# Functional textile surface production by analysing the mechanical properties of cotton, bamboo and linen woven surfaces

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**ABSTRACT – REZUMAT**

**Functional textile surface production by analysing the mechanical properties of cotton, bamboo and linen woven surfaces**

*In the textile industry, it is seen that the use of nanomaterials is increasing to meet the demands for long-lasting and sustainable products. This research aims to improve the mechanical properties of 1×1 plain weave cotton, bamboo and linen surfaces made of natural yarns by coating them with ZnO, $TiO_2$ and $SiO_2$ to provide sustainable natural life and create a sustainable functional textile surface. For this reason, coatings were made with nanoparticles and applied to textile surfaces. The blade (stripping knife) coating method with subsequent dosing was used when the coating agent was liquid with an appropriate viscosity value. The surface morphology of the treated fabric was characterized by SEM, EDS and FT-IR analysis. Mechanical properties were analysed by thickness, weight and tear strength tests and antibacterial activity against S. Aureus and E. Coli bacteria were tested. When the results were examined, it was determined that cotton, linen and bamboo surfaces, which did not have antibacterial properties except for E. Coli (49.56%), showed antibacterial properties (100%) in bamboo and linen after coating with ZnO and $TiO_2$, and in bamboo after coating with $SiO_2$. The coating material also caused different effects in terms of thickness, weight and strength change.*

**Keywords:** *nanoparticles, mechanical properties, natural fabric, antibacteriality, cotton, linen, bamboo*

**Producția suprafețelor textile funcţionale prin analiza proprietăților mecanice ale suprafețelor țesute din bumbac, bambus și in**

*În industria textilă, se observă că utilizarea nanomaterialelor este în continuă creștere pentru a satisface cerințele de produse sustenabile și durabile. Acest studiu își propune să îmbunătățească proprietățile mecanice ale suprafețelor din bumbac, bambus și in țesute cu legătură pânză 1×1, realizate din fire naturale, prin acoperirea acestora cu ZnO, $TiO_2$ și $SiO_2$, pentru a oferi o viață naturală durabilă și a crea o suprafață textilă funcțională durabilă. Din acest motiv, acoperirile au fost realizate cu nanoparticule și aplicate pe suprafețele textile. Metoda de acoperire cu cuţitul (raclu) cu dozare ulterioară a fost utilizată atunci când agentul de acoperire a fost lichid cu o valoare adecvată a viscozității. Morfologia suprafeței țesăturii tratate a fost caracterizată prin analize SEM, EDS și FT-IR. Proprietățile mecanice au fost analizate prin determinarea grosimii, masei și rezistenței la rupere și a fost testată activitatea antibacteriană împotriva bacteriilor S. Aureus și E. Coli. La examinarea rezultatelor, s-a observat că suprafețele din bumbac, in și bambus nu aveau proprietăți antibacteriene, cu excepția E. Coli (49,56%). Suprafeţele de bambus şi in au prezentat proprietăți antibacteriene (100%) după acoperirea cu ZnO și $TiO_2$, iar după acoperirea cu $SiO_2$ bambusul a prezentat activitate antibacteriană. Materialul de acoperire a provocat, de asemenea, efecte diferite în ceea ce privește modificarea grosimii, masei și rezistenței.*

**Cuvinte-cheie**: *nanoparticule, proprietăți mecanice, țesătură naturală, antibacterian, bumbac, in, bambus*

## INTRODUCTION

Cotton is the most common plant grown in more than 80 countries around the world, and cotton fabrics are among the most preferred fabric types due to their high breathability [1]. Approximately 75% of clothing products contain at least some cotton, and these surfaces help keep body temperature balanced by reducing perspiration. Its advantage is that it is compatible with nature and biodegradable, provides long-lasting durability, and is resistant to fraying and tearing, while its disadvantage is that it can easily ignite in ambient conditions with an LOI of 16–18% [2–5]. In addition to its hypoallergenic and non-toxic structure, it is known to provide a suitable environment for the growth of microorganisms due to its hydrophilic structure that retains oxygen, nutrients and moisture [6]. Therefore, a lot of research and work is being done to improve and enhance the antibacterial properties of cotton fabrics [7–9].

On the other hand, linen surfaces with breathable structures have high air permeability values and insulation properties. Thanks to their ability to absorb water, they quickly absorb sweat and allow the moisture in the body to be expelled. Processed flax fibres show low density and tensile strength between 264 and 2000 MPa [10–13]. Surfaces produced with flax fibre, the most durable fibre after silk, are also resistant to long-term use and washing. Thanks to their hypoallergenic structure, they minimize skin irritation and prevent the formation of bacteria and fungi with their antibacterial structure [14, 15]. It is seen that linen surfaces, which have been preferred since ancient times, have properties that support wound healing and do not lose these properties during industrial processing [15].

On the other hand, bamboo fabrics are natural and environmentally friendly, with high air permeability, breathability and moisture absorption. Their soft and smooth structure provides superior comfort features. Thanks to the "bamboo kun" substance found in the bamboo plant, they prevent the formation of bacteria and fungi and prevent the formation of malodorous by reducing bacterial growth. Therefore, these antimicrobial surfaces are also antistatic and provide protection against UV rays [16–21].

One or both surfaces of woven, knitted or nonwoven structures can be coated with a chemical agent. The coating procedure combines the advantages of polymers, foams and films on the applied surface, to improve the physical properties of the surfaces and change their aesthetic properties, thereby extending the range of use of the product [22, 23]. Textile products obtained by coating and lamination processes, which constitute an essential part of the textile industry, have increased their demand with the innovations and advantages they offer [24, 25].

Coated and laminated textile surfaces are formed by applying thin, flexible films of natural or synthetic polymers as a viscous liquid to textile surfaces. Coating agents are grouped into polymer dispersions, coating powders and coating pastes according to their chemical content. Coating powders can be based on polyolefins such as polyethylene, polyamide groups, polyester, polyurethane, etc. These chemicals constitute the basis of the coating paste. In addition, the coating paste may also present chemicals such as dispersing agents, solubilizing agents, foaming agents, softeners, thickeners and ammonia. Polymer dispersions, poly(meth)acrylate (butyl, ethyl, methyl, etc.), polyacrylic acid polyacrylonitrile, polyacrylamide, polystyrene, polyvinyl acetate and copolymers of these and similar polymers are the basis of these dispersions [26].

It is known that textile products create environments that provide suitable temperature, humidity and nutrients for microorganisms to live and multiply in terms of their structure and where they are used. These organisms can harm the product itself and the user. Thanks to the surfaces coated with various techniques, in addition to improving mechanical properties, antimicrobial activities are also reduced, and high-performance, superior functional textile products can be easily produced. With the variety of antimicrobial products obtained, the adverse effects caused by microorganisms can be reduced or eliminated [27].

Nowadays, due to the development of drug-resistant bacteria, there is a need to search for new more effective antibacterial agents. In this context, various nanoparticles have been proposed as novel antimicrobial agents against different pathogens due to their unique physicochemical properties [28–31].

Nano-sized metals and metal oxides; silver (Ag), titanium dioxide ($TiO_2$), zinc oxide (ZnO), and copper (II) oxide (CuO) are the leading antimicrobial materials studied [32, 33]. Nanoparticles have unique chemical, electrical and optical properties. These properties vary depending on size, shape and crystalline structure. As the size of nanoparticles decreases, the surface area increases, and this increases the antimicrobial activity [34, 35]. However, since nanoparticles act in a non-specific manner, multiple mechanisms may explain their activity, making it more difficult to interpret the main mechanism responsible for antimicrobial activity. Moreover, the lack of standardization regarding microbial activity determinations, methods and material differences used in studies causes uncertainty in microbiological testing methodologies. Consequently, the antibacterial activity of the nanoparticles utilized on the surfaces may vary depending on various physical and chemical factors [36, 37].

Zinc oxide (ZnO), titanium dioxide ($TiO_2$) and silver (Ag) can be used in different fields to control microbial growth [38]. Nevertheless, ZnO possesses notable advantages due to its superior photocatalytic effectiveness compared to other inorganic photocatalytic materials, making it a very desirable option. Also, ZnO exhibits enhanced biocompatibility in comparison to titanium dioxide. Moreover, ZnO has greater selectivity, better durability and heat resistance. This substance is employed for the purpose of combating diverse bacteria, including *S. Aureus* [39–41] and *E. Coli* [38]. The activity of ZnO against bacteria is enhanced when its size is decreased to the nanoscale [42]. Several studies have investigated the mechanisms of action of ZnO NPs on bacteria and fungi, but these studies have not yielded conclusive results [40, 43, 44]. Moreover, due to its semiconductor properties, ZnO has high photocatalytic efficiency, which may contribute to its antimicrobial effect [42, 45]. Additionally, there have been studies indicating that the presence of hydrogen ions might lead to the production of hydrogen peroxide, resulting in the eradication of microorganisms [45–48].

However, the utilization of ZnO nanoparticles (NPs) presents a potentially advantageous solution for mitigating the development of microbial resistance [36].

Silicon dioxide ($SiO_2$) nanoparticles possessing favorable tensile strength and impact strength are extensively employed for enhancing mechanical properties owing to their specific surface effect, tiny size effect, and quantum size effect [49–52].

Nanoparticles of silicon dioxide ($SiO_2$) are frequently employed for the purpose of emulsion or coating modification. The main structural component of polysilicon is comprised of silicon (Si) and oxygen (O), while the secondary chain is built of a non-polar alkyl group that is arranged in an outward pattern.

The literature suggests that this material demonstrates exceptional performance in terms of its water-repellency and resistance to dust [53].
Hydroxyl radicals formed in the redox reactions of titanium dioxide ($TiO_2$) nanoparticles affect their antimicrobial activity. The particles form hydroxyl radicals by interacting with ultraviolet light at the appropriate wavelength. These radicals inactivate microorganisms by oxidizing organic compounds in the structure of microorganisms [54, 55]. In the literature, the observation of the antimicrobial ability of titanium and the conclusion that it has excellent antimicrobial activity in improving cell compatibility can prevent microbial adhesion due to its photocatalytic activity [56, 57]. When $TiO_2$ is excited by photons, minimum energy, electron/hole (e–/h+) pairs equal to its bandgap, are produced, providing powerful redox reactions to kill germ cells [58]. The introduction of doping agents has the potential to reduce the band gap of $TiO_2$ and enhance the separation of charges within the material. Consequently, this can lead to an improved antibacterial effect when $TiO_2$ is excited by light [58, 59]. However, it is important to note that this effect is not observed in the absence of light, hence restricting its applicability in the field of biomedicine [60, 61]. Furthermore, antimicrobial strategies targeting germ membrane functions are promising in treating persistent infections [62–64]. Biomaterials are biocompatible materials that do not interfere with the regular changes of the surrounding tissues and do not cause unwanted reactions (inflammation, coagulation, etc.) in the tissue [65]. Biocompatibility can be defined as compatibility with the body. Therefore, it is seen that bioceramic materials added to textile products affect thermal properties, do not cause problems in terms of comfort and reduce the temperature difference between the body and the garment [66]. Non-specific mechanisms of action enable NPs to operate in pathways that are beyond the reach of antibiotics. Furthermore, it should be noted that the primary processes responsible for antibiotic resistance are not directly associated with nanoparticles. These mechanisms do not necessarily require the penetration of nanoparticles [36].
The antibacterial and strength results obtained from the nanoparticle materials used in this study are shared below. These are also distinguished to those in the literature where cotton, linen and bamboo surfaces which were also evaluated together, and their mechanical and antibacterial results were examined. *E. Coli* cells are longer than *S. Aureus* cells and can come into contact with a larger number of spherical particles, cell wall components have different pathways for the absorption of NPs [31, 36, 67]. This situation causes differences between the methods applied and the results obtained, and structures that are resistant to *E. Coli* may not show the same sensitivity against *S. Aureus* [68]. In this study, cotton, bamboo and linen untreated raw surfaces were treated with three different chemicals and then compared, which is important in terms of finding and evaluating all three together in the literature.

## MATERIALS AND METHODS

From the yarns selected within the scope of the study, a 1×1 plain weave fabric weighing 100 g/m$^2$ was woven. The surfaces were produced on a narrow-width sample weaving machine. The raw fabrics were pre-treated to obtain hydrophilicity and permanent whiteness. They were subjected to the coating process without any treatment to reduce the workflows and chemical usage of the surfaces and thus show that the material's performance properties can be improved through the natural structure. The weaving density, weight, air permeability, thickness and strength values of the fabrics obtained are given in table 1.

### Bioceramic nanoparticles and coating chemicals

Within the scope of the study, three different nanoparticles were used. Sigma-Aldrich supplied nanoparticles. The recipe and chemicals for the preparation of the coating paste, the properties of the particles used and the viscosity values of the prepared coating paste are given in table 2. Coating chemicals were obtained from Rudolf Duraner.
The chemicals used in the preparation of the coating paste were mixed with a Janke Kurkel brand mixing device. The viscosity values of the prepared coating paste were measured with a Brookfield DV-E Viscometer at 50 rpm using a Sp6 tip.

### Application of the coating process

The coating paste is spread on the fabric after the material is prepared for the coating process. The distance between the stripping knife and the fabric was adjusted to 0.3 mm during this process. The coating

Table 1

WEAVING DENSITY, WEIGHT, AIR PERMEABILITY, THICKNESS AND STRENGTH VALUES

| Samples | Weaving Density (pcs/cm) | | Air Permeability (mm/s) | Weight (g/m$^2$) | Thickness (mm) | Strength Values (gf) | |
|---|---|---|---|---|---|---|---|
| | Weft | Warp | | | | Weft | Warp |
| 100% Cotton | 28 | 34 | 1082 | 100 | 0.340 | 857.60 | 1734 |
| 100% Linen | 15 | 17 | 2478 | 100 | 0.385 | 2384 | 2475 |
| 100% Bamboo | 21 | 15 | 2152 | 100 | 0.355 | 3600 | 5433 |

Table 2

| PURITY OF NANOPARTICLES, PARTICLE SIZES AND VISCOSITY VALUES OF THE PREPARED COATING SOLUTION AND FORMULA | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Nanoparticle type** | **Degree of purity (%)** | **Particle size (nm)** | **Viscosity (cP)** | **Formula** | | | |
| | | | | **Material** | **Ratio** | **Material** | **Ratio** |
| Titanium Dioxide ($TiO_2$) | 99.9 | 17 | 7020 | Anionic Binder Acrylate (AC 111) | 20% | Anionic crosslinker/fixing agent(RUCO-COAT FX 8011) | 1.5% |
| Silicon Dioxide ($SiO_2$) | 98.5 | 55-75 | 11600 | Dispergator (AD 719) | 0.5% | Distilled Water | 75.5% |
| Zinc Oxide (ZnO) | 99.5 | 30-50 | 4800 | Anionic Thickener (RUCO-COAT TH 5020) | 1.5% | Nanoparticles | 1% |

paste applied to the fabrics in double layers was subjected to drying and thermofixing at 165°C for 2 min. Ataç GK40 RKL device was used for coating processes.

### Measurements and analysis

*Evaluation of FT-IR measurements*

Infrared (IR) spectroscopy is a tool for characterizing organic or inorganic compounds [49]. The IR spectrum shows the fingerprint of the measured surface with absorption peaks corresponding to the frequencies generated by the vibration of the bonds between the atoms that make up the substance [50]. Every meaning has its spectrum [51–53].

FT-IR analysis was applied to identify the internal bonds of the molecular structures of the obtained systems. In the infrared spectra examined, the presence and activity of the bioceramic material were analysed. The bandwidths of the measurements performed on the Perkin Elmer Spectrum IR device are shown.

*Antimicrobial activity analysis*

The antimicrobial activity of nano-treated and untreated fabric was quantitatively evaluated by standard test methods [54]. The test procedure applied is the 12$^{th}$ revision of the AATCC Test Method 100-2019, Assessment of Antibacterial Activity on Textile Materials test procedure [55]. The study was performed against gram-positive *S. Aureus* and gram-negative *E. Coli* bacteria. The colony counting method determines the results and is expressed as a percentage bacterial reduction (%R). For this test, the number of viable species in suspension is estimated, and the percentage reduction is measured relative to untreated samples. This procedure observes the reduction by measuring at Time 0, after 12 and 24 hours. This approach is designed for a surface capable of a 50–100% reduction in the required contact time [56]. The formula below (equation 1) calculates the percentage of bacteria that die within the specified time:

$$(\%)\ R = 100(C - A)/C \qquad (1)$$

where $A$ is the test treated at the end of the contact time (24 hours) and $C$ – the number of bacteria obtained from the treated test sample after inoculation (0 h).

*Mechanical properties*

Weight, thickness and tear strength tests were applied to the woven surfaces raw and after treatment and the results were analysed. Tear strength was measured by Elmendorf Digital Tear Strength device by ASTM D1424 standard. Measurements were performed in both the weft and warp directions of the fabrics. Average values are obtained from measurements of 5 specimens. All specimens were conditioned in the laboratory at 21 ± 2°C and 65 ± 2% relative humidity for 24 hours before each test.

## RESULTS AND DISCUSSION

### Evaluation of FT-IR measurements

For the Fourier Transform Infrared Spectrum (FT-IR) analysis of the woven surfaces coated with ZnO, $SiO_2$ and $TiO_2$, Nicolet is10, Thermo Scientific brand device was used. The FT-IR analysis images obtained are shown in figure 1.

When the FT-IR spectra of the treated fabric samples were examined, the -OH stretching vibration of cellulose was observed around 3330 cm$^{-1}$, and the stretching vibration of CH groups in the alkene chain was observed around 2900 cm$^{-1}$. The deformation vibration of -$CH_2$- was around 1445 cm$^{-1}$, C-H bending vibration was around 1370 cm$^{-1}$, C-O-C bonds gave peaks in 1160–1035 cm$^{-1}$ [57–61]. The characteristic peaks of Si-O-C and Si-O-Si bonds are observed at 1020 and 1100 cm$^{-1}$. Broadband is observed between 500–900 cm$^{-1}$ due to Ti-O vibration [62–65]. The bands around 500 cm$^{-1}$ and at lower frequencies are attributed to the bending vibration of the characteristic peak for Zn-O bonds [66]. FT-IR analysis proved the presence of zinc, silicon and titanium in the coatings.

### Evaluation of EDS measurements

EDS analysis is a method used in the elemental analysis of materials. It is a component of scanning electron microscopy. EDS analysis was performed using SEM images to show the elemental content of the

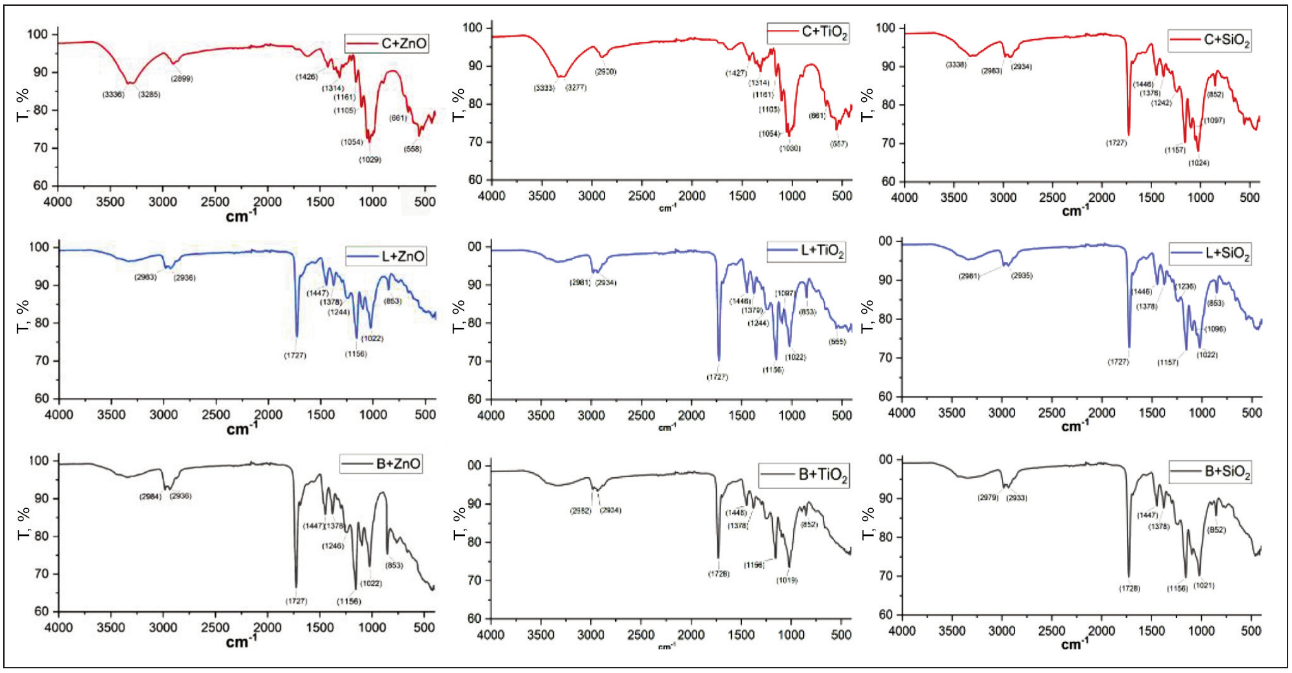



Fig. 1. FT-IR analysis results of cotton, linen and bamboo surfaces coated with coating paste

samples and to examine the elemental percentages and changes. Table 3 shows the elemental distributions of the samples.

When the analysis results (table 3/1b, 2b, 3b) are evaluated, the characteristic peaks of C and O in the EDS spectrum show the presence of these elements in the bioceramic nanoparticle structure. When the ZnO-coated surfaces are examined, the order of linen>bamboo>cotton is observed. The presence of element C increased after the bonding of ZnO nanoparticles with cellulose and hemicellulose in the structure of linen. When $TiO_2$-coated surfaces are examined, the bamboo>linen>cotton order is observed. After the bonding with hemicellulose and lignin in the structure of bamboo and linen, it is seen that the C element is detected on these surfaces more than cotton. When $SiO_2$-coated surfaces are examined, the order of bamboo>linen>cotton was determined as in $TiO_2$. $SiO_2$ and $TiO_2$ nanoparticles are thought to increase element C's presence in hemicellulose and lignin groups due to their building blocks. Table 3 lists the images of the surfaces taken at 20 µm after coating and the images of the presence of C, O, ZnO/$SiO_2$/$TiO_2$ elements after EDS analysis.

## Evaluation of SEM images

Scanning Electron Microscopy (SEM) was used to prove the presence of layers containing ZnO, $SiO_2$ and $TiO_2$ nanoparticles on the coated cotton, linen and bamboo surfaces. In the electron microscope, the general network appearance, whether the coating material has a uniform structure, the formation of particles, the smoothness of the structure, the superficial cross-section and nanoparticle particles were evaluated at 20 µm_500X in the step. The material distribution in the obtained materials has a uniform structure. Distributions are seen on the fibres, and it is observed that adhesion is provided everywhere. Table 3 (1a, 2a, 3a) lists the SEM images of each surface after treatment with the coating material.

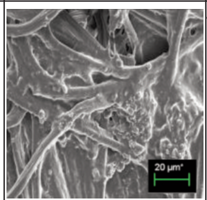
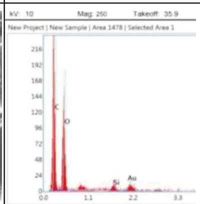
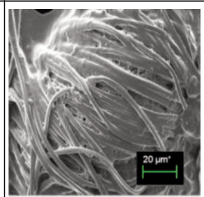
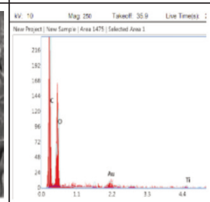
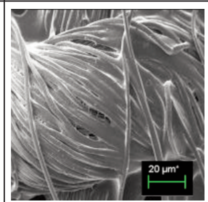
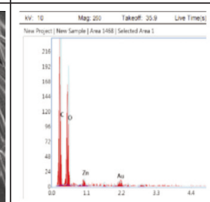
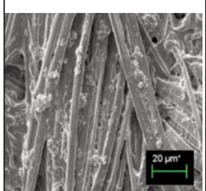
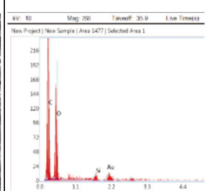
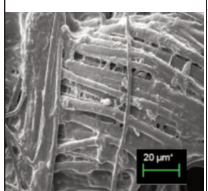
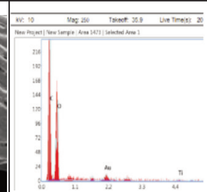
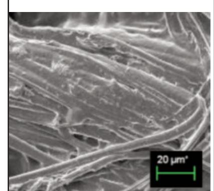
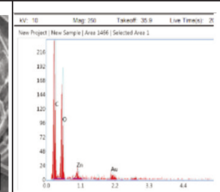
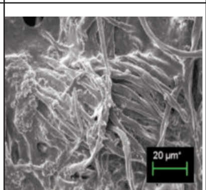
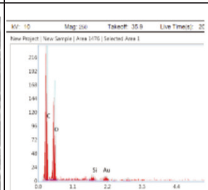
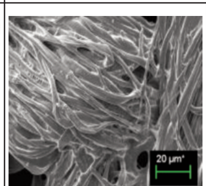
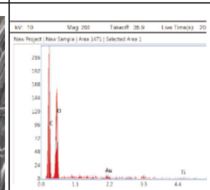
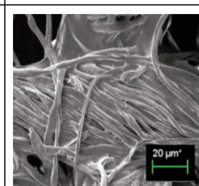
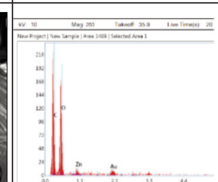
## Evaluation of antimicrobial activity

The percentage reduction of gram-positive and gram-negative bacteria of ZnO, $TiO_2$ and $SiO_2$ nanoparticle-coated cotton, linen and bamboo fabrics is presented as %R. In the application made by the AATCC 100 standard, textile samples are immersed in diluted bacterial solutions (Initial) and then dripped onto agar plates. Afterwards, the bacterial colonies on the agar plates were counted, and the results of bacterial reduction after 24 hours for *S. Aureus* and *E. Coli* in raw and nanoparticle-treated fabrics after $10^{-2}$ dilution are shown in table 4. The agar plate with the bacterial reduction image of all treated and untreated materials is shown in table 4.

When table 4 is examined, it is seen that bamboo has antibacterial properties (*E. Coli*, 49.56%), but cotton and flax do not (shown with (-) value in the table). After the coating processes, the cotton fabric did not gain antibacterial properties, but linen gained 100% antibacterial properties after the coating paste containing ZnO and $TiO_2$ nanoparticles. Bamboo, on the other hand, gained 100% antibacterial structure after coatings.

The size of NPs is important [40, 46, 69]. Better activities were observed for *S. Aureus* and *E. Coli* bacteria by colony counting method in structures with particle sizes less than 100 nm [70, 71]. The nanoparticle sizes used in this research are less than 100 nm (table 2).

Table 3

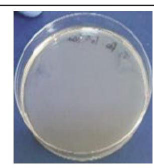
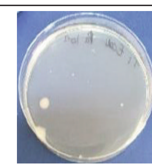
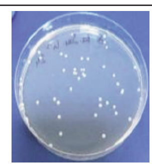
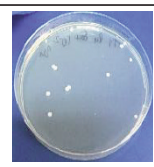
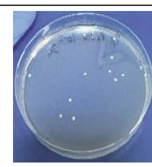
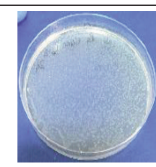
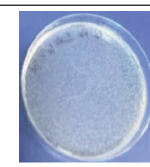
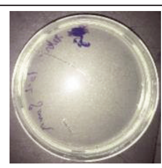
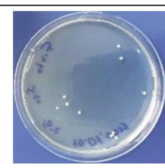
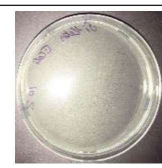
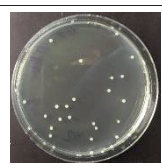
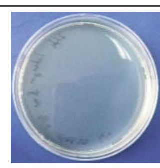
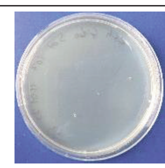
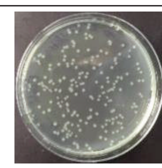
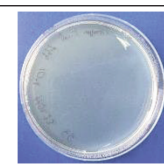
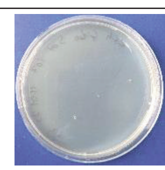
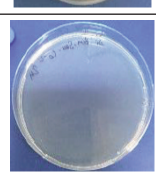
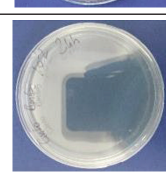
| SEM, EDS ANALYSIS RESULTS AND ELEMENT DISTRIBUTIONS OF COATING SURFACES | | | | | | |
|---|---|---|---|---|---|---|
| M | **1a** | **1b** | **2a** | **2b** | **3a** | **3b** |
| | SEM | EDS | SEM | EDS | SEM | EDS |
| | $SiO_2$ | $SiO_2$ | $TiO_2$ | $TiO_2$ | ZnO | ZnO |
| Bamboo |  |  |  |  |  |  |
| EDS | - | Wt% | - | Wt% | - | Wt% |
| | C | 60.79 | C | 66.41 | C | 57.96 |
| | O | 36.99 | O | 30.69 | O | 40.49 |
| | $SiO_2$ | 1.42 | $TiO_2$ | 2.18 | ZnO | 0.99 |
| Linen |  |  |  |  |  |  |
| EDS | | Wt% | | Wt% | | Wt% |
| | C | 60.09 | C | 66.04 | C | 60.4 |
| | O | 37.76 | O | 31.12 | O | 37.41 |
| | $SiO_2$ | 1.28 | $TiO_2$ | 2.19 | ZnO | 1.46 |
| Cotton |  |  |  |  |  |  |
| EDS | | Wt% | | Wt% | | Wt% |
| | C | 59.31 | C | 61.66 | C | 56.67 |
| | O | 38.74 | O | 35.79 | O | 14.51 |
| | $SiO_2$ | 1.36 | $TiO_2$ | 2.1 | ZnO | 1.05 |

**Mechanical Tests**

When the weight measurements of the surfaces are evaluated according to figure 2, *a*, the raw surfaces are woven with a constant weight of fabric which is 100 g/$m^2$. They were coated with a coating paste containing ZnO, $SiO_2$ and $TiO_2$. When the results are evaluated, bamboo fabric is heavier than linen (131.2 g), $SiO_2$ (136 g) and $TiO_2$ (139.2 g) coated surfaces coated with ZnO-containing paste. The weight of the bamboo surface increased after coating with $TiO_2$ and $SiO_2$ with 139.2 g and 136 g respectively. Since the differences in the moisture absorption rates of the raw surfaces used in the research and the absorption rates of the material after the coating process will differs, the weight values change.

In figure 2, *b*, 10 different parts of the coated surfaces were measured with a digital thickness gauge and then the calculated average values were tabulated. When the results are evaluated, raw linen (0.385 mm) is the thickest surface. According to the coating procedure, the coating paste was achieved with a 0.3 mm adjustable blade. However, the change in the absorption rates of the raw materials caused a change in the order of thickness values. Accordingly, the cotton surface with a thickness value of 0.373 mm with a 9.70% change in the surfaces with ZnO-containing paste stands out. Cotton is the densest material with an air permeability of 1082 mm/s and a density of 28/34 (weft/warp). Although ZnO has the lowest viscosity value (4800 cP), it is more adhered to the surface after the density of the fabric. $SiO_2$ and $TiO_2$ increased the weight of the bamboo surface more with a change of 20.56% and 19.15% respectively. $SiO_2$ has a viscosity value of 11600 cP and TiO2 7020 cP. They stand out as the best adherent materials on the bamboo surface.

Table 4

| AGAR PLATES AND %R VALUES AT BASELINE AND 24 HOURS AFTER COATING | | | | | | |
|---|---|---|---|---|---|---|
| **Surface** | **Cotton** | | | | | |
| Bacteria | *S. Aureus* | | | *E. Coli* | | |
| Coating | $SiO_2$ | $TiO_2$ | ZnO | $SiO_2$ | $TiO_2$ | ZnO |
| Beginning |  |  |  |  |  |  |
| 24th hour |  |  |  |  |  |  |
| %R | (-) | (-) | (-) | (-) | (-) | (-) |
| Surface | **Linen** | | | | | |
| Bacteria | *S. Aureus* | | | *E. Coli* | | |
| Coating | $SiO_2$ | $TiO_2$ | ZnO | $SiO_2$ | $TiO_2$ | ZnO |
| Beginning |  |  |  |  |  |  |
| 24th hour |  |  |  |  |  |  |
| %R | (-) | 100 | 100 | (-) | 100 | 100 |
| Surface | **Bamboo** | | | | | |
| Bacteria | *S. Aureus* | | | *E. Coli* | | |
| Coating | $SiO_2$ | $TiO_2$ | ZnO | $SiO_2$ | $TiO_2$ | ZnO |
| Beginning |  |  |  |  |  |  |
| 24th hour |  |  |  |  |  |  |
| **%R** | 100 | 100 | 100 | 100 | 100 | 100 |

According to figures 2, *c* and *d*, strength measurements were made with Elmendorf Digital Tear Strength device. When the results are evaluated, the strength values for weft and warp yarns without any coating material are ranked as bamboo>linen>cotton. While ZnO material increased the strength values of bamboo and linen material after coating, it strengthened in weft yarn on cotton surface but decreased in warp yarn. While the coating paste with $SiO_2$ increased the strength of the surface, it caused loss of strength on bamboo and cotton surfaces. On the surfaces coated with $TiO_2$ containing material, the strength values are seen as linen>bamboo>cotton. In figure 2, the strength change values of raw and coated materials after the coating process are tabulated. In accordance with the literature, the cotton woven surface lost value in the warp and weft direction after coating with ZnO [90–92].

## CONCLUSIONS

Within the scope of the study, after the literature review, ZnO was selected as the coating material due

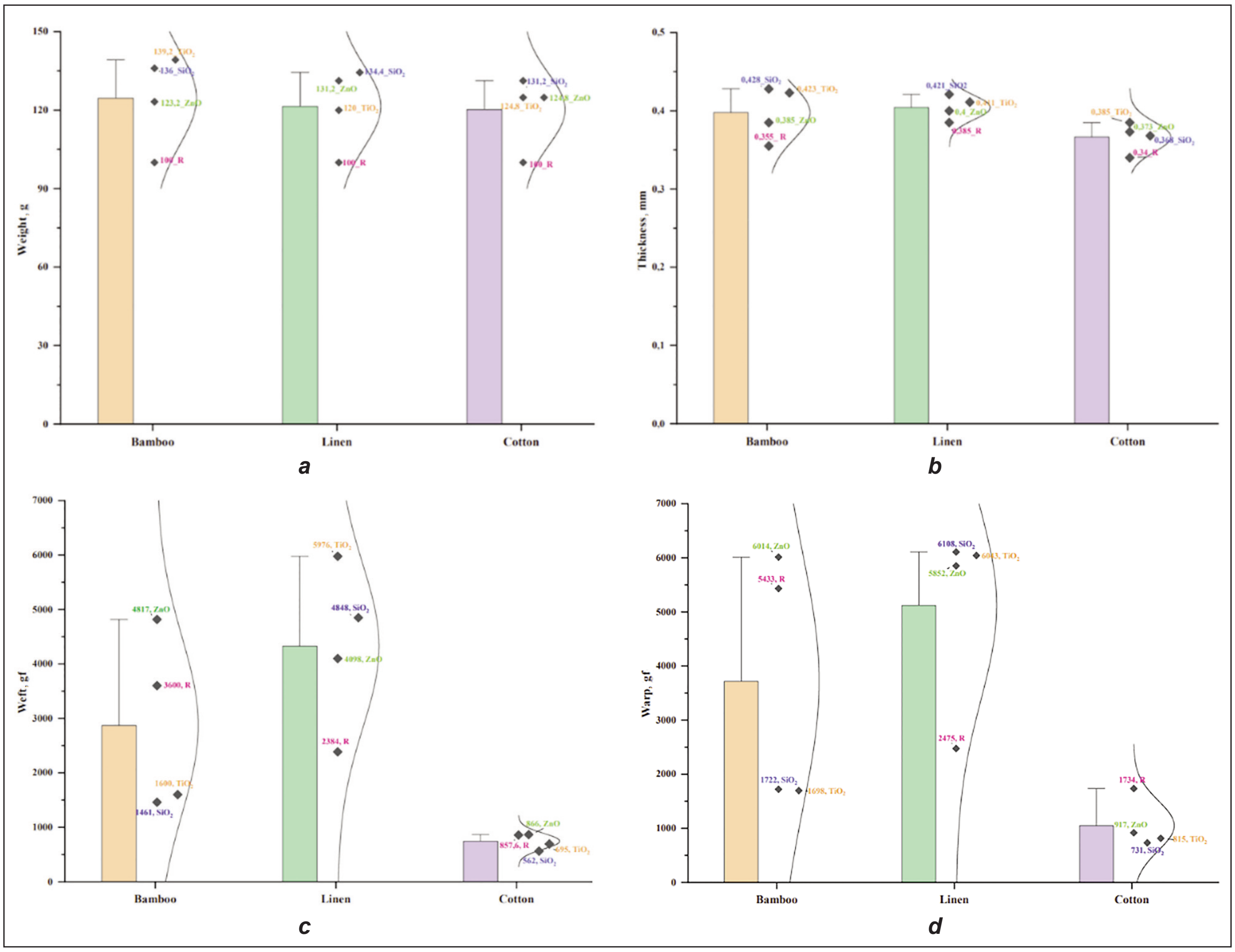



Fig. 2. Graphical changes on the woven surfaces: *a* – weight; *b* – thickness; *c* – strength on weft direction; *d* – strength on warp direction

to its UV protection, fibre protective structure and oxidative catalysis feature, $TiO_2$, which has all the properties of zinc oxide, as well as chemical and biological protective performance and self-sterilization feature, and nanoparticle forms of $SiO_2$ with its super waterproof finishing structure.

When the FT-IR analysis of the obtained surfaces is evaluated, it is seen that the materials provide adhesion on the surface. The related results are also seen with SEM and EDS analyses. The mechanical properties and antibacterial results of the surfaces were also examined.

Among the raw materials, only bamboo showed 49.56% resistance against *E. Coli* bacteria, while cotton and linen did not have antibacterial properties against gram-negative and gram-positive bacteria. Bamboo also did not show antibacterial properties against gram-positive (*S. Aureus*) bacteria.

It is seen that the coating paste prepared with ZnO, $TiO_2$, $SiO_2$ nanoparticles with superior properties applied to the surfaces have no effect on the cotton surface and cotton does not show antibacterial properties. No antibacterial structure was formed in linen with $SiO_2$. On the other hand, linen and bamboo after coating with ZnO, $TiO_2$ and bamboo after coating with ZnO, $TiO_2$, $SiO_2$ turned the material into a 100% protected structure in both bacterial species.

Studies in the literature show a decrease in the mechanical properties of cotton fabrics coated with ZnO nanoparticles. The investigations are consistent with the literature for cotton fabric. It is seen that the tear strength of other surfaces used in our study increased after ZnO coating. Considering the superior performance properties of ZnO nanoparticles and the fact that it is a relatively cheap and reliable material, it can be used for coating bamboo and linen surfaces rather than cotton.

The applied process was only tested on the 100% raw plain woven materials which are also non treated and plain weave material. Future studies can be applied to raw knitted surfaces, blended woven surfaces and on different weaving types. The produced materials obtained from this study is gathered as a simple and rapid production and can be used for the production of functional textile surfaces in the future.

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