin has been explored as a finishing agent to PET textile, but only ortho vanillin is reported to generate functional property like antimicrobial activity onto PET textile but p-vanillin shows neither any color value (K/S) nor any functional properties such as antimicrobial action (Gressier et al. 2019). This is due to white to off-white color of p-vanillin which does not impart any color (K/S) to textile. It is also reported in the preceding research that p-vanillin having high topological polar surface area (TPSA) interacts inefficiently with hydrophobic polyester and does not get trapped properly due to polarity. It comes out of PET easily due to its chemical structure. On the other hand, nanomaterials are being explored in every area of research such as biosensor, flame retardancy, energy harvesting, and storage devices, due to their exceptional properties such as high response, catalytic effect, and low add on required for its functional activity (Bairagi and Ali 2019, 2020; Chawla, Sharma, and Randhawa 2017; Durrani et al. 2020; Rajpoot et al. 2021; Sharma et al. 2018; Sharma Ali 2022; Sharma, Chawla, and Randhawa 2016). Nanomaterials such as silver and ZnO have extensively been explored as functionalizing agents to textiles but fate of nanomaterial is still not known completely. However, silver nanoparticles, triclosan, and quaternary ammonium salts have already been reported as toxic in many studies and their usage in creating functionalities onto textile substrates is becoming limited due to their environmental concerns (Boholm and Arvidsson 2014; Panyala, Peña-Méndez, and Havel 2008; Zhang et al. 2015). Use of antibacterial textiles has successfully been demonstrated in various sectors such as hospital, sportswear, home furnishing textiles (like curtains, tablecloth, etc.) and bed sheets for controlling odor and to limit the spread of infection. Natural materials based on essential oils have previously been explored on textile substrates but in the form of encapsulation of other polymeric material which is an additional component used for encapsulation and in many times it is synthetic in nature such as cyclodextrin (Bezerra et al. 2020). As discussed above, ortho-vanillin has somewhat been tried to explore in textile segment. But it is also known that p-vanillin is much safer than ortho vanillin. There has a surge of literature to explore this much safer variety in textile sector which is not yet been done may be because it has no color and displays insufficient functional activity on textile substrates. So, the authors in the present work have taken an initiative to explore the properties of p-vanillin onto cotton textiles as it is safer and has more sustainable approach. It is also interesting to mention that very recently vanillin has also been synthesized even from polyester waste bottles using microbes which is an excellent example to convert plastic wastes into useful materials (Sadler and Wallace 2021). In present study, authors have explored p-vanillin (as such, without any structural modification) on cotton fabric and at the same time p-vanillin has also been integrated in the presence of Cu salt to retain the developed functionalities for multiple washing cycles. In this respect, it has been observed that only p-vanillin-treated cotton textile does not show desirable functional properties but copper complex with vanillin enhances the antimicrobial activity up to 99%, along with its attractive shade and UPF of finished textile. Both copper salt and p-vanillin act as complementary to each other in a synergic way to enhance the properties of treated textiles to a remarkable extent whereas each component by itself does not provide these properties. Thus, this novel product (p-vanillin) explored in the current research can find huge application in various “sectors” such as sustainable approach for creating functionalities. In the field of textiles, there is an urgent need for green chemicals where vanillin has already been demonstrated as green carrier in one of the research articles (Pasquet et al. 2013) and vanillin Schiff base as finishing agent in a recent article (Sharma and Ali 2022). But having its great potential as antioxidant, antimicrobial, anticancer, antiviral, antifungal, and anti-diabetic in pharmaceutical industries (Arya et al. 2021) vanillin can also be explored as novel and green finishing agent on textile substrates to develop various functional products (like antibacterial, antifungal, antiviral, and antioxidant textiles).
Material and methods

Materials

Bleached cotton fabric (ready for dyeing, RFD category) of GSM 100 g/m² of twill weave without containing any optical brightening agent was purchased from a local market, New Delhi. Vanillin and copper acetate of analytical grade were sourced from Fisher Scientific and used without further purification. For NMR analysis of the sample, extra pure deuterated chloroform of analytical grade was used. DI water was used throughout the experiment.

Application method

High temperature-high pressure (HTHP) IR dyeing machine was used for integration of the agent into cellulosic textile i.e., cotton fabric. Three different concentrations of vanillin (i.e., 25, 50, 100 mg/40 mL) were explored by keeping the copper salt concentration fixed to 50 mg. In a separate experiment, only 100 mg vanillin (without copper salt) was used to treat the cotton fabric. Four pieces of 2 g each of cotton were cut and placed in four IR dyeing machine beakers and 40-mL water was poured into each beaker and at the end 50-mg copper acetate was added in first three beakers (containing 25, 50, and 100 mg vanillin) keeping the fourth beaker without addition of salt but only 100 mg vanillin. Beakers were placed in IR dyeing machine and heated at 120°C for 15 min. The treatment temperature was gradually raised to 120°C at the rate of 2°C per min and then held it for 15–20 min. Finally, the temperature was lowered to 40°C at the rate 2°C per min, and the samples were taken out and washed with running water followed by drying in an air oven.

Characterizations

UV-Vis spectroscopy

UV-visible spectrophotometer (Shimadzu Model 2450) was used to measure the absorbance peak of vanillin and vanillin-Cu complex present in dilute water. The scan was performed in the wavelength range 200–800 nm.

Raman spectroscopy

Raman spectrophotometer (Micro Raman Spectrometer of Renishaw Company) was used to study the vibrational modes of vanillin. The material was first dried completely under vacuum. The scan was performed from 200 to 2500 cm⁻¹ in 785 nm laser.

FTIR analysis

FTIR model Nicolet iS50 FT-IR of Thermo scientific company was used to analyze functional groups of various samples. The scan was performed from 400 to 4500 cm⁻¹ and data were recorded accordingly.

NMR spectroscopy

NMR spectrophotometer model Ascend™ 400 MHz of Bruker Company was used to study the chemical structure of vanillin. The scanning was performed at 400 MHZ instrument and data were recorded accordingly.
**XRD spectroscopy**

XRD was done to study the crystallinity of the sample. The analysis was done using Xpert pro having scan rate 0.02 and rate of 6 ° per min. The vanillin sample was exposed to copper ray 1.54 Å and data were recorded.

**Color strength**

Premier color scan spectrophotometer having model no 5100, Lambda (35 model) equipped with an integrating sphere was used to study color strength of the treated and untreated cotton fabric. Different color parameters were kept same as reported in the earlier published context (Basak and Ali 2019).

**Washing fastness**

Washing fastness of the treated fabrics was tested using a laboratory grade launder-o-meter (R.B Electronics and Engineering) following the standard, AATCC 61 1A method. ECE phosphate reference detergent was used for washing operation. Cotton fabric of 15 cm × 5 cm dimension was cut and washed with 200 mL water containing standard recipe (AATCC 61A) at 40 °C for 45 min.

**UPF measurement**

UPF tester instrument of Model UPF 2000, Labsphere was used to study the ultraviolet protection ability of the treated and untreated cotton fabric. The samples were tested using standard method AATCC 183:2014 and result were reported.

**Antimicrobial activity**

Antimicrobial activity of cotton samples treated with only vanillin and vanillin-copper was evaluated using standard testing method (AATCC 100) against *E. coli* (Gram-negative bacteria) and *S. aureus* (Gram-positive bacteria). The automatic colony counter was used to calculate the number of colonies of control and treated cotton fabrics and bacteria percentage reduction (BPR) was calculated using the following formula:

\[
\text{Percentage Reduction} = \frac{(A - B)\times 100}{A}
\]

where A is the number of viable microorganisms before treatment and B is number of viable microorganisms after treatment.

**Tensile testing**

Tensile strength of the untreated and the treated fabrics were evaluated by following grab test method (ASTM D5034) using tensile testing machine (Tinius Olsen, Model: H5KS). All the samples were tested at the speed of 300 mm/min with the sample dimension of 200 mm × 50 mm.

**Sem edx**

The SEM EDX analysis was done to check the presence of copper in the treated textiles. Before the scanning, the samples were coated with a conducting material (Gold/Palladium) of 100 angstroms thickness (accelerating voltage: 20 KV). TM3000 tabletop microscope (HITACHI, Swift ED3000) was used to explore the elemental composition of both the untreated and treated samples.
Results and discussion

Integration of vanillin and vanillin-Cu inside cotton fabric

As discussed in the introduction part of the article, $p$-vanillin is much safer than ortho-vanillin and has potential to replace non-ecofriendly textile finishing agents (Pasquet et al. 2013) and thus it has been used in the present study to explore its potential as multifunctional agent on cotton fabric. Vanillin itself may not be suitable as finishing agent due to its smaller chemical structure and may leach out from fabric as also observed in current research. However, solubility of vanillin is much less in cold water, but it is quite soluble in hot water. Due to its small structure, even after its integration at high temperature, a very small amount of vanillin may adhere to the treated cotton fabric. On the other hand, in the presence of copper salt vanillin can form vanillin-Cu complex and the resultant size of the molecule gets increased as well as solubility also gets decreased at lower temperature (once the treatment process is over). Thus, it generates beautiful color on cotton fabric and act as ecofriendly finishing material having multifunctional properties. The possible mechanism of entrapment of vanillin and vanillin-Cu complex is represented in Figure 1. The vanillin-Cu complex formed inside the cellulose fiber is mainly responsible for generating color as well as ultraviolet and bacteria protection of the treated fabric. The formation of this type of complex is also reported in a previous research work where (de Medeiros et al. 2018) vanillin-Cu has been used as DNA cleaving agent along with some other additives. Vanillin can only get entrapped within cotton textiles through hydrogen bonding (as depicted in Figure 1a) and may get trapped due to poor water solubility as observed in the present study. But vanillin can easily get washed out at much extent after one wash as also evident from lowered UPF and antibacterial activity (as discussed in detail in the later part of this article). But formation of copper-complex (Figure 1b) results in increased interaction with cotton as well as it is mildly soluble at higher temperature and almost insoluble at low temperature which make it suitable to get trapped tightly in the cotton textiles. Combined effects of insolubility and structure modification of vanillin-Cu complex within the fiber are mainly responsible for enhanced durability than only vanillin-treated cotton.

Analysis of functional groups: FTIR spectroscopy

FTIR spectra of control cotton, vanillin-treated cotton, and vanillin-Cu-treated cotton as such and in expanded form are represented in Figures 2(a,b) which clearly indicate the presence of vanillin and vanillin-Cu complex in the treated cotton.
Peak at 3312 cm$^{-1}$ is certainly due to the presence of OH groups in cotton which gets broadened in case of vanillin cotton and even becomes more broadened in vanillin-Cu complex imparted cotton which may be due to interaction of vanillin and vanillin-Cu with cotton. In addition, vanillin-Cu complex is not soluble in water at room temperature which is another major factor responsible for durability. Also peak due to aldehyde group as well as C=C of benzyl ring in range 1525 cm$^{-1}$ was observed in vanillin and vanillin-Cu-treated fabric which confirms the presence of vanillin and vanillin-Cu complex. Color value and UV-Vis absorption of vanillin-Cu also supports the formation of vanillin-copper complex into cotton fabric. The prominent C=O peak is observed in case of vanillin-Cu-treated fabric (Figure 2b) wherein shifting of the same in vanillin-Cu-treated fabric is also more due to interaction of carbonyl groups of vanillin with copper. However, very weak peak of vanillin (aldehyde group) is observed for the only vanillin-treated fabric which clearly indicates that vanillin itself does not adhere to cotton properly due to its smaller structure.

**Color strength of untreated and treated textile**

Vanillin itself is of off-white color and thus does not provide any color to cellulosic textile after the treatment. However, when copper salt is used in addition to vanillin, the treated cotton fabric gains an attractive brownish-yellow color (pictures of various samples have been represented in Figure 3). Three different concentrations of vanillin have been studied by keeping the concentration of copper acetate fixed. A very attractive and good coloration has been observed when vanillin is taken as 100 mg and that of copper acetate concentration is 50 mg.

In addition to this the optimized concentration has also shown good UPF activity (as discussed in the later part of this article). The detail data on color strength (before and after the washing of treated fabric) is reported in Table 1. It is observed that among all the concentrations of vanillin and copper acetate used in the experiments, the sample treated with 100 mg vanillin and 50 mg Cu compound shows the optimized color value.

**UPF of untreated and treated cotton fabric**

Ultraviolet protection factor (UPF) measurement of the untreated and treated fabric has been performed using UPF 2000 Labsphere instrument. UPF value of the untreated cotton fabric has been noted as 10 as calculated using the standard AATCC 183:2014 method. On the other hand, treated fabric has shown 50+ UPF factor value for the all the cotton samples treated with vanillin-Cu
However, only vanillin-treated fabric has shown UPF of just 11 which is closer to untreated fabric. Thus, it is assured that smaller size molecule of vanillin is not enough to provide any ultraviolet protection of the fabric efficiently. Even vanillin gets washed off out of the treated fabric just after one wash (Standard AATCC 61 1A) as shown by UPF value which becomes 10 i.e., equal to untreated fabric. But vanillin-Cu complex within the fabric results in significant improvement in UPF value. This may be due to enhanced size of the formed complex structure of vanillin and copper which certainly accommodate the ultraviolet light within the structure and dissipates the same. However, vanillin has
been explored in three different doses (i.e., 25, 50, 100 mg in 40 mL water during the treatment process), whereas the amount of copper salt has been taken as 50 mg. It has been observed that reasonable UPF of the treated cotton fabric even beyond two machine washes can be retained in case of 100 mg vanillin in the presence of 50 mg copper salt (Table 2) wherein the value goes below 50 after 6th machine washing.

**Mechanical properties of the treated fabric**

It is very important to evaluate the physical properties of textile fabric after any chemical processing. To incorporate functionalities such as anti-crease property, antimicrobial activity, and flame retardant property, basic physical properties of the fabric should not get hampered. In this respect, assessment of mechanical properties of treated textiles is very important and it has been done using a tensile testing machine. The dimension of each fabric has been fixed at 20 cm × 5 cm. It has been observed that there is not any significant adverse effect on the strength of cotton textile after the treatment operation. Tensile strengths of control cotton and treated cotton fabrics are depicted in Figure 4. Tensile strength of the control cotton observed was 610 N, whereas 100 mg vanillin-treated cotton showed 596 N and 25 mg vanillin along with 50 mg copper acetate-treated fabric showed 629 N strength. The tensile strength values for 50 mg vanillin along with 50 mg copper acetate-treated fabric and 100 mg vanillin along with 50 mg copper acetate-treated fabric were 639 N and was 683 N, respectively. Therefore, it can be commented that the treatment process is quite safe as far as mechanical properties of the fabric are concerned.

**Table 2.** UPF value of untreated and treated cotton fabric.

| Cotton samples                             | UPF | UPF after 1\(^{st}\) wash | UPF after 2\(^{nd}\) wash | UPF after 6\(^{th}\) wash |
|--------------------------------------------|-----|-----------------------------|-----------------------------|-----------------------------|
| Untreated                                  | 10  | -                           | -                           | -                           |
| 100 mg vanillin-treated fabric             | 11  | 10                          | -                           | -                           |
| 25 mg vanillin and 50 mg copper acetate-treated fabric | 51  | 31                          | 24                          | 17                          |
| 50 mg vanillin and 50 mg copper acetate-treated fabric | 54  | 33                          | 29                          | 20                          |
| 100 mg vanillin and 50 mg copper acetate-treated fabric | 78  | 64                          | 55                          | 40                          |

![Figure 4](image-url)  

**Figure 4.** Tensile strength of (1) control cotton, (2) 100 mg vanillin-treated cotton, (3) 25 mg vanillin along with 50 mg copper acetate-treated fabric, (4) 50 mg vanillin along with 50 mg copper acetate-treated fabric, (5) 100 mg vanillin along with 50 mg copper acetate-treated fabric.
SEM EDX

SEM EDX has been recorded for the treated samples at different areas of cotton fabric to assess the uniformity of treatment. It was observed that only vanillin (100 mg)-treated cotton textile shows the presence of carbon and oxygen however, in case of vanillin-Cu (vanillin 100 mg and copper acetate 50 mg)-treated cotton textile peaks correspond to copper are also visible which confirm the presence of copper and carbon, oxygen and copper content in percentage was represented in Figure 5 (a–). The presence of copper can also be confirmed by observing the color of the treated cotton with vanillin and copper together as also elucidated in Figure 3 in earlier section. Vanillin (100 mg)-treated cotton fabric showed carbon-61.13% and oxygen-38.87%, whereas Vanillin-Cu (Vanillin 100 mg & copper acetate 50 mg)-treated cotton fabric sample showed carbon-58.73%, Oxygen-38.92 and copper- 2.23% in SEM EDX analysis.

Assessment of antimicrobial activity

Standard method (AATCC 100) has been used for evaluating the antimicrobial performance of the treated cotton fabric as compared to the control one (untreated cotton fabric). It has been observed that vanillin-treated fabric shows 70% antimicrobial activity against E. coli (Gram-negative) bacteria, whereas vanillin-Cu-treated cotton fabric shows 99% antimicrobial activity against the same species (presented in Figure 6). It has also been observed that after 1 launder-o-meter wash, vanillin-treated fabric loses 30% antimicrobial activity which also follows the same trend as UPF (which means vanillin

![Figure 5](image-url)
due to smaller chemical structure gets leached out of the cotton fabric easily). It may retain in small amount in the treated textile due to lower solubility in normal water before washing. But vanillin-Cu complex is absolutely a suitable solution as finishing agent which renders excellent antimicrobial properties as well as good UPF and color strength on cotton fabric. Similar trend was observed for vanillin and vanillin-Cu-treated fabric against *S. aureus* (Gram-positive) bacteria. In this case, vanillin-treated fabric showed nearly 60% antimicrobial activity, whereas vanillin-Cu complex showed 99% antimicrobial activity and even after six washes this activity retained to a significant extent as presented in Figure 6. In addition to this, there is a mild vanillin fragrance from both the fabrics which adds value to treated textiles further. Figure 6 shows the bacteria colony forming unit on Agar plate for untreated (control fabric) and various treated cotton fabrics. Antimicrobial efficacy against *E. coli* and *S. aureus* of the treated and untreated fabric in the presence of vanillin and vanillin-Cu complex is clearly presented. Table 3 represents reduction in colonies of *E. coli* and *S. aureus* bacteria for vanillin (100 mg) and vanillin–Cu (100 mg vanillin and 50 mg copper acetate)-treated samples with respect to the untreated sample. The antimicrobial efficacy (in percentage) of the treated fabrics is also presented in Table 3.

It was observed that antimicrobial activity of the vanillin-treated fabric was significantly reduced after six washes which directly reflects that vanillin has very weak interactions with cotton structure (as also supported by the findings of UPF analysis and K/S value measurement shown in Figure 7).
However, vanillin-Cu-treated cotton retains its activity up to 97% and 93% against *E. coli* and *S. aureus* bacteria, respectively, even after six launder-o-meter washes. Overall multifunctional effects are represented in Figure 7 using bar graph. It is clearly visible that vanillin-Cu-treated cotton fabric shows good color strength, UPF activity and antimicrobial activity before as well as after washing. So these value-added multifunctional cotton textiles imparted by eco-friendly vanillin-Cu can be explored in various fields of applications (such as various home furnishing textiles, medical applications of textiles, and sport textiles).

### Conclusions

The present study successfully demonstrates complexation of *p*-vanillin with toxicity-free metal ions (in this case copper). The approach helps to enhance the size of the resultant molecule in one hand and on the other hand demonstrates synergistic enhancement of functional properties in combination which is not possible otherwise only with vanillin or even with copper salt (wherein copper salt cannot sustain alone in cotton structure because of its water solubility). The present research successfully demonstrates that after addition of copper salt, properties of the treated fabric drastically get improved, and also the complex compound provides attractive color to textile substrate. Antimicrobial activity gets increased up to 99% compared to 70% in case of only vanillin-treated fabric which is also not even durable for one machine wash. However, antioxidant property does not increase much even after addition of copper. In case of only vanillin, it may not get attached to fabric properly and in case of vanillin-Cu complex, certainly it makes a complex with phenolic groups of

| Sample description                                                                 | No. of colonies | BCR % |
|------------------------------------------------------------------------------------|-----------------|-------|
| Untreated fabric                                                                    | 560             | 100   |
| 100 mg vanillin-treated fabric                                                      | 168             | 70    |
| 100 mg vanillin and 50 mg copper acetate-treated fabric                             | 5               | 99.1  |

| Sample description                                                                 | No. of colonies | BCR % |
|------------------------------------------------------------------------------------|-----------------|-------|
| Untreated fabric                                                                    | 1568            |       |
| 100 mg vanillin-treated fabric                                                      | 630             | 60    |
| 100 mg vanillin and 50 mg copper acetate-treated fabric                             | 6               | 99.6  |

Figure 7. (a) color strength, (b) UPF activity, (c) antimicrobial efficacy of treated samples as such (before washing) and after various washing cycles.

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**Table 3.** Reduction of colonies of *E. coli* and *S. aureus* bacteria in treated fabric as compared to the untreated fabric and antimicrobial efficiency in percentage.
vanillin. However, copper salt increases the vanillin uptake by the fabric and the wash durability. The prepared finished textiles can successfully be used for making curtain, tablecloth, bed sheet in hospital, also in other products where antimicrobial activity is required. The treated textile can also be explored as functional material having antimicrobial property as well as good fragrance where washing of clothes is not very frequent (e.g., for making seats in automobiles, etc.).

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