SCIENTIFIC PAPER

# Influence of Texture and Nanomaterials on the Produced Natural Fiber Characteristics

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## Abstract

This research investigated the type of texture and nano-materials and evaluated the effect of these two parameters on the final properties of the fabric. The 100% warp-weft cotton fabric and electrospun cellulosic nano fabric, which are treated with strontium titanate and zinc titanate, are produced using is a specific method. Scanning electron microscopy and elemental mapping proved the existence of nanoparticles and helped to analyse the morphology of produced samples. The result of bactericidal property and its durability during washing cycles against *Escherichia coli* and *Bacillus cereus* (two common negativegram-negative/positive bacteria) was excellent. The strength and abrasion resistance of the treated specimens is higher than the untreated specimens due to presence of nanoparticles and their special structural characteristics and the bond formation of these nanoparticles with fiber. On the other hand, the anti-inflammatory property of samples enhanced in comparison with raw samples due to the reduction of the production of inflammatory cytokines by nanomaterials.



**Keywords:** Strontium Titanate, Zinc Titanate, Anti-Inflammatory, Electrospinning, Texture


**Highlights:**

- Influence of nano strontium titanate and zinc titanate on composite properties.
- Enhancing anti-inflammatory of composite by doping nano particles.
- Increasing bactericidal property and its durability by nano materials.
- Enhancing strength and abrasion resistance of composite.

## Introduction

In the ever-evolving world of textile manufacturing, researchers are constantly exploring innovative methods to enhance the strength and durability of fabrics. Two nanomaterials that have recently gained attention are strontium titanate and zinc titanate. These nanopowders have shown great potential in improving the strength and abrasion resistance of textiles and have remarkable properties such as bactericidal, self-cleaning, and UV blocking, etc. These properties are crucial in various industries where maintaining hygiene and preventing the spread of bacteria is of utmost importance [1-4].

Strontium titanate ($SrTiO_3$) and zinc titanate ($ZnTiO_3$) are both perovskite-type compounds that possess excellent electrical and mechanical properties. When incorporated into fabric finishes, these nanopowders can enhance the properties of textiles. The small size and high surface area of the nanoparticles allows for better penetration and adhesion to the fabric fibers, resulting in improved performance [5,6].

Strontium titanate is known for its high dielectric constant and piezoelectric properties. When applied as a fabric finish, it forms a thin, uniform layer on the fabric surface, which helps to strengthen the fabric structure. Additionally, strontium titanate nanoparticles can impart anti-static properties to the fabric, reducing the accumulation of static charges and preventing discomfort or damage caused by electrostatic discharge [7].

Zinc titanate, on the other hand, possesses excellent photocatalytic properties and can absorb ultraviolet (UV) radiation. By incorporating zinc titanate nanopowders into fabric finishes, textiles can become more resistant to UV degradation, thus prolonging their lifespan. This makes them suitable for outdoor applications where exposure to sunlight is common[8].

A study published in the Journal of Natural Fibers [9] examined the impact of nano strontium titanate-treated cork web on UV-blocking and strength of cork webs. The results showed a significant increment in UV-blocking property and improvement in tensile strength. This was attributed to the enhanced adhesion between the web and the nano particles, which resulted in a more robust fabric structure.

Another study conducted by Zohoori et al. [10,11] investigated the effects of incorporating strontium titanate and titanium dioxide nanopowders into cotton fabrics. The researchers found that the treated fabrics exhibited higher self-cleaning properties.

In the field of oncology, research studies have explored the potential of fabric treated with zinc titanate nanoparticles in inhibiting the growth of cancer cells. A study published in the International Journal of Nanomedicine [12] examined the cytotoxicity of zinc titanate-treated fabric on cancer cell lines. The results demonstrated selective cytotoxicity, with cancer cells experiencing apoptosis while healthy cells remained unaffected. This targeted approach holds promise for the development of garments that provide comfort and potential therapeutic benefits for cancer patients.

Moreover, studies have been conducted to evaluate the durability of the zinc titanate treatment on fabric. The fabric samples were subjected to washing and rubbing tests to assess the longevity of the antimicrobial and cytotoxicity properties. The results indicated that the treatment remained effective even after multiple wash cycles and abrasion highlighting the practicality and durability of fabric treated with zinc titanate [13-15].

Further studies have explored the durability of the nanomaterial finishing on fabric. The fabric samples were subjected to washing, strength and abrasion tests to evaluate the longevity of the anti-inflammatory properties. Results showed that the treatment remained effective even after multiple wash cycles, demonstrating the durability and practicality of incorporating nanoparticles into fabric treatments [16-19].

These research studies provide valuable insights into the potential of zinc titanate and strontium titanate as a fabric finish for enhancing the strength and abrasion resistance of textiles. By incorporating zinc titanate and strontium titanate nanopowders into fabric finishes, manufacturers can produce high-performance textiles that can withstand the rigors of everyday use. Producing nanofibers containing nano zinc titanate and strontium titanate has shown great potential in various applications such as catalysis, sensor technology, and energy storage. However, there are certain limitations that need to be addressed for further advancements in this field. One major limitation is the difficulty in achieving a homogeneous distribution of the nano Zn/Ti particles within the nanofiber matrix. This can lead to variations in the properties and performance of the resulting nanofibers. Another limitation is the lack of understanding regarding the mechanism of nanoparticle incorporation and its effect on the overall structure and properties of the nanofiber. There are several potential applications for producing nanofibers that contain nano Zn/Sr. One possible application is in the field of medicine. These nanofibers could be used to develop advanced wound dressings that promote faster healing and reduce the risk of infection. Overall, the production of nanofibers containing nano Zn/Sr opens up possibilities for various applications in medicine and environmental protection.

## Experimental

### Materials and Devices

Nano strontium titanate powder (CAS No.12060-59-2) with a molecular weight of 183.49 particle size of <100 nm. and density of 4.81g/mL was prepared from Sigma Aldrich. Also zinc titanate nano powder with a molecular weight of 161.26 and particle size of <100nm was prepared from Sigma Aldrich too. The 100% bleached cotton fabric with a warp density of 22yarn/cm, weft density of 18 yarn/cm, and fabric weight of 119.4 g/m$^2$ was prepared from Yazd-Baff Company. Bio-renewable succinic acid (CAS No.110-15-6) as a cross-link factor, Sodium hypophosphite and Schweizer's reagent was prepared from Merck. Euronda ultra-sonic bath model Eurosonic 4D, 350 W, 50/60Hz (Italy) was used. The tensile strength was examined by a tabletop uniaxial testing apparatus (INSTRON 3345). A double-head rotary platform method was used to study the abrasion resistance through ASTM D-3884-09. The specimen's morphology was investigated by scanning electron microscopy (SEM-MIRA3-TESCAN), and the samples were covered by gold film.

**Method**

As shown in Table 1, two kinds of texture with different percentage of nanomaterials were used. In samples A and B, warp/weft fabric was finished one with nano strontium titanate and the other with nano zinc titanate. In samples C and D, the electrospinning fabric (nonwoven) was finished with these two nanomaterials. The finishing method of samples A and B was as follow: in the first step the cotton fabric was washed with distilled water at 85°C for 60 min. Then the washed fabric was floated in sodium hypophosphite/succinic acid as a catalyst/cross-link agent (respectively) for 60 min. The ratio of sodium hypophosphite/succinic acid was 4/6(wt). In the next step the fabric was dried at 80°C for 4 min and immediately at 180°C for 2 min. During the above steps, a beaker of nano strontium titanate and a beaker of nano zinc titanate suspension were prepared and sonicated for half an hour in an ultrasonic bath. Then the cured and dried fabric was immersed in these suspensions and sonicated for 30 min at 80°C. Then the samples were kept in an oven for 3 min at 100°C to fix nano particles and finally finished samples were washed in an ultrasonic bath for 10 min to remove un-bonding nanoparticles. So, samples A and B were prepared by this method. The electrospinning method was used to produce samples C and D. In this method, 100% cellulose was dissolved in Schweizer's reagent ($[Cu(NH_3)_4(H_2O)_2](OH)_2$) and sonicated with 1.5% nanomaterials and loaded in a syringe on the electrospinning apparatus. The distance between the collector and nozzle was 15 cm, the drum speed was 135rpm, feeding rate was 0.5ml/h, the voltage was 20kV, and the traverse speed was 0.4m/min. So, nonwoven fabric is prepared during this method.

Table 1.

The technique and condition of the bactericidal feature were done through AATCC 100-2004 standard versus both Bacillus cereus (a gram-positive bacteria) and Escherichia coli (a gram-negative bacteria). The bactericidal feature was investigated through equation1 as below, where A is the quantity of bacteria recovered from the inoculated treated test specimen incubated over a day while B is the quantity of bacteria recovered from the inoculated treated test specimen immediately after inoculation.

$$\text{The reduction of bacteria } (\%) = \frac{\text{A}-\text{B}}{\text{A}} \times 100 \qquad \text{Eq.1}$$

In order to investigate the tensile property, the samples were cut to 5 cm × 3 cm sheets and loaded into the apparatus. The experiment was done at a rate of 5 mm/min.

Twenty-one male Wistar rats were chosen and protected in the same conditions for one day. All tests and experiments were done according to animal rights laws. Then the back skin of the rats was shaved and coated with produced samples (5 rats for each sample and one for the control sample, which its back was coated with Indomethacin cream as reference sample) and tied firmly.

## Results and Discussion

### Morphological Analysis

Scanning electron microscopy images of samples is illustrated in Figure 1. Figure1(A-B) shows that the nano particles are distributed in fibers. Also, their elemental mapping analysis proves the existence of Zn and Sr particles and proved their good distribution on the surface of fibers (it must be mentioned that aggregation of nanoparticles cause nanoparticles low effectiveness and well distribution of them increase their effectiveness). Also, as shown in Figure (C-D), the nanofibers are formed through electrospinning, which contains nano particles. By close look, it demonstrates that the thickness of nano fibers is about 40 nm, which is very good. On the other hand, elemental mapping of these nano fibers proves the existence and good distribution without aggregation or agglomeration. (The elemental mapping of Sr particles is shown with green dots and the elemental mapping of Zn particles is shown with red dots.)

Figure 1.

**Bactericidal Properties and Durability**

*Escherichia coli* and *Bacillus cereus* are two common negative/positive bacteria, respectively. Bacillus cereus is a rod-shaped bacteria found in abundance in food and soil and can cause nausea, diarrhea, and vomiting syndrome [20]. On the other hand, the gram-negative bacteria E.coli can cause the gastroenteritis, urinary tract infections, neonatal meningitis, hemorrhagic colitis, and Crohn's disease[21]. Nano ZnO is biocompatible for pharmaceutical textile usages[22]. Furthermore, nano particles of ZnO have unparalleled specifications such as photocatalytic properties and bacteriostatic effect [23]. As it is demonstrated in Figure 2, the bactericidal property of all samples against *Escherichia coli* are higher than those of *Bacillus cereus*. This phenomenon is due to the various stoutness and thicknesses of the cell walls of bacteria. In contrast, the cell wall thickness of *Escherichia coli* is lower than *Bacillus cereus* (10-20nm and 20-40 nm, respectively). The bactericidal properties of strontium titanate and zinc titanate nanopowders can be attributed to their unique composition and structure. These powders are composed of tiny particles, typically less than 50 nanometers in size, which allows for more significant surface area contact with bacteria. When these nano powders come into contact with bacteria, their structure disrupts the cell walls of the microorganisms, preventing their growth and spread. Furthermore, these nano powders' high surface area-to-volume ratio enhances their bactericidal effectiveness. The increased surface area provides more opportunities for the nano powders to interact with bacteria, maximizing their antibacterial action. Additionally, the nano-sized particles can penetrate the bacteria more effectively, ensuring a higher degree of eradication. While the bactericidal properties of strontium titanate and zinc titanate nano powders is impressive, their durability is equally essential in ensuring long-term effectiveness. In applications where these nanopowders are subjected to repeated washing cycles, it is crucial that their antibacterial effect remains intact. Durability in antimicrobial materials refers to their ability to withstand wear and tear, including exposure to harsh conditions such as washing, without compromising their antimicrobial properties. For strontium and zinc titanate nanopowders, durability is key in maintaining their bactericidal effectiveness over an extended period. As it was shown, bactericidal durability after 15 washing cycles was excellent and is more than 93% for both grams negative/positive bacteria. The exceptional durability of strontium titanate and zinc titanate nano powders can be attributed to their inherent properties and structural characteristics. These materials possess high chemical stability, allowing them to withstand exposure to various detergents, chemicals, and environmental factors without degradation. Additionally, their unique structure ensures that the antibacterial effect remains intact, even under challenging conditions. By comparing bactericidal property of samples, it demonstrates that warp/weft samples have a little higher antibacterial property in comparing of nonwoven samples, but this is not significant and it is negligible. On the other hand, the bactericidal property of samples which contain Sr is higher than the samples which have Zn. Strontium titanate and zinc titanate nano powders share similar properties and demonstrate exceptional bactericidal effectiveness. However, strontium titanate nano powder exhibits excellent photocatalytic properties, which can further enhance its bactericidal action. When exposed to light, strontium titanate nano powder generates reactive oxygen species (ROS) that contribute to the destruction of bacteria. This photocatalytic property makes it particularly effective in environments with ample light exposure, such as hospitals or outdoor applications.

Figure 2.

**Strength and Abrasion Properties**

Fabrics are subjected to various stressors and forces during their lifespan, including stretching, bending, and abrasion. The strength and abrasion resistance of a fabric determine its durability and ability to withstand wear and tear. Traditionally, fabric finishes like coatings or treatments have been used to enhance these properties. However, the introduction of nanotechnology has opened up new possibilities for fabric finishing.

This comprehensive research study delves into the detailed analysis of the durability and strength of textile materials, with a specific focus on abrasion resistance and tensile strength of treated and untreated fabric samples. The aim of this section is to discover how different conditions can enhance the performance of fabrics when subjected to stress and wear. To simulate regular wear, both sets of fabric samples were subjected to abrasion tests. These tests are designed to mimic the friction and stress that fabrics endure during their lifespan. The durability of a fabric is often gauged by its ability to retain integrity and functionality after repeated abrasive wear, which reflects on the quality of the material for potential uses such as clothing, furniture upholstery, or industrial applications. The abrasion resistance analysis was done by a double-head rotary platform technique through ASTM D-3884-09. For each specimen, a rubbing test of 50 cycles was done and the discrepancy in specimen mass before and after abrasion was studied. Once the abrasion tests were completed, the weight of the fabric samples was recorded. These measurements were crucial in quantifying the percentage of abrasion resistance. By comparing pre-test and post-test weights, we calculated the mass lost due to the abrasion, indicating how much of the material was worn away. A lower percentage of weight loss signifies increased resistance to abrasion, a desirable trait in many textile applications. As shown in Table 2, the abrasion resistance of the treated specimens are higher than the untreated specimens. From the analysis of the data obtained, treated samples, indicated as A, B, C, and D, showcased a significant enhancement in both abrasion resistance and tensile strength when contrasted with their raw counterparts. This improvement is a testament to the effectiveness of the nanomaterial treatments employed, contributing to the overall performance and lifespan of the fabrics. Within the treated samples, a compelling insight was that Sample A led the treated warp/weft group with an impressive abrasion resistance of 91.68% and a 30.11% increase in tensile strength. Similarly, in the nonwoven category, Sample C outperformed others with an exceptional 86.51% abrasion resistance and a marked 34.54% improvement in tensile strength. This is due to the present of strontium titanate and its special structural characteristics and the bond formation of this nanoparticle with fiber. The findings of the study clearly illuminate the positive impact that fabric treatments can impart on the functional attributes of textile materials. The evidence indicates that through scientific processing and treatment, even fabrics that are inherently less resistant to wear and tension can be significantly fortified, thus extending their potential applications and service life. The implications of such developments hold substantial value for the textile industry, which constantly seeks to innovate and improve material performance to meet the demands of various consumer and industrial markets.

Table 2.

**Anti-inflammatory Analysis**

Anti-inflammatory properties in fabric play a crucial role in providing relief to individuals with sensitive skin or skin conditions. Redness, irritation, and itching are common issues that many people face, and these can be exacerbated by wearing certain fabrics. However, fabric treated with nano strontium titanate and zinc titanate contains nanoparticles that possess anti-inflammatory properties. These nanoparticles help to reduce inflammation and soothe the skin, providing a much-needed respite for those with skin sensitivities. Based on the Winter method [24], before and after of carrageenan injection, the diameter of the hind paw was calculated by a calliper and every one-hour measuring was repeated. The results are shown in Figure 3 as an edema diagram. The control sample quickly reduced the edema, but the samples (A-D) demonstrated the anti-inflammatory property after 2h, and after 5-6h the effect of samples A and C were close to each other, while samples B and D had anti-inflammatory property but not as well as samples A and C. Nano strontium titanate, a compound composed of strontium, titanium, and oxygen, is known for its unique properties that make it a valuable addition to fabric treatments. When incorporated into the fabric, nano strontium titanate enhances the anti-inflammatory properties, providing a soothing effect to the wearer. Nano strontium titanate reduces the production of inflammatory cytokines, which are responsible for triggering inflammation in the body. The nanoparticles in the fabric interact with the skin, releasing ions that modulate the inflammatory response, thereby reducing redness, irritation, and itching. This is particularly beneficial for individuals with sensitive skin or skin conditions such as eczema or dermatitis. Furthermore, nano strontium titanate has been found to have antioxidant properties, which contribute to its anti-inflammatory effects. Oxidative stress is a common factor in many inflammatory conditions, and the presence of antioxidants helps neutralize harmful free radicals, reducing inflammation and promoting skin health. The incorporation of nano strontium titanate into fabric treatments harnesses these beneficial properties, offering a unique solution for individuals seeking comfortable and skin-friendly clothing options.

Figure 3.

**Conclusion**

The results gained in this paper demonstrate that the kind of texture has an effect on final product properties. Also, using nanomaterials (strontium titanate and zinc titanate) besides the method of composite fabrication can improve the chemical and physical properties. Anti-inflammatory properties of produced samples increased due to nanoparticle interaction with the skin cells and releasing ions which modulate the inflammatory response. The strength and abrasion resistance of the produced samples enhanced and the results indicate that strontium titanate has a better effect in this experiment. On the other hand, the antibacterial properties of the samples were very good for both texture and materials, against both negative and positive bacteria, which makes this product a suitable option for mass production. Accordingly, the research not only contributes valuable data and insights to the fabric production sector but also propels forward the understanding of how different treatments can fundamentally alter the characteristics of both traditionally woven and nonwoven textiles. Moreover, future work can focus on characterizing the structural and functional properties of nanofibers containing nano strontium titanate and zinc titanate. Additionally, efforts can be made to explore new applications for these nanofibers, such as antimicrobial coatings or water purification membranes. By addressing the current limitations and conducting comprehensive research on nanofibers containing nano strontium titanate and zinc titanate, we can unlock their full potential and contribute to advancements in various technological fields.

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**Availability of data**

Data available on request from the authors

**Conflict of Interest**

All authors declare that they have no conflicts of interest.

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## Figure Captions

Figure1. SEM of samples and elemental mapping of Sr and Zn

Figure2. Bactericidal properties of samples and their washing durability

Figure3. Inflammatory diagram of samples

Table 1. Specification of samples

| Sample Code | Texture Type | $SrTiO_3$ (%) | $ZnTiO_3$ (%) |
|---|---|---|---|
| A | Warp/Weft | 1.5 | 0 |
| B | Warp/Weft | 0 | 1.5 |
| C | Nonwoven | 1.5 | 0 |
| D | Nonwoven | 0 | 1.5 |

Table 2. Abrasion resistance and tensile strength of samples

| Sample | Fabric weight before abrasion (g) | Fabric weight after abrasion (g) | Abrasion resistance (%) | Tensile strength(MPa) | Improved tensile strength (%) |
|---|---|---|---|---|---|
| Raw(warp/weft) | 5.896 | 4.993 | 84.68 | 0.694 | |
| A | 6.744 | 6.183 | 91.68 | 0.993 | 30.11 |
| B | 6.193 | 5.507 | 88.92 | 0.862 | 19.48 |
| Raw(nonwoven) | 4.075 | 3.188 | 78.23 | 0.451 | |
| C | 4.842 | 4.189 | 86.51 | 0.689 | 34.54 |
| D | 4.905 | 4.173 | 85.07 | 0.617 | 26.90 |

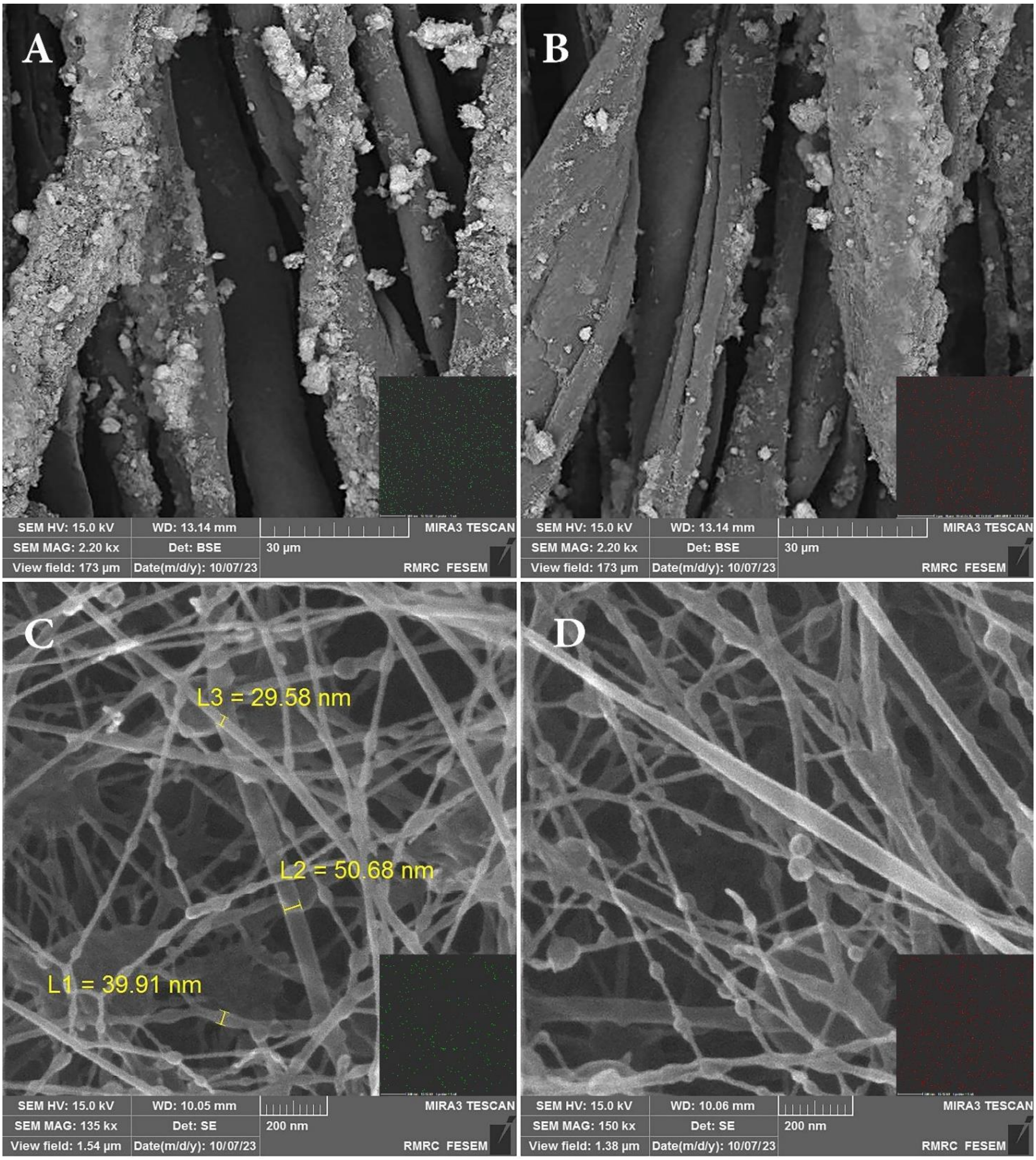
A
SEM HV: 15.0 kV
WD: 13.14 mm
MIRA3 TESCAN
SEM MAG: 2.20 kx
Det: BSE
30 µm
View field: 173 µm
Date(m/d/y): 10/07/23
RMRC FESEM
B
SEM HV: 15.0 kV
WD: 13.14 mm
MIRA3 TESCAN
SEM MAG: 2.20 kx
Det: BSE
30 µm
View field: 173 µm
Date(m/d/y): 10/07/23
RMRC FESEM
C
L3 = 29.58 nm
L2 = 50.68 nm
L1 = 39.91 nm
SEM HV: 15.0 kV
WD: 10.05 mm
MIRA3 TESCAN
SEM MAG: 135 kx
Det: SE
200 nm
View field: 1.54 µm
Date(m/d/y): 10/07/23
RMRC FESEM
D
SEM HV: 15.0 kV
WD: 10.06 mm
MIRA3 TESCAN
SEM MAG: 150 kx
Det: SE
200 nm
View field: 1.38 µm
Date(m/d/y): 10/07/23
RMRC FESEM

Figure 1

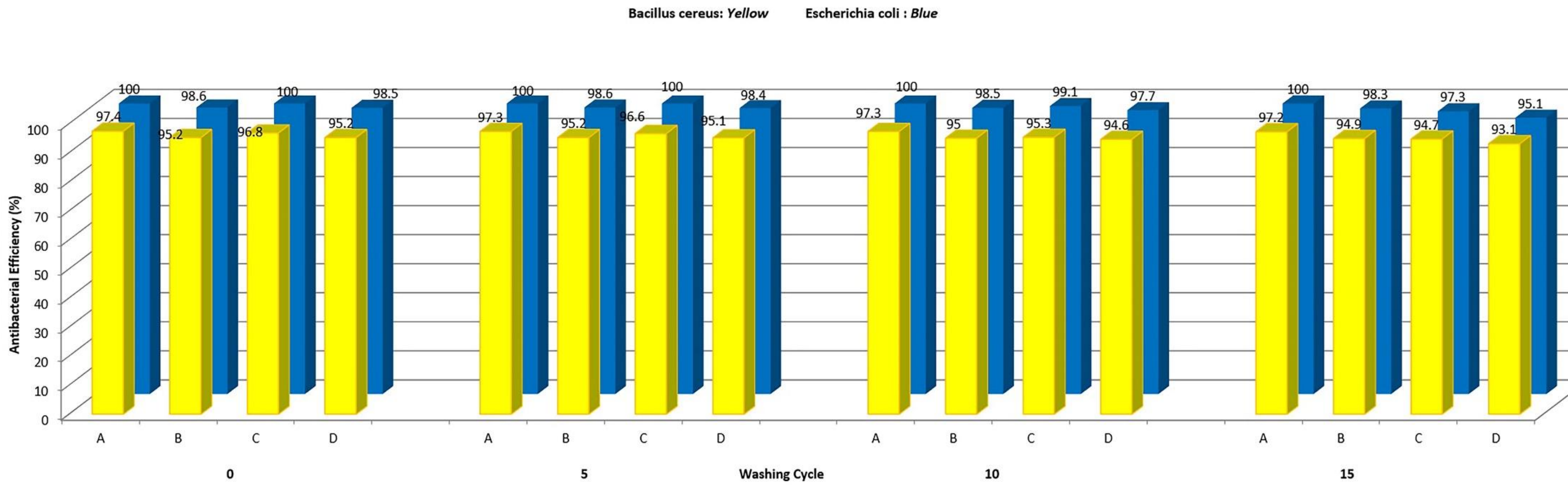
Bacillus cereus: *Yellow*
Escherichia coli : *Blue*
Antibacterial Efficiency (%)
Washing Cycle
0
5
10
15
A
B
C
D
100
97.4
98.6
95.2
100
96.8
98.5
95.2
100
97.3
98.6
95.2
100
96.6
98.4
95.1
100
97.3
98.5
95
99.1
95.3
97.7
94.6
100
97.2
98.3
94.9
97.3
94.7
95.1
93.1

Figure 2

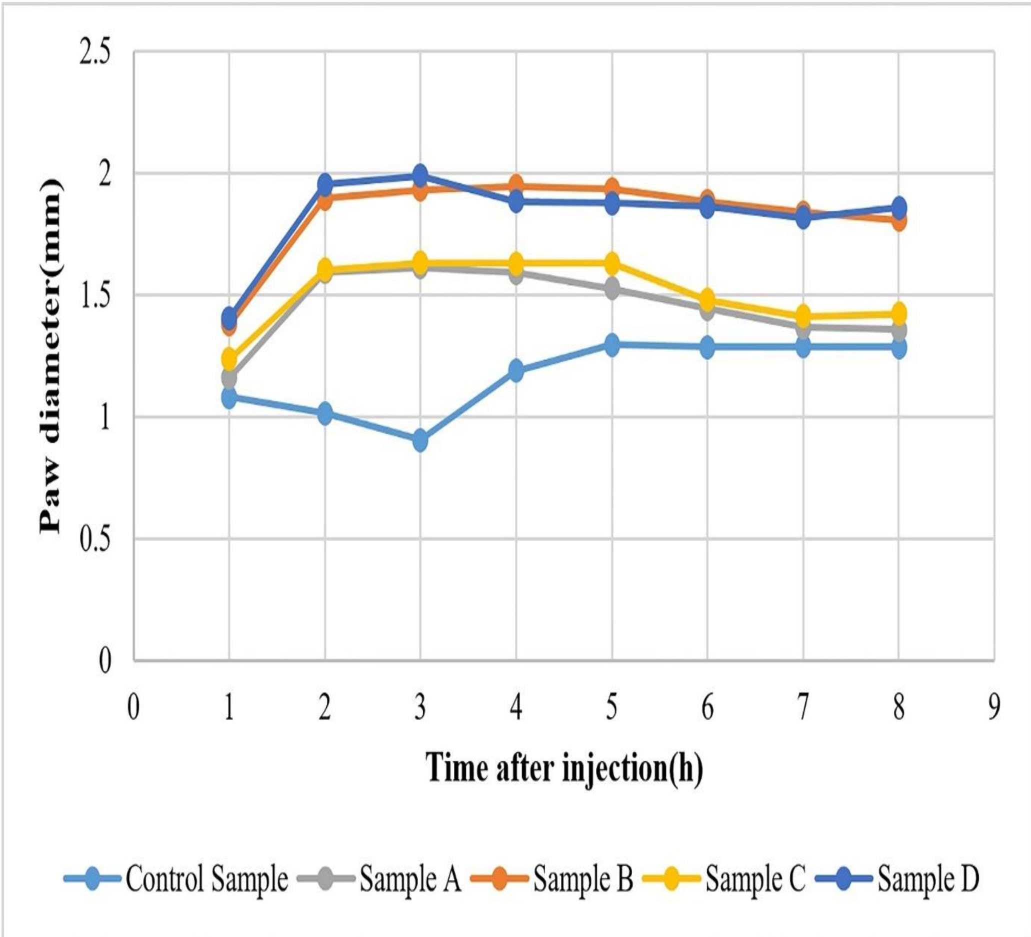
2.5
2
1.5
1
0.5
0
Paw diameter(mm)
0
1
2
3
4
5
6
7
8
9
Time after injection(h)
Control Sample
Sample A
Sample B
Sample C
Sample D

Figure 3