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# Effect of different washing processes, twill direction and yarn types on the performance properties of denim fabrics

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**ABSTRACT – REZUMAT**

**Effect of different washing processes, twill direction and yarn types on the performance properties of denim fabrics**

*This study aims to investigate the effects of different washing processes, twill directions, and yarn types on the performance properties of denim fabrics. For this purpose, 100% cotton elastane, 85% cotton/15% Modal elastane, and 85% cotton/15% Tencel elastane including denim fabrics were produced with two different weaves (3/1 Z and 3/1 S), and four different industrial washing operations were applied to these denim fabrics. In addition, untreated fabrics (not industrially washed) were used to compare the performance of the fabrics before and after industrial washing. The highest warp-breaking strength values were observed in the rinse-washed fabrics, whereas the highest shrinkage, elasticity, and rubbing fastness values were observed in the bleach-washed fabrics. In addition, it can be said that industrial washing processes reduce the growth values of untreated fabrics and reduce the bagging during use. Although the crystallisation degree of Tencel fibre is higher than that of Modal fibre, it was concluded that the use of Modal fibre with cotton increased the strength values. In contrast, the use of Tencel fibre with cotton increased the elasticity and rubbing fastness values of the denim fabrics.*

***Keywords:*** *denim, Tencel, Modal, bleach washing, enzyme washing, rinse washing, stone washing*

**Influența diferitelor procese de spălare, direcția legăturii diagonal și tipurile de fire asupra proprietăților de performanță ale țesăturilor denim**

*Acest studiu își propune să investigheze influența diferitelor procese de spălare, direcțiile legăturii diagonal și tipurile de fire asupra proprietăților de performanță ale țesăturilor denim. În acest scop, ţesături din 100% bumbac elastan, 85% bumbac/15% Modal elastan și 85% bumbac/15% Tencel elastan, inclusiv țesături din denim, au fost produse cu două legături diferite (3/1 Z și 3/1 S) și patru operaţii de spălare industriale diferite au fost aplicate acestor ţesături denim. În plus, țesăturile netratate (care nu au fost spălate industrial) au fost folosite pentru a compara performanța țesăturilor înainte și după spălarea industrială. Cele mai mari valori ale rezistenței la rupere a urzelii au fost observate la țesăturile spălate şi clătite, în timp ce cele mai mari valori de contracție, elasticitate și rezistență la frecare au fost observate la țesăturile spălate cu înălbitor. În plus, se poate spune că procesele de spălare industrială reduc valorile de creștere ale țesăturilor netratate și reduc deformarea în timpul utilizării. Deși gradul de cristalizare al fibrei Tencel este mai mare decât cel al fibrei Modal, s-a ajuns la concluzia că utilizarea fibrei Modal cu bumbac a crescut valorile rezistenței, în timp ce utilizarea fibrei Tencel cu bumbac a crescut elasticitatea și valorile de rezistență la frecare ale țesăturilor denim.*

***Cuvinte-cheie****: denim, Tencel, Modal, spălare cu înălbitor, spălare cu enzime, spălare cu clătire, spălare chimică*

## INTRODUCTION

Denim fabrics are typically produced as 100% cotton or polyester in the weft direction. Today, expectations from denim have increased, and consumers demand aesthetic, comfort, and performance features. Different fibre structures are used in denim production to satisfy comfort features. Owing to the increasing consumption rates of natural textile fibres, cellulosic regenerated fibres (viscose, Modal, and Tencel) have emerged. Tencel fibre, which can be given as an example of these fibres, provides production opportunities without harming the environment. Modal fibres are preferred especially in textile products where comfort, aesthetics, brightness, and naturalness are sought. Currently, yarns such as core-spun and dual-core are used in denim structures to improve elasticity and recovery properties. In addition, different industrial washing processes (bleach, enzyme, rinse and stone) have been applied to denim fabrics to improve their aesthetic properties. Sülar and Kaplan investigated the impact of different finishing operations on the performance of denim fabric. It was found that stone washing and its combination with bleaching produced pleasant hand assessment results, despite poor mechanical properties [1]. Khan and Mondal (2012), investigated the amount of enzyme, washing temperature, and time on indigo-dyed cotton denim fabrics. The results indicated that enzyme washing decreased the tensile strength, stiffness, and colour shade of denim fabrics [2]. Juciene et al. explored the impact of laser treatment and industrial washing on denim fabrics. It was observed that the thickness of fabrics increased after laser operation and industrial washing; however, mechanical features were damaged because the fabric became thinner [3]. Another study investigated the impact of washing operations on the physical properties of twill and dobby woven denim fabrics. The results showed that the colourfastness values of the washed and unwashed fabrics were the same, and the highest shrinkage was measured in the weft direction for the light-washed fabrics [4]. While some studies on denim fabrics have focused on the impact of the washing process, others have focused on the elasticity features of denim fabrics and the elastane yarn used in the weft. Eryürük investigated the effects of elastane on the performance of denim fabrics. It was found that elastane increased the drape and handling features of denim fabrics by decreasing bending and shear stiffness [5]. In another study, the impact of the elastane composition on the stretch and bagging features of denim fabrics was investigated. It was found that the bagging and permanent bagging results for denim fabrics declined with an increase in the elastane ratio [6]. Üte investigated the impact of core-spun and double-core yarns in the weft direction on the mechanical and dimensional features of denim fabrics. It was found that the elongation and elasticity of double-core woven fabrics were higher than those of core-spun woven fabrics [7]. In another study, the impact of the elastane properties on the dimensional and mechanical features of stretchable denim fabrics was investigated. It was found that the linear density and draft ratio of elastane equally affect the stretchability, stiffness, skewness, and bow of denim fabrics [8]. Shaw and Mukhopadhyay (2021) investigated the impact of wear on body movement and shape retention, so the effect of the fabrics on the first break, recovery and flexibility properties, and the effect of the elastane ratio were examined. It was found that fabrics with higher elastane content suffered more loss of shape retention owing to abrasion [9].

As a result of the literature research, it was observed that there are not many studies on the effect of weft yarns with different fibre compositions on the performance properties of denim fabric, and the studies are mostly focused on cotton denim fabrics. This study aims to investigate the effects of using cotton/elastane, cotton/Tencel elastane, cotton/Modal elastane weft yarns, two twill directions (S and Z), and industrial washing differences on the performance properties of denim fabric. In addition, untreated fabric samples were used to compare the effects of industrial washings on the performance properties of denim fabrics.

## MATERIALS AND METHODS

In this study, three different types of weft yarn and two different weave types (S and Z-twill directions) were used to produce 3/1 twill-weaved denim fabrics. All the fabrics were woven with the same warp yarns by exchanging the weft yarns. The yarns used in all fabrics were produced by twisting in the Z direction. The properties of the tested samples and the washing operations applied are listed in table 1. Denim fabrics composed of 100% cotton elastane, 85% cotton 15% Modal elastane, and 85% cotton 15% Tencel elastane were treated with different industrial washing methods such as bleach, enzyme, rinse, and stone washings, to improve fabric quality and comfort. In addition, fabrics subjected to industrial washing processes were compared to untreated fabrics (not industrially washed). The flow of the industrial washing processes is presented in table 2. During the bleach-washing process, the bleaching effect was applied to the denim fabric with sodium hypochlorite. A soft touch effect has been given to the fabrics with the rinse-washing process. In the enzyme-washing process, the denim fabric is given a soft and shiny touch with the help of the cellulase enzyme. In the stone washing process, with the help of pumice stones, the denim fabric is given a soft and full attitude as well as ageing effects. The thickness of the fabrics was measured according to the TS 7128 EN ISO 5084 standard using a James Heal thickness tester (ASTM D1777). The shrinkage values of the denim fabrics in the weft and warp directions after washing were measured using the ISO 6330 3XHL test standard (%). The Crockmaster device and the AATCC 8 standard were used to measure the rubbing fastness values of the fabrics under dry and wet conditions. The breaking strength values of fabrics were measured with Titan 5 device according to ASTM D-5034 and the elasticity value of fabrics was measured with this device according to EN 14704-1 9.1 Method A. The tear strength of the denim fabrics in the warp and weft directions was measured according to the ASTM D-1424 test standard using an Elmatear device. The growth values of the fabrics were measured using a Prowhite test device, according to ASTM3107. All washing operations were performed using the same machine to eliminate machine differences. The effect of the factors was investigated by performing a multivariate test in the SPSS 28 statistical package program, and the Student-Newman-Keuls (SNK) test was performed to analyse the difference between the groups at a level of $p < 0.05$.

## RESULTS AND DISCUSSIONS

### Results of shrinkage in warp and weft direction

The shrinkage values of the fabric in the weft and warp directions were determined after washing to ensure that the designed garment was produced by predetermined dimensions during the usage phase. More shrinkage values were observed in the weft direction because elastane yarn was used in the denim structure, as in a previous study. Double-core and core-spun weft yarns were used in the denim structure, and the highest shrinkage value in the weft direction was measured at 23% in the denim [7]. For

Table 1

| PROPERTIES OF DENIM FABRICS | | | | | |
|---|---|---|---|---|---|
| **Fabric type** | **Warp yarn count (Ne)** | **Weft yarn count (Ne)** | **Composition** | **Washing type** | **Weight ($g/m^2$)** |
| CZ | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Untreated | 322 |
| CZ1 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Bleach | 405 |
| CZ2 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Enzyme | 396 |
| CZ3 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Rinse | 396 |
| CZ4 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Stone | 408 |
| CS | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Untreated | 330 |
| CS1 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Bleach | 393 |
| CS2 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Enzyme | 388 |
| CS3 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Rinse | 387 |
| CS4 | 9.97 | 16 | 100% Cotton + 78 Dtex Elastane | Stone | 396 |
| MZ | 9.97 | 16 | 85%Cotton + 15% Modal + 78 Dtex Elastane | Untreated | 337 |
| MZ1 | 9.97 | 16 | 85%Cotton + 15% Modal + 78 Dtex Elastane | Bleach | 415 |
| MZ2 | 9.97 | 16 | 85% Cotton + 15% Modal + 78 Dtex Elastane | Enzyme | 412 |
| MZ3 | 9.97 | 16 | 85% Cotton + 15% Modal + 78 Dtex Elastane | Rinse | 411 |
| MZ4 | 9.97 | 16 | 85% Cotton + 15% Modal + 78 Dtex Elastane | Stone | 419 |
| MS | 9.97 | 16 | 85% Cotton + 15% Modal + 78 Dtex Elastane | Untreated | 327 |
| MS1 | 9.97 | 16 | 85% Cotton + 15% Modal + 78 Dtex Elastane | Bleach | 401 |
| MS2 | 9.97 | 16 | 85% Cotton + 15% Modal + 78 Dtex Elastane | Enzyme | 407 |
| MS3 | 9.97 | 16 | 85% Cotton + 15% Modal + 78 Dtex Elastane | Rinse | 402 |
| MS4 | 9.97 | 16 | 85%Cotton + 15% Modal + 78 Dtex Elastane | Stone | 406 |
| TZ | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Untreated | 340 |
| TZ1 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Bleach | 410 |
| TZ2 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Enzyme | 412 |
| TZ3 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Rinse | 411 |
| TZ4 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Stone | 418 |
| TS | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Untreated | 321 |
| TS1 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Bleach | 403 |
| TS2 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Enzyme | 376 |
| TS3 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Rinse | 397 |
| TS4 | 9.97 | 16 | 85% Cotton + 15% Tencel + 78 Dtex Elastane | Stone | 403 |

Note: * C = 100% Cotton elastane fabric, M = Modal included fabric, T = Tencel included fabric, Z = twill direction Z, S = twill direction S, 1 = bleach washing, 2 = enzyme washing, 3 = rinse washing and 4 = stone washing.

almost all fabric types, the lowest shrinkage values were measured for the untreated fabrics, except for rinse washings. The highest shrinkage values in the warp direction were observed in the fabrics produced with MZ2 and MZ4 coded Modal blended weft yarn, and in which enzyme and stone washing operations were performed (figure 1). When the shrinkage values in the weft direction were examined, the determining factor was found to be the weaving direction. The fabrics woven in the Z-twill direction exhibited more shrinkage than those woven in the S-twill direction, even though the weft yarn was the same. The SNK test of the shrinkage values is presented in table 3. The cotton/Modal elastane and cotton/Tencel elastane weft yarn woven fabrics exhibited significant differences in the warp direction, with the cotton/Tencel weft yarn woven fabrics exhibiting the lowest shrinkage values. When the effect of industrial washing on the shrinkage values in the warp and weft directions was examined, rinse washing showed statistically different results, and the lowest shrinkage values were measured for this washing. Previous studies have stated that the effect of rinse washing on the shrinkage value was higher than that of other washes [10]; however, the rinse-washed fabrics showed the lowest shrinkage value for all fabric types in this study. In another study, more shrinkage values were obtained by bleach washing in the warp direction and by enzyme washing in the weft direction [11]. It was observed that rinse washing reduces the shrinkage value of the fabric, while bleach washing increases this value.

Table 2

| WASHING PROCESS CHEMICALS AND DETAILS | | | | | | |
|---|---|---|---|---|---|---|
| Process No/Name | Step | Washing process details | | | | |
| | | Time (min.) | Temperature (°C) | Chemicals | Quantity | After treatment |
| 1/Bleach washing | Bleaching | 15 | 40–60 | Hypo | 2 g/l | Rinsing 1 min cold |
| | Neutralization | 5 | Cold | Sulphite | 2 g/l | Rinsing 1 min cold |
| | Drying | 35–40 | 80 | - | - | Spray |
| 2/Enzyme washing | Enzyme wash | 40 | 40-60 | Hot enzyme<br>Dispergatör<br>Sequestrants<br>Surfactants | 0.5 g/l<br>1 g/l<br>0.5 g/l<br>0.5 g/l | Rinsing 1 min cold |
| | Drying | 35-40 | 80 | - | - | Spray |
| 3/Rinse washing | Pre-wash | 10 | 50 | Dispergatör<br>Surfactants<br>Sequestrants | 1 g/l<br>0.5 g/l<br>0.5 g/l | Rinsing 1 min cold |
| | Drying | 35–40 | 80 | - | - | Spray |
| 4/Stone washing | Stone washing | 40–60 | 40–60 | Hot enzyme<br>Dispergatör<br>Sequestrants<br>Pumice stone | 1g/l<br>0.5 g/l<br>0.5 g/l<br>10 kg | Rinsing<br>1 min cold and stone washing |
| | Rinsing | 1 | Cold | - | - | - |
| | Drying | 35–40 | 80 | - | - | Spray |

Table 3

| THE SNK TEST FOR WARP SHRINKAGE VALUES OF SAMPLES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Warp shrinkage | | | | Weft shrinkage | | | | |
| Factors | | | | Factors | | | | |
| Weft yarn | N | Subset | | Weft yarn | N | Subset | | |
| | | 1 | 2 | | | 1 | 2 | 3 |
| Cotton/Modal | 24 | –3.417 | | Cotton/Tencel | 24 | –17.271 | | |
| Cotton | 24 | –3.104 | –3.104 | Cotton/Modal | 24 | –17.125 | | |
| Cotton/Tencel | 24 | | –2.875 | Cotton | 24 | –17.062 | | |
| Washing type | N | Subset | | Washing type | N | Subset | | |
| | | 1 | 2 | | | 1 | 2 | 3 |
| Bleach washing | 18 | –3.361 | | Bleach washing | 18 | –18.278 | | |
| Stone washing | 18 | –3.333 | | Enzyme washing | 18 | | –17.500 | |
| Enzyme washing | 18 | –3.306 | | Stone washing | 18 | | –17.500 | |
| Rinse washing | 18 | | –2.528 | Rinse washing | 18 | | | –15.333 |

### Results of rubbing fastness in dry and wet conditions

For rubbing fastness, a piece of white fabric was placed on the probe of the Crockmeter device, and the rubbing fastness value was determined from the colour change in the fabric as a result of the back-and-forth friction movement. For colour fastness to rubbing, grade 5 is the best and grade 1 is the worst [12]. The dry rubbing fastness values of all the untreated fabrics were measured as grade 4, and the wet rubbing fastness values of all the untreated fabrics were measured as grade 2 according to the scale. Figure 2 shows the results of colour fastness to rubbing of stretch denim fabrics for bleach, enzyme, rinse, and stone washes. When the test results under dry and wet conditions were compared, the highest fastness values were obtained for the bleach washing. In addition, it was concluded that the rubbing fastness values of enzyme-washed fabrics were lower than those of other fabrics under both industrially washed and untreated conditions (except TZ2). When the results were evaluated based on the grey scale, it was observed that all fabrics in the dry condition showed average to good rubbing fastness values and in the wet condition the washings had poor values (except bleach). The multiple comparisons of the factor levels are presented in table 4.

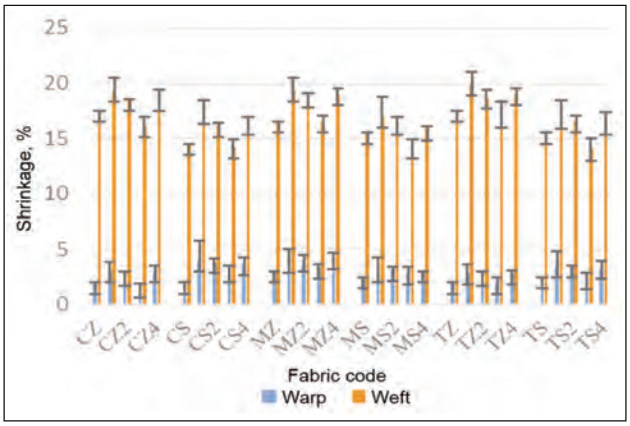


Fig. 1. Shrinkage values of fabrics

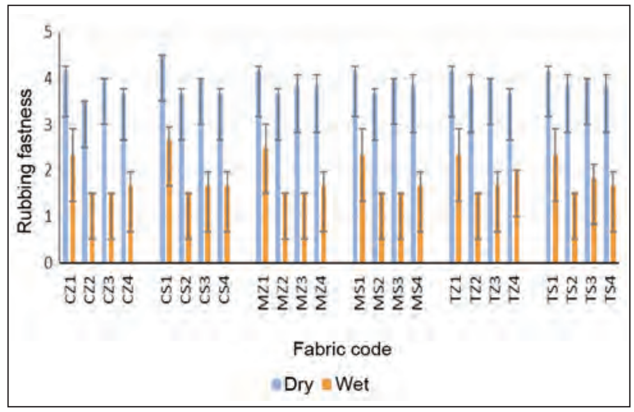


Fig. 2. The rubbing fastness values of industrially washed fabrics

Table 4

| THE SNK TESTS FOR DRY AND WET RUBBING FASTNESS VALUES OF FABRICS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Wet rubbing fastness** | | | | **Dry rubbing fastness** | | | | |
| **Factors** | | | | **Factors** | | | | |
| **Weft yarn** | **N** | **Subset** | | **Weft yarn** | **N** | **Subset** | | |
| | | **1** | **2** | | | **1** | **2** | **3** |
| Cotton/Modal | 24 | 1.771 | | Cotton | 24 | 3.896 | | |
| Cotton | 24 | 1.813 | | Cotton/Modal | 24 | 3.896 | | |
| Cotton/Tencel | 24 | 1.854 | | Cotton/Tencel | 24 | 3.937 | | |
| **Washing type** | **N** | **Subset** | | **Washing type** | **N** | **Subset** | | |
| | | **1** | **2** | | | **1** | **2** | **3** |
| Enzyme washing | 18 | 1.500 | | Enzyme washing | 18 | 3.694 | | |
| | 18 | 1.611 | | Stone washing | 18 | 3.750 | | |
| Stone washing | 18 | 1.722 | | Rinse washing | 18 | | 3.972 | |
| Bleach washing | 18 | | 2.417 | Bleach washing | 18 | | | 4.222 |

Although it was stated in a previous study that the degree of dry and wet rubbing fastness for enzyme washing was relatively better than that of the others [13], the highest rubbing fastness values were measured in the case of bleach washing under dry and wet conditions in this study. In addition, it was observed that the dry and wet rubbing fastness values were higher than those of the untreated fabrics for bleach washing.

### Results of breaking strength in warp and weft directions

When the breaking strength values in the warp and weft directions were compared, the highest breaking strength values were observed for the rinse-washed fabrics in the warp direction. The lowest breaking strength values in the warp direction were measured for the bleach-washed fabrics (figure 3). The SNK test results for the warp and weft breaking strengths of the fabrics are listed in table 5. Considering the effect of the weft yarn on the warp-breaking strength values, the highest warp-breaking strength value was measured for the fabric woven with cotton/Modal elastane weft yarn. In previous studies, it was stated that fabrics woven with Modal had higher strength values than cotton and viscose [14]. When the breaking strength measurement results in the weft direction were compared, it was observed that weft yarn differences did not have a statistically significant effect on this value. The crystallisation value of the Tencel fibre is higher than that of the Modal fibre. For this reason, it is thought that water molecules entering the structure during washing change the structure of the Tencel fibre and break down weaker hydrogen bonds but cannot influence the regions of a high order, causing a decrease in strength values. Considering the impact of washing on the warp and weft breaking strengths, the highest breaking strength values were observed in the case of rinse washing in the warp direction. In the weft direction untreated fabrics and rinse-washed fabrics showed close strength values to each other which supports rinse washing reduced the strength value less than other types of washing [15]. In this study, the lowest breaking strength results were observed for bleach washing. Because the use of bleach reduces the strength value owing to the oxidant reaction [16].

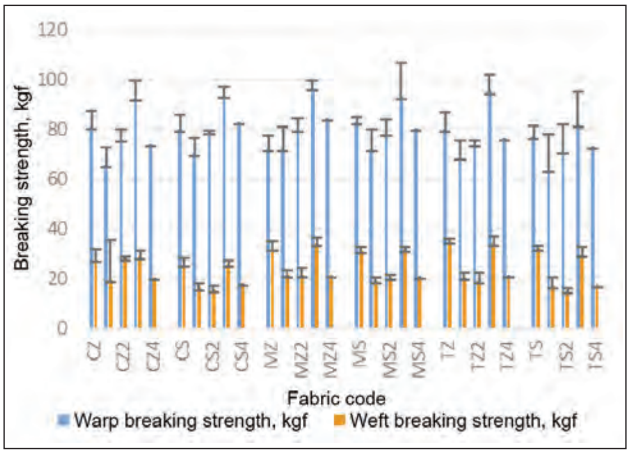


Fig. 3. Breaking strength values of fabric

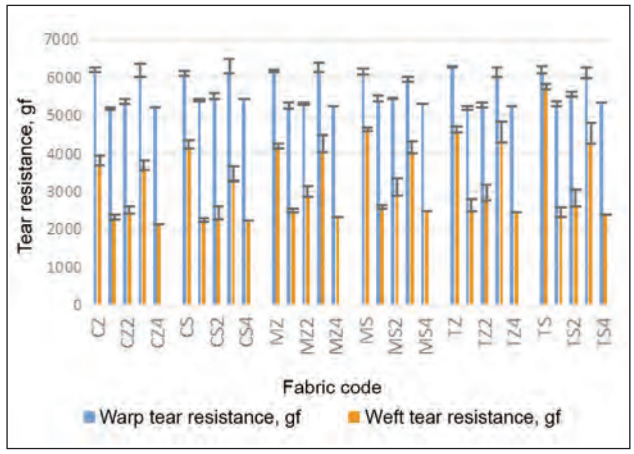


Fig. 4. Tear resistance values of fabrics

Table 5

| THE SNK TEST FOR WARP AND WEFT BREAKING STRENGTH OF FABRICS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Warp breaking strength** | | | | | **Weft breaking strength** | | | | |
| **Factors** | | | | | **Factors** | | | | |
| **Weft yarn** | **N** | **Subset** | | | **Weft yarn** | **N** | **Subset** | | |
| | | **1** | **2** | | | | **1** | **2** | **3** |
| Cotton/Tencel | 24 | 75.67 | | | Cotton | 24 | 21.54 | | |
| Cotton | 24 | 79.33 | 79.33 | | Cotton/Tencel | 24 | 21.83 | | |
| Cotton/Modal | 24 | | 82.21 | | Cotton/Modal | 24 | 23.87 | | |
| **Washing type** | N | **Subset** | | | **Washing type** | **N** | **Subset** | | |
| | | **1** | **2** | **3** | | | **1** | **2** | **3** |
| Bleach washing | 18 | 68.89 | | | Bleach washing | 18 | 19.00 | | |
| washing | 18 | | 76.50 | | Stone washing | 18 | 19.94 | | |
| Stone washing | 18 | | 78.67 | | Enzyme washing | 18 | 20.06 | | |
| Rinse washing | 18 | | | 92.22 | Rinse washing | 18 | | 30.67 | |

### Results of tear resistance in warp and weft directions

Tear resistance is defined as the force required for the continuation of an initiated tear on the fabric. The tear resistance of the denim fabrics in the warp and weft directions is shown in figure 4. One of the most important factors affecting tear strength is the mobility of the yarns in the fabric. The strength properties of the yarns affect the tear strength as well as the breaking strength. Considering the effect of weft yarn differences on tear strength, it was observed that the weft tear resistance of the Modal and Tencel included fabrics was higher than that of the 100% cotton elastane woven fabrics. Industrial washings reduced the tear resistance values of the fabrics compared to that of untreated fabrics. On the other hand, rinse washing yielded tear resistance results close to those of the untreated fabrics. The lowest tear resistance values in the warped way were seen in the fabrics that were treated with bleach washing (except MS4), and in the weft, way were seen in the fabrics that were treated with stone washing (except CS4 and TS4).

The SNK test results for warp and weft tear resistances are listed in table 6. When the impact of the weft yarn on the weft tear resistance value was investigated, it was observed that the 100% cotton fabric showed statistically different results from the others and the lowest weft tear resistance value was measured when cotton yarn was used in the weft. It was concluded that using Tencel and Modal blended yarns in the weft direction increased the tear resistance value in the weft direction. Previous studies have reported that Modal woven fabrics have higher tear strength values owing to their high tenacity and breaking strength [17] and the ratio of Tencel (Lyocell) fibre in the weft yarn increased, the tear strength value in the weft direction increased [18]. Considering the effect of industrial washing on warp and weft tear resistance values, there was a statistically significant difference between the rinse wash and other washes, and the highest warp and weft tear resistance values were measured in the case of rinse washing. The lowest weft tear resistance was measured in the case of stone washing.

Table 6

| THE SNK TESTS FOR WARP AND WEFT TEAR RESISTANCE OF FABRICS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Warp tear resistance** | | | | **Weft tear resistance** | | | | |
| **Factors** | | | | **Factors** | | | | |
| **Weft yarn** | **N** | **Subset** | | **Weft yarn** | **N** | **Subset** | | |
| | | **1** | **2** | | | **1** | **2** | **3** |
| Cotton/Modal | 24 | 5467.83 | | Cotton/Tencel | 24 | 2539.38 | | |
| Cotton | 24 | 5482.67 | | Cotton/Modal | 24 | | 2946.92 | |
| Cotton/Tencel | 24 | 5512.54 | | Cotton | 24 | | 2948.67 | |
| **Washing type** | **N** | **Subset** | | **Washing type** | **N** | **Subset** | | |
| | | **1** | **2** | | | **1** | **2** | **3** |
| Bleach washing | 18 | 5245.89 | | Bleach washing | 18 | 2327.33 | | |
| Stone washing | 18 | 5306.94 | | Enzyme washing | 18 | 2371.89 | | |
| Enzyme washing | 18 | 5366.06 | | Stone washing | 18 | | 2638.89 | |
| Rinse washing | 18 | | 6031.83 | Rinse washing | 18 | | | 3908.50 |

**Elasticity results of fabrics**

Elasticity can be defined as the return of a material to its original shape without any deformation under a certain force and duration [19]. Garments with elasticity values between 5% and 30% are called easy-stretching garments, whereas those with elasticity values between 30% and 50% are called very stretchable garments [20]. When the impact of the weft composition on the elasticity property was examined, the highest elasticity values were observed in the Tencel weft yarn blended fabrics (figure 5). The highest elasticity value was measured in the fabric that had been treated with the bleaching process Tencel Z-twill direction fabric (58%). The lowest elasticity values were observed in the Modal S-twill woven fabrics. When the fabrics were compared in terms of the industrial washing process, the lowest elasticity values were observed in the fabrics subjected to rinse washing. It is also noteworthy that the elasticity values of rinse-washed fabrics were close to those of the untreated fabrics. Although the use of hydrogen peroxide and its derivatives in washing is a cheap method, it has some disadvantages. One of them is that it causes yellowing if good neutralization is not performed, and it interacts with cotton and decreases its strength [21]. In contrast, the highest elasticity values were observed in bleach washing for all fabrics in both the S and Z-twill directions (except MS1) in this study. This was attributed to the use of an appropriate amount of hydrogen peroxide and a good neutralization process. The SNK test results for the elasticity values of the fabrics are presented in table 7. The elasticity values of the cotton/Tencel elastane weft yarn woven fabrics were significantly different from those of the other fabrics, and the highest elasticity values were observed for these fabrics. A good fibre must have a certain amount of void volume. The void ratio decreases with increasing stretching of the fibres; therefore, the proportion of void ratio is greatest in viscose fibres, followed by lyocell (Tencel) fibres, and the smallest voids have the most stretched Modal fibres [22]. Therefore, it can be said that the fabric produced from the cotton/Tencel elastane yarn has higher elasticity than that produced from the cotton/Modal elastane yarn.

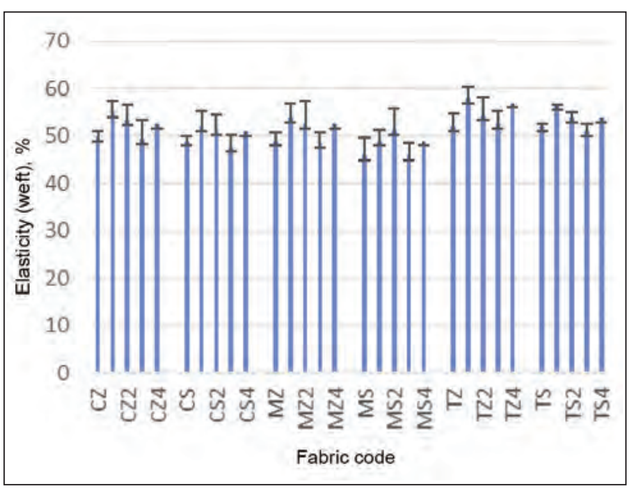


Fig. 5. Elasticity values of fabrics

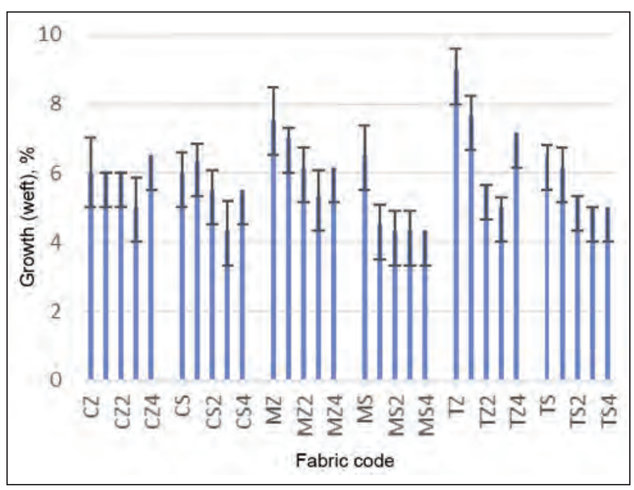


Fig. 6. The growth values of fabrics

Table 7

| THE SNK TESTS GROWTH AND ELASTICITY OF FABRICS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Growth** | | | | | **Elasticity** | | | |
| **Factors** | | | | | **Factors** | | | |
| **Weft yarn** | **N** | **Subset** | | | **Weft yarn** | **N** | **Subset** | |
| | | **1** | **2** | | | | **1** | **2** |
| Cotton/Modal | 24 | 5.271 | | | Cotton/Modal | 24 | 50.42 | |
| Cotton | 24 | | 5.646 | | Cotton | 24 | 51.54 | |
| Cotton/Tencel | 24 | | 5.875 | | Cotton/Tencel | 24 | | 54.71 |
| **Washing type** | **N** | **Subset** | | | **Washing type** | **N** | **Subset** | |
| | | **1** | **2** | **3** | | | **1** | **2** |
| Rinse washing | 18 | 4.833 | | | Rinse washing | 18 | 49.22 | |
| Enzyme washing | 18 | | 5.500 | | Stone washing | 18 | | 52.72 |
| Stone washing | 18 | | 5.778 | | Enzyme washing | 18 | | 52.83 |
| Bleach washing | 18 | | | 6.278 | Bleach washing | 18 | | 54.11 |

### Growth results of fabrics

Fabric manufacturers and designers want the growth value of the fabrics used in garment production to be as low as possible. This is because, as the growth value increases, bagging also increases. When the growth values of the fabrics were investigated, it was observed that the growth value was between 4–9%. It was observed that the growth values of all the rinse-washed fabrics were lower than those of the other fabrics (figure 6). The highest growth values were observed for the cotton/Modal elastane and cotton/Tencel elastane untreated fabrics. In addition, TZ1 and TZ4 coded Tencel Z-twill weave bleach and stone-washed fabrics showed the highest growth value after untreated fabrics. Because the polymerization degree of the Tencel fibre is higher than that of the other fibres, it can be said that the deterioration in the crystalline region causes an increase in the growth value of the fabrics made from this fibre. The growth value increased in the case of bleach washing in the Modal and Tencel weaved fabrics, whereas an increase in this value was observed in the case of stone washing in the cotton Z-twill fabrics. The SNK test results for the growth values of the fabrics are presented in table 7. The results demonstrated that there was a significant difference between the cotton/Modal elastane weft woven fabric and other fabrics, and the lowest growth value was observed in this fabric. Considering the effect of washing, the lowest growth value was observed in the case of rinse washing, and the highest growth value was observed in the case of bleach-washed fabrics after untreated fabrics. In previous studies, it was stated that the growth value of rinse wash was lower than that of other washes because of the lower washing time and temperature [23]. Therefore, it can be concluded that rinse washing decreases the growth value of denim fabrics more than other industrial washing methods. Although subjecting the fabrics to stone washing for a long time and adding bleach after stone washing deteriorates the elastane fibre, which reduces the recovery value and increases the growth value of the fabric. It can be concluded that industrial washing decreases the growth value of fabrics compared with untreated fabrics.

## CONCLUSIONS

In this study, the effects of three different factors (weft yarn, twill direction, and washing) on the performance properties of denim fabrics were investigated. When the untreated fabric and industrially washed fabrics were compared, it was observed that the shrinkage, elasticity, and weft-breaking strength values of rinse-washed fabrics were close to those of the untreated fabrics, the rubbing fastness values of the untreated fabrics were lower than those of the bleach washed fabrics, and the highest tear strength values were measured in the untreated fabrics. In addition, it can be said that industrial washing processes reduce the growth values of untreated fabrics and reduce the bagging occurring during use. The rinse-washed fabrics showed the lowest shrinkage, elasticity, and growth, and the highest warp-breaking values because chemicals are not used in rinse washing (such as hypo and enzyme), washing temperatures, and duration are low. The highest shrinkage, elasticity, rubbing fastness values, and lowest breaking strength were measured for the bleach washing. Considering the effect of the weft yarn on the measured parameters, the highest elasticity, growth, and rubbing fastness were observed in the fabric woven with the cotton/Tencel elastane weft yarn. The highest weft and warp breaking strengths and weft tearing resistances were measured in fabrics woven with cotton/Modal elastane weft yarn. Thus, it can be concluded that the use of Modal fibre with cotton in the fabric structure increased the strength more than the Tencel fibre, and the use of Tencel yarn with cotton increased the elasticity and rubbing fastness values more than the Modal fibre. In addition, it was observed that twill direction only affected the shrinkage and elasticity values, and Z-twill fabrics exhibited higher shrinkage and elasticity values.

**ACKNOWLEDGEMENTS**

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# Evaluation of psychological occupational health constraints according to the Karasek model among female sewing machine operators in Tunisia

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**ABSTRACT – REZUMAT**

**Evaluation of psychological occupational health constraints according to the Karasek model among female sewing machine operators in Tunisia**

*Stress has become a major concern of modern times as it can cause harm to employee's health and performance. Mental health is a fundamental constituent of occupational health. Scientific studies on psychological occupational health in the textile industry are relatively rare in Tunisia. This study seeks to estimate the rate of occupational stress, reveal associated factors and design strategies and ways to improve the work situations in a clothing company in the Monastir region. We performed a transversal study among female sewing machine operators. For the evaluation of professional stress, we used the Karesek questionnaire, a validated self-administered questionnaire. To carry out the descriptive analyses, we estimated frequencies and odds ratios (ORs). To explore associations linking organizational and socio-demographic variables and stress, we calculated adjusted ORs using a logistic regression model. As a result, the present study pointed out a strong degree of stress among operators: 30% of study participants reported that they were suffering from stress according to the Karasek stress scale. Our study revealed a statistically relevant correlation between stress and age, work experience, perceived non-adaptation of the task, and a poor perception of the organization. Stress is related to multiple socio-professional determinants. Most operators needed ergonomic interventions and prevention and risk management recommendations. Evaluation of the width of psychosocial risk factors at the workplace enables preventive strategies to preserve operators' mental health.*

***Keywords:*** *occupational health, stress, Karasek, textile industry, Tunisia*

**Evaluarea constrângerilor psihologice de sănătate ocupaţională conform modelului Karasek în rândul operatorilor de mașini de cusut de sex feminin din Tunisia**

*Stresul a devenit o preocupare majoră a timpurilor moderne, deoarece poate dăuna sănătății și performanței angajaților. Sănătatea mintală este o componentă fundamentală a sănătății ocupaţionale. Studiile științifice privind sănătatea psihologică ocupaţională în industria textilă sunt relativ rare în Tunisia. Acest studiu urmărește să estimeze rata stresului profesional, să dezvăluie factorii asociați și să conceapă strategii și modalități de îmbunătățire a situațiilor de muncă într-o companie de îmbrăcăminte din regiunea Monastir. A fost efectuat un studiu transversal în rândul operatorilor de mașini de cusut de sex feminin. Pentru evaluarea stresului profesional a fost utilizat chestionarul Karesek, un chestionar autoadministrat validat. Pentru a efectua analizele descriptive, au fost estimate frecvențele și rapoartele probabilităţilor (OR). Pentru a explora asocierile care leagă variabilele organizaționale și socio-demografice și stresul, au fost calculate OR ajustate prin intermediul unui model de regresie logistică. Drept urmare, studiul de față a evidențiat un grad puternic de stres în rândul operatorilor: 30% dintre participanții la studiu au raportat că suferă de stres conform scalei de stres Karasek. Studiul nostru a relevat o corelație relevantă din punct de vedere statistic între stres și vârstă, experiența de muncă, neadaptarea percepută la sarcină și o percepție slabă a organizației. Stresul este legat de multipli determinanți socio-profesionali. Majoritatea operatorilor aveau nevoie de intervenții ergonomice și recomandări de prevenire și management al riscurilor. Evaluarea amplorii factorilor de risc psihosocial la locul de muncă permite conducerea strategiilor preventive și păstrarea sănătății mintale a operatorilor.*

***Cuvinte-cheie***: *sănătate ocupaţională, stres, Karasek, industria textilă, Tunisia*

## INTRODUCTION

In clothing companies, time is a key success factor. Time constraints added to productivity objectives as well as quality and efficiency expectations will cause the operator to be under considerable stress and pressure and can lead to stress-related health problems [1]. A series of challenges are faced, like new strategies adopted to be adapted to the external environment's requests and new technologies implemented [2]. Work-related stress is considered the harmful physical and emotional response consequence of an imbalance between job demands and the capabilities of the worker [3, 4]. Furthermore, compensatory behaviours like smoking, alcoholism, eating disorders, health illnesses [5], and work-related stress could potentially have a negative influence on companies, including a decrease in productivity, worker turnover, absenteeism, and rising healthcare costs [6, 7].

Lately, as a consequence of globalization and the global financial crisis that is affecting all countries, professions and all categories of workers, professional stress is considerably increasing [3]. In industrialized countries, the prevalence of occupational stress has been assessed through several studies however scientific research on this topic is rare when it comes to developing countries. To implement a prevention policy in workplaces, stakeholders need valid and accurate information which is in most situations scarce [8]. Tunisia workers, as in other developing countries, are facing various constraints such as non-ergonomic workstation design, poor work management and dangerous working conditions. These mentioned constraints and others can cause occupational stress and make the physical and mental state of employees vulnerable. This study aims to assess the prevalence of occupational stress, to identify associated factors among the operators of a textile company based in Tunisia and to design strategies and ways to improve the work conditions.

Work-related stress evaluation was conducted via a scientifically validated tool: Karasek's Job Content Questionnaire (JCQ) [9, 10]. Several research underlined the predictive validity of Karasek's model for mental illness [11]. The relevance of the Karasek model is its plainness; moreover, it's an empirically studied model in several epidemiological and psychophysiological research conducted in numerous countries. These different research had as purpose of investigating the impact of the working system on workers' mental health [12].

## METHODOLOGY DESCRIPTION

### Study framework

This transversal study was performed in a Tunisian textile company based in the region of Monastir which was employing 110 agents. The study's target population consisted of all people working in the factory, except those assigned to administrative service (25 agents). The population included all workers assigned to production service (85 agents).

### Study protocol

The study objectives were communicated to the participants as well as the confidentiality of the data and all of their questions were answered by the interviewer. Questionnaires were administered in semi-structured interviews. Socio-professional data concerned: age, work experience, and marital status. The questionnaire encompasses three questions about the worker's perception of work and their coping with it.

The questionnaire includes three dimensions: Job Demands (JD), Decision Latitude (DL) and Social Support (SS). We can distinguish two classes for each dimension. The first class is for low scores (L) which includes any score below the median score of the whole sample for the corresponding dimension. The second class is for the high score (H) which includes any score above the median score of the whole sample for the corresponding dimension. By the chosen methodology, operators' scores were segmented into four categories: Active, corresponding to high job demand [HJD] and high decision latitude [HDL], Job strain, corresponding to high job demand [HJD] and low decision latitude [LDL]), Passive (LJD and LDL) and Relaxed (LJD and HDL). Another category is presented in the model; the «Iso-strain» category, blending a high job demand, low decision latitude and low social support. In figure 1, the job strain model is outlined [13].

JCQ scale means, standard deviations, reliabilities, and correlations were compared and validated, in a study that dealt with the cross-national validity of the JCQ scale in six broadly different populations from four industrial societies [14]. At the Tunisian level a study that aims to assess the prevalence of psycho-organizational constraints among Tunisian workers in different companies was conducted via descriptive cross-sectional investigation of employees of eight sectors of activity (fourteen companies) was carried out. The project was based on the Karasek questionnaire and they obtained valid results [15].

### Data analysis

Data was analysed using the SPSSTM software. The analysis process aims to pinpoint factors related to the socio-professional aspect of the work eventually causing the prevalence of professional stress among workers. First, we proceeded to a descriptive approach to the data collected, then to an analytical

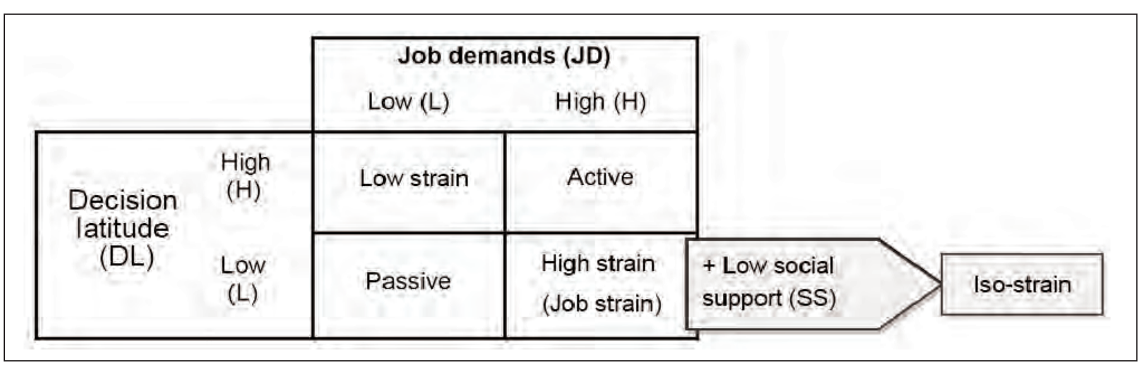


Fig. 1. Categories of the job based on the Karasek model

approach aiming at identifying the eventual correlation between each of the dependent variables and the independent variables. Crossings were performed and the estimation of the unadjusted odds ratio (OR) was measured to identify associations in a univariate analysis. The trends observed after performing the univariate analysis were confirmed via proccing to the multivariate analysis consisted of evaluating the association between these variables. Under 0.05 P-value was considered statistically significant.

## RESULTS

In table 1 the description of the variables studied are summarized. The questionnaire was answered by all participants. They were all female, 90% of them were married and mostly aged between 20 and 29 years old (76%) and 80% had a < 9-year work experience. The "job strain" category assembled 30% of participants. The dimension of social support was considered separately, and low social support concerned 70% of operators. When considering that dimension in Karasek's model, 18% of workers move to the "Iso-strain" category.

In table 2 the number of workers perceiving stress, by Karasek's questionnaire in functions of socio-demographic and organizational variables are illustrated.

We can also notice through the second table that «job strain» is significantly related to ≤ 29-year-old age group, ≤ 9-year work experience, non-adaptation to work, and being single.

Table 3 summarizes the main results of the multivariate analysis that was performed to highlight associations between the different variables studied and perceived stress in the population of the study.

According to Karasek's methodology, stress is significantly associated with work experience (≤ 9 years), age (≤29 years old), non-adaptation to work and the perception of a poor work organization as shown in table 3.

Table 1

VARIABLES STUDIED DESCRIPTION

| Variables | Categories | N | % |
|---|---|---|---|
| Age | 20–29 years | 65 | 76 |
| | ≥ 30 years | 20 | 24 |
| Marital status | Single | 8 | 10 |
| | Married | 77 | 90 |
| Work experience | 1–9 years | 68 | 80 |
| | ≥ 10 years | 17 | 20 |
| Work organization | Good | 44 | 52 |
| | Poor | 41 | 48 |
| Adaptation to work | Yes | 64 | 75.0 |
| | No | 21 | 25.0 |
| Stress according to Karasek's model | Yes | 26 | 30 |
| | No | 59 | 70 |
| Iso-strain | Yes | 15 | 18.0 |
| | No | 70 | 72.0 |

Table 2

JOB STRAIN ACCORDING TO KARASEK'S MODEL AND DISTRIBUTION OF SOCIO-DEMOGRAPHIC AND ORGANIZATIONAL VARIABLES

| Variables | No job strain N (%) | Job strain N (%) | p-value |
|---|---|---|---|
| Age | | | |
| 20–29 years | 39 (60) | 26 (40) | 0.59 |
| ≥ 30 years | 8 (40) | 12 (60) | |
| Marital status | | | |
| Single | 6 (75) | 2 (25) | 0.36 |
| Married | 7 (10) | 70 (90) | |
| Work experience | | | |
| 1–9 years | 48 (71) | 20 (29) | 0.03 |
| ≥ 10 years | 6 (36) | 11 (64) | |
| Work organization | | | |
| Good | 30 (68) | 14 (32) | 0.10 |
| Poor | 17 (40) | 24 (60) | |
| Adaptation to work | | | |
| Yes | 46 (72) | 18 (28) | < 0.01 |
| No | 2 (11) | 19 (89) | |

Table 3

ASSOCIATIONS BETWEEN JOB STRAIN AND INDIVIDUAL AND ORGANIZATIONAL CHARACTERISTICS ACCORDING TO KARASEK'S MODEI

| Variables | Unadjusted OR (95% CI) | p-value | Multiv. OR* (95% CI) | p-value |
|---|---|---|---|---|
| Age | 1.3 (0.60–2.22) | 0.52 | 5.5 (1.69–16.55) | < 0.01 |
| Work experience | 2.8 (1.19–6.65) | 0.01 | 13.1 (3.66–46.55) | < 0.01 |
| Marital status | 1.4 (0.68–3.68) | 0.40 | | NS |
| Work organization | 1.6 (0.99–3.56) | 0.13 | 5.5 (1.89–12.56) | < 0.01 |
| Adaptation to work conditions | 3.9 (1.93–8.41) | < 0.01 | 6.8 (3.85–16.86) | < 0.01 |

## DISCUSSIONS

Studies on stress at work are very uncommon in North Africa [16]. The present study develops a methodology for assessing the prevalence of work-related stress in a Tunisian textile business, diagnosing possibly related determinants and designing strategies and ways to improve the work situations.

According to Karasek's approach, the textile company's evaluation of employee stress levels revealed that 30% of employees experienced stress. The percentages found in that firm are comparable to those found in previous studies conducted in both industrialized and developing nations. Edimansyah et al. [17] found a 31% job strain in an automobile assembly company in Malaysia. Moreover, a foundry firm in India's workforce saw a 25% rate of job strain, according to research conducted by Mohan and colleagues. The garment industry often faces a major issue of very high lead times [18].

According to Karasek's model, the multivariate analysis of the current study revealed a strong correlation between stress and age (≤ 29 years old), work experience (≤ 9 years), the perceived lack of job adaptability, and the negative perception of work organization. These findings support those made by Tsutsumi et al. in Japan [19] and Lotfizadeh et al. in Iran [20]. They do not, however, agree with research done in Belgium by Clays et al. [11], who found higher levels of stress among workers. These differences in outcomes can be explained by the properties of the population studied. The worker population studied was 35–59 years aged and included 70% of men and 30% of women.

The associated factors to stress were also the age and work experience. Younger operators and those with an experience under 5 years were more likely to experience stress. A study led by Bourbonnais et al. [21], claimed that young, less experienced operators were more vulnerable to stress due to less theoretical and theoretical expertise in dealing with demanding or challenging situations. According to these studies, with experience, workers gain confidence, assertiveness, self-esteem and the ability to make decisions [12, 22].

In the present case study, stress also depended on the perception of a non-adaptation to work and a poor work organization. This was also reported by other studies [9, 11, 23, 24]. The factors associated with stress depended on the model we employed. In our study, we applied Karasek's model which granted linking occupational risk and work experience.

After diagnosing the stress risk factors, the strategies to adopt to face stress for work improvement focused on: Adjusting the demands of work, guaranteeing that workers develop or already have the adequate skills and knowledge to perform their tasks effectively. Finally, it's important to increase the amount and quality of social support they receive. Based on the results questionnaire, the managers decided to work on reducing the risk factors by addressing three levels of action: At the organizational level focusing on the questions: how does the way of organizing work induce these situations? And how can we organize work differently? At the cognitive and collective level by becoming aware of the impact of these situations. At the individual level making employees feel valued is important, helping to build a strong workplace culture. The constraints and tensions in work weigh heavily on feelings and affect motivation. Offering places and times for employees to express and share the reality of work helps to identify solutions. Finally, we have initiated ways of reduction and prevention of stress at the workplace. Training and informing strategies are required to reduce stress factors at work and related pathologies.

## CONCLUSIONS

Stress is not always dangerous, but being stressed beyond one's capacities is dangerous and affects mental and physiological health by creating many illnesses. In the present study, a methodology is developed to estimate occupational stress among operators working in a textile company in Tunisia. The measurement of stress level reached out to 30% of workers according to Karasek's model. A statistically significant association was observed between stress and age, work experience, perceived non-adaptation to work and the poor perception of organization. Priorities for action point to the need for monitoring psychosocial hazards and work-related stress and the need to develop an occupational health and safety culture. So governments and social organizations must be conscious to reduce the stress in the textile sector.

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# Factorial experimental design based on multiple factors for sensors and actuators development

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**ABSTRACT – REZUMAT**

**Factorial experimental design based on multiple factors for sensors and actuators development**

*This paper presents several use cases for a full factorial experimental design method used in the development of flexible sensors and actuators. The full factorial experimental designs consisted of 4 factors with discrete values (3–4 levels) based on known parameters of the experimental devices. In general, the selected factors can influence other dependent variables. This study aims to investigate the main effects and the interaction effects (antagonistic, synergistic, ceiling) among the different factors and to optimize an experimental design for reducing the consumption (raw materials, water, energy, chemicals) and obtaining the optimal values for surface electrical resistance using a reduced number of experiments. The use of the complete factorial experimental plan and optimization with a minimization function helps to select, from the set of possible experiments, the experiments including the optimal parameters for obtaining the desired result. Therefore, the number of experimental plans and the corresponding amount of resource consumption is reduced (e.g., from 81–256 experiments to 10–20 experiments) while obtaining electroconductive textile electrodes for sensors and actuators.*

***Keywords:*** *factorial design, sensors, actuators, textile, conductive, electrical resistance, experiment, optimization*

**Proiectare experimentală factorială pe bază de factori multipli pentru dezvoltarea senzorilor şi actuatorilor**

*Această lucrare prezintă mai multe cazuri de utilizare pentru metoda de proiectare experimentală factorială completă pentru dezvoltarea senzorilor și actuatorilor flexibili. Proiectarea experimentală factorială completă a avut la bază 4 factori cu valori discrete (3–4 niveluri) ale unor parametri cunoscuți pentru dispozitivele experimentale. În general, factorii selectați pot influența alte variabile dependente. Acest studiu își propune să investigheze principalele efecte și interacțiunea efectelor (antagoniste, sinergice, plafon) între diferiții factori și să optimizeze proiectarea experimentală pentru reducerea consumului (materii prime, apă, energie, substanțe chimice) și obținerea unor valori optime pentru rezistenţa electrică de suprafață utilizând un număr redus de experimente. Utilizarea planului experimental factorial complet și optimizarea prin intermediul funcției de minimizare ajută la selectarea, din setul de experimente posibile, a experimentelor care prezintă parametrii optimi pentru obținerea rezultatului dorit. Prin urmare, numărul de planuri experimentale și cantitatea corespunzătoare de resurse consumate sunt reduse (de exemplu, de la 81–256 de experimente la 10–20 de experimente) pentru obţinerea electrozilor textili electroconductivi pentru senzori și actuatori.*

***Cuvinte-cheie:*** *proiectarea factorială, senzori, actuatori, textil, conductiv, rezistenţă electrică, experiment, optimizare*

## INTRODUCTION

To create smart textile-based sensors or actuators, there are two types of integration in textile products, such as textiles with conventional electronics (e.g., sensors or actuators mounted on PCB boards), based on whether the textile material is a support material or surface electrodes for textile actuators or sensors, which offer easy integration and operate on capacitive, resistive and piezoelectric principles. In these systems, structural integration occurs on small surfaces of a few mm or cm [1–5]. In this work, experimental plans are reported for reducing redundant experiments using static methods (e.g., using full factorial design, optimization or principal component analysis).

In research, factorial experimental design is part of an experimental plan that includes both important and insignificant factors. To develop a factorial design, researchers identify important factors (independent variables) and responses to these factors (dependent variables) for use in the optimization and development of the experimental plan. A full factorial design involves at least 2 factors with different value levels (2 to *n*), and the experimental units cover all possible combinations of these factors having different levels. The factorial experimental design method can be full or fractional, and it is used in numerous studies to reduce the consumption, time and costs allocated for new studies. Full factorial design has been used in numerous investigations, such as temperature for e-textiles [6–8], fabric reinforcement or optimization of carbon electrode parameters [9], parameter optimization of photoelectrocatalytic degradation of a textile dye [10], optimization of carbon electrodes based on commercial activated carbons with differing surface areas and pore dimensions [11, 12], and design of piezoresistive sensors [14–19].

## EXPERIMENTAL PART

To develop a full factorial design for sensors, 4 factors (temperature1, temperature2, concentration, time) and a dependent variable (electrical resistance) were considered. Table 1 shows the factors used for experimental plan design in the case of the sensors, where:
- concentration refers to the amount of metal particles in a certain amount of polymer used as the matrix;
- temperature1 ($Temp_1$, °C) is the temperature used for crosslinking;
- temperature2 ($Temp_2$, °C) is the temperature of the prepared conductive paste;
- time ($T$, min) refers to the time allocated for crosslinking;
- surface resistance ($Rs$, Ω).

Table 1

| FACTORS INFORMATION FOR SENSORS | | |
|---|---|---|
| **Factor** | **Levels** | **Values** |
| Temperature1 (°C) | 3 | 70, 80, 90 |
| Temperature2 (°C) | 3 | 150, 160, 170 |
| Concentration (%) | 3 | 10, 20, 90 |
| Time (min) | 3 | 5, 10, 15 |

In our development of a full factorial design for an actuator, 4 factors: rotational speed, volume, concentration, and time) specific to the method of thin film deposition by spin coating methods (rotational speed, time) and the parameters specific to the conductive polymer dispersion, such as the volume and concentration of micro/nanoparticles in polymeric dispersions, were used. Thus, 4 variable influence factors and 4 distinct values for each factor were considered, as follows: rotational speed (250, 500, 750, 1000), time (10, 15, 30, 60), concentration (10, 20, 30, 40) and volume (100, 250, 500, 1000). Table 2 presents the factors used for actuator development.

Table 2

| FACTORS INFORMATION FOR ACTUATORS | | |
|---|---|---|
| **Factor** | **Levels** | **Values** |
| Rotational speed (rpm) | 4 | 250, 500, 750, 1000 |
| Volume (μl) | 4 | 100, 250, 500, 1000 |
| Concentration (%) | 4 | 10, 20, 30, 40 |
| Time (s) | 4 | 10, 15, 30, 60 |

In an experimental plan, using the factorial method redundant variables to reconstruct $np\,x_{ij}$ values from an $Xn\times p$ table, through the reduction of rank $q$, using equation 1:

$$X = u_1 v_1' + u_2 v_2' + \cdots + u_q v_q' + E \qquad (1)$$

where $E$ is the residual matrix that can reconstruct from $q(n+p)$ values of the vectors $u_\alpha$ and $v_\alpha$ ($\alpha$ = 1,..., $q$) the $np$ values of $X$.

Table 3

| FULL FACTORIAL PLAN DESIGN FOR FLEXIBLE SENSORS | | | | | |
|---|---|---|---|---|---|
| **Std Order** | **Run Order** | **$Temp_1$ (°C)** | **$Temp_2$ (°C)** | **Concentration (%)** | **Time (s)** |
| 33 | 1 | 80 | 150 | 20 | 15 |
| 47 | 2 | 80 | 170 | 10 | 10 |
| 1 | 3 | 70 | 150 | 10 | 5 |
| 66 | 4 | 90 | 160 | 10 | 15 |
| 17 | 5 | 70 | 160 | 90 | 10 |
| 58 | 6 | 90 | 150 | 20 | 5 |
| 32 | 7 | 80 | 150 | 20 | 10 |
| 4 | 8 | 70 | 150 | 20 | 5 |
| 55 | 9 | 90 | 150 | 10 | 5 |
| 28 | 10 | 80 | 150 | 10 | 5 |
| 44 | 11 | 80 | 160 | 90 | 10 |
| 48 | 12 | 80 | 170 | 10 | 15 |
| 5 | 13 | 70 | 150 | 20 | 10 |
| 35 | 14 | 80 | 150 | 90 | 10 |
| 53 | 15 | 80 | 170 | 90 | 10 |
| 60 | 16 | 90 | 150 | 20 | 15 |
| 40 | 17 | 80 | 160 | 20 | 5 |
| 34 | 18 | 80 | 150 | 90 | 5 |
| 6 | 19 | 70 | 150 | 20 | 15 |
| 41 | 20 | 80 | 160 | 20 | 10 |
| 9 | 21 | 70 | 150 | 90 | 15 |
| 24 | 22 | 70 | 170 | 20 | 15 |
| 63 | 23 | 90 | 150 | 90 | 15 |
| 81 | 24 | 90 | 170 | 90 | 15 |
| 59 | 25 | 90 | 150 | 20 | 10 |
| 57 | 26 | 90 | 150 | 10 | 15 |
| 25 | 27 | 70 | 170 | 90 | 5 |
| 52 | 28 | 80 | 170 | 90 | 5 |
| 31 | 29 | 80 | 150 | 20 | 5 |
| 16 | 30 | 70 | 160 | 90 | 5 |
| 71 | 31 | 90 | 160 | 90 | 10 |
| 72 | 32 | 90 | 160 | 90 | 15 |
| 23 | 33 | 70 | 170 | 20 | 10 |
| 78 | 34 | 90 | 170 | 20 | 15 |
| 22 | 35 | 70 | 170 | 20 | 5 |
| 18 | 36 | 70 | 160 | 90 | 15 |
| 37 | 37 | 80 | 160 | 10 | 5 |

Note: $Temp_1$ is the temperature used for preparing the electroconductive paste; $Temp_2$ is the temperature used for the crosslinking process; Concentration refers to the metallic micro/nanoparticles from polymeric paste; Time refers to the time allocated for the cross-linking process.

Principal component analysis consists of the algebraic decomposition of a data matrix into a structure of components (factors) having the greatest common variability. Eigen analysis of the correlation and covariance matrix of the principal components for sensors development is presented in table 5, and the

Table 4

| FULL FACTORIAL PLAN DESIGN FOR FLEXIBLE SENSORS | | | | | |
|---|---|---|---|---|---|
| **Std Order** | **Run Order** | **Speed[1] (rpm)** | **Volume[2] (µl)** | **Concentration[3] (%)** | **Time[4] (s)** |
| 10 | 1 | 250 | 100 | 30 | 15 |
| 158 | 2 | 750 | 250 | 40 | 15 |
| 215 | 3 | 1000 | 250 | 20 | 30 |
| 13 | 4 | 250 | 100 | 40 | 10 |
| 24 | 5 | 250 | 250 | 20 | 60 |
| 141 | 6 | 750 | 100 | 40 | 10 |
| 184 | 7 | 750 | 1000 | 20 | 60 |
| 198 | 8 | 1000 | 100 | 20 | 15 |
| 17 | 9 | 250 | 250 | 10 | 10 |
| 232 | 10 | 1000 | 500 | 20 | 60 |
| 102 | 11 | 500 | 500 | 20 | 15 |
| 68 | 12 | 500 | 100 | 10 | 60 |
| 139 | 13 | 750 | 100 | 30 | 30 |
| 143 | 14 | 750 | 100 | 40 | 30 |
| 126 | 15 | 500 | 1000 | 40 | 15 |
| 176 | 16 | 750 | 500 | 40 | 60 |
| 86 | 17 | 500 | 250 | 20 | 15 |
| 2 | 18 | 250 | 100 | 10 | 15 |
| 252 | 19 | 1000 | 1000 | 30 | 60 |
| 218 | 20 | 1000 | 250 | 30 | 15 |
| 42 | 21 | 250 | 500 | 30 | 15 |
| 51 | 22 | 250 | 1000 | 10 | 30 |

Note: Speed represents the rotational speed (rpm) for the spin coater necessary for thin film deposition; Volume represents the volume of the conductive dispersion used to be deposited on the textile surface; Concentration represents the amount of metallic micro/nanoparticles in the polymeric dispersion; Time represents the necessary time for the spin coating process.

eigenvectors for sensors development are presented in table 6. The analysis of principal factors identifies a small number of factors (latent variables) that explain the common variance of the variables (concentration, temperature1, temperature2, time) that subsequently influence the dependent variable (electrical resistance).

Table 7 presents the unrotated matrix of the principal factors and the matrix rotated by the Varimax method for sensors development.

The Eigen analysis of the correlation and covariance matrix of the principal components for actuators' development is presented in table 8, and the eigenvectors for actuators' development are presented in table 9. The analysis of principal factors identifies a small number of factors that explain the common variance of the variables (rotational speed, volume, concentration and time) that subsequently influence the dependent variable (electrical resistance).

Table 10 presents the unrotated matrix of the principal factors and the matrix rotated by the Varimax method for actuators' development.

To graphically represent the correlation between the values of the variables (temperature$_1$, temperature$_2$, concentration and time), we generated a correlogram (figure 1), which compares Pearson correlation coefficients for each pair of variables, indicating properties including the direct/indirect and linear relationship between the variable pair, depending on the corresponding electrical resistance values. Figure 1 shows that between concentration and temperature$_2$ and between time and temperature$_2$, where there is a direct linear relationship because the correlation coefficients are very close to 1 (Correlation_coefficient$_{time,temp2}$ = 0.9; Correlation_coefficient$_{Concentration, temp2}$ = 0.87) for obtaining a textile electrode for flexible sensors with low surface resistance ($Rs$ = 20 Ω).

Table 5

| EIGENANALYSIS OF THE CORRELATION AND COVARIATION MATRICES FOR SENSORS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Correlation matrix** | | | | **Covariance matrix** | | | |
| Eigenvalue | 1 | 1 | 1 | 1 | 1282.5 | 67.5 | 67.5 | 16.9 |
| Proportion | 0.25 | 0.25 | 0.25 | 0.25 | 0.894 | 0.047 | 0.047 | 0.012 |
| Cumulative | 0.25 | 0.5 | 0.75 | 1 | 0.894 | 0.941 | 0.988 | 1 |

Table 6

| EIGENVECTORS FOR CORRELATION AND COVARIANCE FOR FLEXIBLE SENSORS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Correlation** | | | | **Covariance** | | | |
| | **PC1** | **PC2** | **PC3** | **PC4** | **PC1** | **PC2** | **PC3** | **PC4** |
| Temp$_1$ | 0 | 0 | 0 | –1 | 0 | –1 | 0 | 0 |
| Temp$_2$ | 0 | 0 | –1 | 0 | 0 | 0 | -1 | 0 |
| Concentration | –1 | 0 | 0 | 0 | –1 | 0 | 0 | 0 |
| Time | 0 | –1 | 0 | 0 | 0 | 0 | 0 | –1 |

Table 7

| PRINCIPAL COMPONENT FACTOR ANALYSIS OF THE CORRELATION AND COVARIANCE MATRICES FOR SENSORS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Unroted matrix** | | | | **Roted matrix** | | | | **Commu-nality** |
| | **Factor1** | **Factor2** | **Factor3** | **Factor4** | **Factor1** | **Factor2** | **Factor3** | **Factor4** | |
| $Temp_1$ | 0 | 0 | 0 | –1 | 0 | 0 | 0 | 1 | 1 |
| $Temp_2$ | 0 | 0 | –1 | 0 | 0 | 0 | 1 | 0 | 1 |
| Concentration | –1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Time | 0 | –1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Variance | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 |
| % Var | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1 |

Table 8

| EIGENANALYSIS OF THE CORRELATION AND COVARIANCE MATRICES FOR ACTUATORS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Correlation matrix** | | | | **Covariance matrix** | | | |
| Eigenvalue | 1 | 1 | 1 | 1 | 117176 | 78431 | 381 | 125 |
| Proportion | 0.25 | 0.25 | 0.25 | 0.25 | 0.597 | 0.4 | 0.002 | 0.001 |
| Cumulative | 0.25 | 0.5 | 0.75 | 1 | 0.597 | 0.997 | 0.999 | 1 |

Table 9

| EIGENVECTORS FOR CORRELATION AND COVARIANCE FOR ACTUATORS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Correlation** | | | | **Covariance** | | | |
| | **PC1** | **PC2** | **PC3** | **PC4** | **PC1** | **PC2** | **PC3** | **PC4** |
| Rotational speed | 0 | –1 | 0 | 0 | 0 | –1 | 0 | 0 |
| Volume | 0 | 0 | 0 | –1 | –1 | 0 | 0 | 0 |
| Concentration | 0 | 0 | –1 | 0 | 0 | 0 | 0 | –1 |
| Time | –1 | 0 | 0 | 0 | 0 | 0 | –1 | 0 |

Table 10

| PRINCIPAL COMPONENT FACTOR ANALYSIS OF THE CORRELATION AND COVARIANCE MATRICES FOR ACTUATORS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Unroted matrix** | | | | **Roted matrix (method Varimax)** | | | | **Commu-nality** |
| | **Factor1** | **Factor2** | **Factor3** | **Factor4** | **Factor1** | **Factor2** | **Factor3** | **Factor4** | |
| Rotational Speed | 0 | –1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Volume | 0 | 0 | 0 | –1 | 0 | 0 | 0 | 1 | 1 |
| Concentration | 0 | 0 | –1 | 0 | 0 | 0 | 1 | 0 | 1 |
| Time | –1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Variance | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 |
| % Var | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1 |

Table 11 presents the variance analysis of the independent variables (temperature1, temperature2, concentration, time).

DF represents the number of degrees of freedom. The number of degrees of freedom of the model error (DF) is given by equation 2.

$$DF_{Error} = n - 1 - \left(\sum DF_{factor_i} + \sum DF_{interact_{ij}}\right) \quad (2)$$

where $n$ is the number of observations in the experiment; $DF_{factor_i}$ represents the number of degrees of freedom of factor $i$; $DF_{interact_{ij}}$ represents the number

| VARIANCE ANALYSIS | | | |
|---|---|---|---|
| **Source** | **DF** | **Adj SS** | **Adj MS** |
| Model | 80 | 921000000 | 11511760 |
| Linear | 8 | 126000000 | 15709203 |
| $Temp_1$ | 2 | 33881511 | 16940756 |
| $Temp_2$ | 2 | 39095622 | 19547811 |
| Concentration | 2 | 19063806 | 9531903 |
| Time | 2 | 33632683 | 16816341 |
| 2-Way Interactions | 24 | 190000000 | 7896005 |
| $Temp_1$*$Temp_2$ | 4 | 8735544 | 2183886 |
| $Temp_1$*Concentration | 4 | 15635285 | 3908821 |
| $Temp_1$*Time | 4 | 20043558 | 5010890 |
| $Temp_2$*Concentration | 4 | 40458310 | 10114578 |
| $Temp_2$*Time | 4 | 9734416 | 2433604 |
| Concentration*Time | 4 | 94897016 | 23724254 |
| 3-Way Interactions | 32 | 2.79E+08 | 8714303 |
| $Temp_1$*$Temp_2$*Concentration | 8 | 48979158 | 6122395 |
| $Temp_1$*$Temp_2$*Time | 8 | 60081532 | 7510191 |
| $Temp_1$*Concentration*Time | 8 | 74161167 | 9270146 |
| $Temp_2$*Concentration*Time | 8 | 95635833 | 11954479 |
| 4-Way Interactions | 16 | 327000000 | 20431583 |
| $Temp_1$*$Temp_2$*Concentration*Time | 16 | 327000000 | 20431583 |
| Error | 0 | * | * |
| Total | 80 | 921000000 | |

Note: Adj SS is the adjusted sum of squares for the model; Adj MS is the square of the adjusted means.

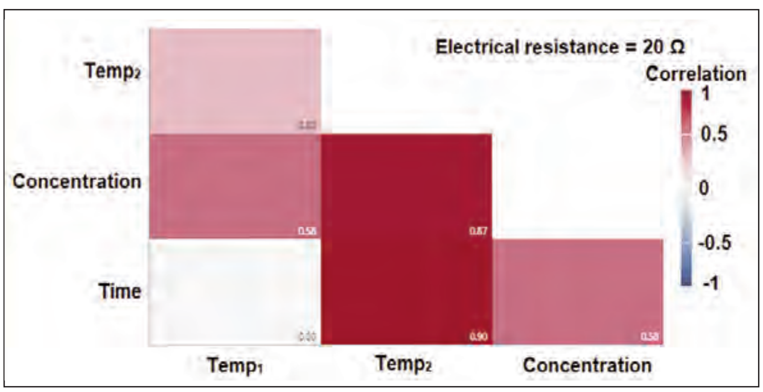


Fig. 1. Correlogram – time, $temp_1$, $temp_2$, concentration depending on electrical resistance (*Rs* = 20 Ω)

of degrees of freedom of the interaction between factor *i* and the *j* factor.

The sum of squares adjusted across the model ($Total_{Adj. SS}$) is presented after the variant analysis and represents the sum of all Adj SS values for all factors, interactions and errors.

## RESULTS AND DISCUSSION

Using the full factorial plan responsive to electrical resistance (dependent variable) and applying optimization toward reducing the sensor's electrical surface resistance to 4 Ω or 10 Ω, we used the minimization function ($F(x) = y$, $y$ = 4 Ω or 10 Ω) and obtained the results presented in table 12. Figure 2 presents the corresponding optimization graph and shows that the minimum value for electrical resistance (4 Ω) can be obtained if values of $temp_1$= 90°C, $temp_2$ = 150°C, concentration 20% and *time* = 5 minutes are used.

Using the full factorial plan including the response in electrical resistance (dependent variable) and applying optimization toward reducing the actuator's electrical surface resistance to 4 Ω or 10 Ω, we used the minimization function ($F(x) = y$, $y$ = 4 Ω or 10 Ω) and obtained the results presented in table 13. Figure 3 presents the corresponding optimization graph and shows that the minimum value for electrical resistance (4 Ω) can be obtained if rotational *speed* = 250 rpm, *volume* = 250 µl, concentration 10% and spin coating time 60 seconds are used.

The optimized solution reduces the number of redundant experiments (e.g., in the case of the conductive textile for actuators, the full factorial plan involves 256 experiments with 4 independent variables, each having 4 levels of values; in the case of sensors, the full factorial plan involves 81 experiments with 4 independent variables each having 3 levels of values), raw material consumption, total costs, and use of utilities (water, energy). However, it is recommended that the textile surface be hydrophobic to ensure a uniform distribution of the conductive dispersion during spin coating, despite that some inconvenience can occur when the textile surface is as flat as a wafer. For example, if the textile surface is hydrophilic and presents polar groups, then the dispersion can be absorbed very quickly before the time allocated for spin coating has ended.

Table 12

| OPTIMIZED SOLUTION FOR SENSORS EXPERIMENTS | | | | | | |
|---|---|---|---|---|---|---|
| **No.** | **$Temp_1$** | **$Temp_2$** | **Concentration** | **Time** | **Resistance fit** | **Composite desiderability** |
| 1 | 90 | 150 | 20 | 5 | 4 | 1 |
| 2 | 90 | 160 | 10 | 5 | 10 | 0.9994 |
| 3 | 90 | 170 | 90 | 5 | 10 | 0.9994 |
| 4 | 90 | 170 | 20 | 15 | 10 | 0.9994 |
| 5 | 90 | 160 | 90 | 10 | 10 | 0.9994 |
| 6 | 90 | 170 | 90 | 15 | 10 | 0.9994 |
| 7 | 80 | 160 | 10 | 10 | 10 | 0.9994 |
| 8 | 90 | 150 | 10 | 5 | 10 | 0.9994 |
| 9 | 80 | 160 | 20 | 15 | 10 | 0.9994 |
| 10 | 70 | 150 | 20 | 15 | 10 | 0.9994 |

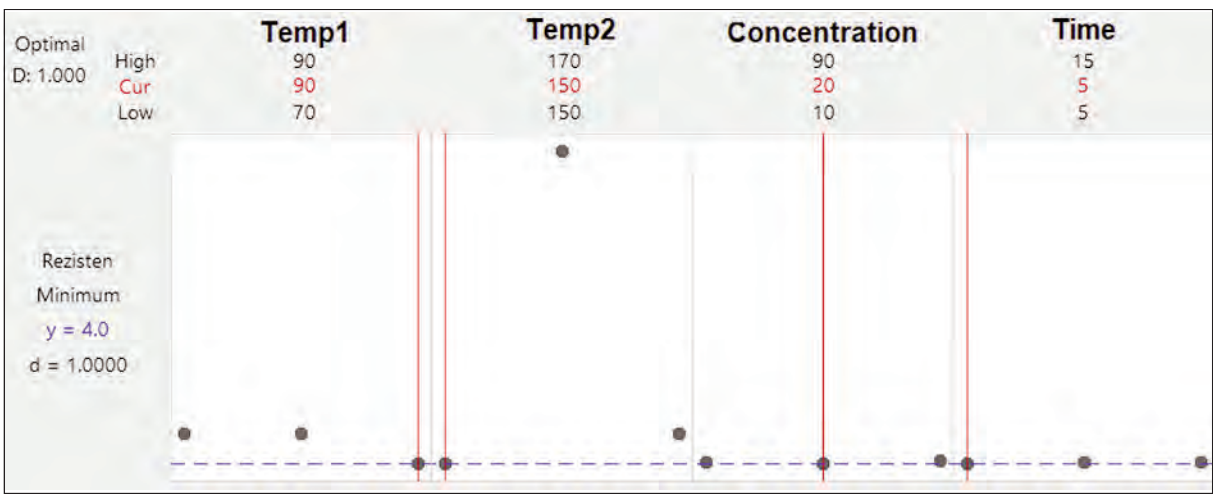


Fig. 2. Optimization graph for the sensor experiments

Table 13

| OPTIMIZED SOLUTION FOR ACTUATORS EXPERIMENTS | | | | | | |
|---|---|---|---|---|---|---|
| **No.** | **Speed** | **Volume** | **Concentration** | **Time** | **Resistance fit** | **Composite desiderability** |
| 1 | 250 | 250 | 10 | 60 | 4 | 1 |
| 2 | 1000 | 100 | 20 | 30 | 4 | 1 |
| 3 | 1000 | 100 | 10 | 10 | 4 | 1 |
| 4 | 250 | 100 | 40 | 30 | 4 | 1 |
| 5 | 1000 | 500 | 40 | 10 | 10 | 0.9994 |
| 6 | 250 | 500 | 30 | 30 | 10 | 0.9994 |
| 7 | 1000 | 250 | 30 | 30 | 10 | 0.9994 |
| 8 | 250 | 1000 | 40 | 60 | 10 | 0.9994 |
| 9 | 500 | 1000 | 40 | 10 | 10 | 0.9994 |
| 10 | 750 | 1000 | 40 | 30 | 10 | 0.9994 |

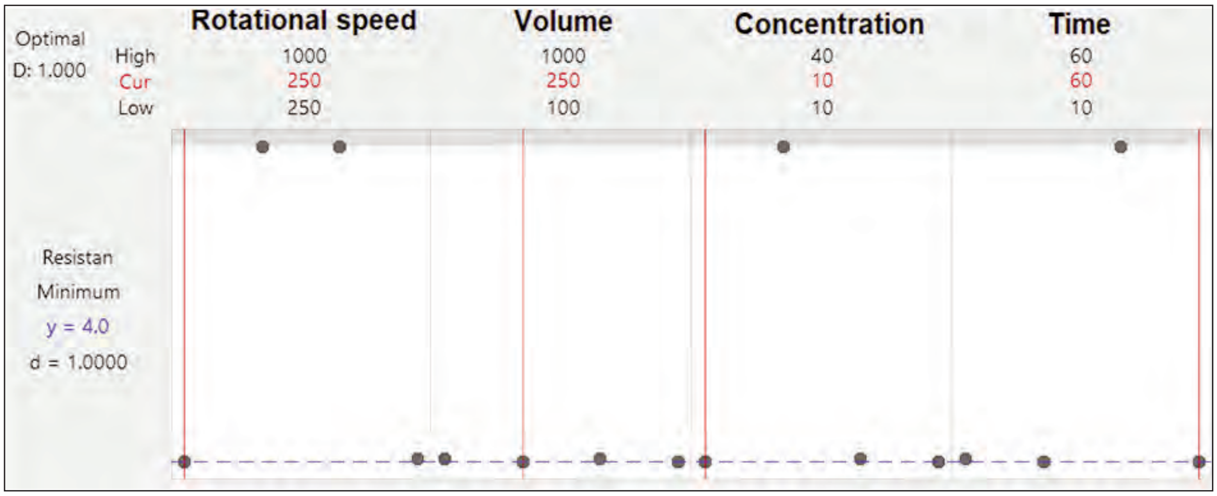


Fig. 3. Optimization graph for actuator experiments

## CONCLUSIONS

In conclusion, the principal component analysis may help reduce redundant data, establish the correlations and covariance between variables that are necessary for the prediction of such variable dependencies, discover which variables are latent and establish the correlation and covariance matrix. However, principal component analysis and full factorial design are rarely mentioned in articles considering the development of textile actuators and sensors.

Here, the use of a full factorial experimental design allows us to optimize the number of experiments and to reduce a huge experimental plan (i.e., 256 or 81 experiments), and the correspondingly large consumption of numerous resources (raw materials, chemicals, water, energy), too few experiments (10 experiments) and minimal resources. With these methods, we more quickly obtain the targeted electroconductive fabric to be used as an electrode for sensors or actuators.

## ACKNOWLEDGEMENTS

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# Prediction of yarn sales price using data mining techniques – a case of yarn manufacturing industry

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**ABSTRACT – REZUMAT**

**Prediction of yarn sales price using data mining techniques – a case of yarn manufacturing industry**

*Data-driven knowledge is required for businesses to make better decisions that result in profit maximisation. In this study, it has been attempted to develop a model to predict yarn sales prices against cotton prices and other parameters. For this purpose, four different data mining techniques namely ARIMA (Autoregressive Integrated Moving Average), Multivariate regression, K-Nearest Neighbor (KNN) and Neural Networks (NN), were considered. The entire analysis was performed on thirty months of data that was collected from the ERP system of a yarn manufacturing industry. The unique aspect of this study is that before separately deploying data mining techniques, significant parameters that impact yarn sales prices were identified through Adjusted R-squared values. Seasonal and trend patterns were checked on yarn sales data, and seasonal adjustments were obtained through data mining algorithms. The performance of all four models was evaluated using Mean Absolute Error and Root Mean Square Error. The analysis shows that the KNN model, in the stated settings, is the most accurate as evident from MAE and RMSE values of 222.85 and 285.082, respectively. This study's unique combination of features and machine learning algorithms is envisaged to be valuable for decision-makers in the textile yarn manufacturing industry.*

***Keywords:*** *yarn price, cotton price, prediction, K Nearest Neighbor, multivariate regression, Neural Network*

**Predicția prețului de vânzare a firelor folosind tehnici de extragere a datelor – un caz al industriei de fabricare a firelor**

*Cunoștințele bazate pe date sunt necesare pentru ca întreprinderile să ia decizii care au ca rezultat maximizarea profitului. În acest studiu, s-a încercat să se dezvolte un model care să preconizeze prețurile de vânzare a firelor în raport cu prețurile bumbacului și alți parametri. În acest scop, au fost luate în considerare patru tehnici diferite de extragere a datelor și anume ARIMA (Autoregressive Integrated Moving Average), regresia multivariată, algoritmul K-Nearest Neighbor (KNN) și reţelele neuronale (NN). Întreaga analiză a fost efectuată pe date colectate pe parcursul a treizeci de luni din sistemul ERP al unei industrii de fabricare a firelor. Aspectul unic al acestui studiu este că, înainte de implementarea separată a tehnicilor de extragere a datelor, parametrii semnificativi care influențează prețurile de vânzare a firelor au fost identificați prin valorile R-pătrat ajustate. Modelele sezoniere și tendințele au fost verificate pe datele vânzărilor de fire, iar ajustările sezoniere au fost obținute prin algoritmi de extragere a datelor. Performanța tuturor celor patru modele a fost evaluată folosind eroarea medie absolută și eroarea medie pătratică. Analiza arată că modelul KNN, în setările menționate, este cel mai precis, așa cum este evident din valorile MAE și RMSE de 222,85 și, respectiv, 285,082. Combinația unică de caracteristici și algoritmi de învățare automată a acestui studiu este considerată a fi valoroasă pentru factorii de decizie din industria producției de fire textile.*

***Cuvinte-cheie****: prețul firelor, prețul bumbacului, predicție, algoritmul K Nearest Neighbor, regresie multivariată, rețea neuronală*

## INTRODUCTION

As supply chains are becoming more and more integrated, the criticality of this task of optimization at every stage of the realization of a product or service is increasing [1, 2]. This is because the decisions taken for one stage can have a direct and significant impact on all upstream and downstream operations, ultimately affecting the overall profit margins [3–5]. The present study is related to the textile yarn manufacturing sector in general and cotton yarn manufacturing in particular. In this sector, it is an established practice to keep a large inventory of raw material, i.e., cotton fibre, to cater for yarn production of up to several months [6]. It is imperative to mention here that several research studies in the past have dealt with the prediction of yarn properties, for instance, yarn strength, using artificial neural networks [7, 8].

However, very few studies regarding price prediction for cotton and cotton yarn are available. Thus, the focus of this research was to analyse the selling price of yarn concerning the variation that occurs in cotton price, labour cost, factory overheads, plant maintenance and electricity consumption in the manufacturing of yarn, etc. In addition, warehousing and delivery costs were also taken into account. Technical analysis of the aforementioned parameters was carried out using different methods to design a "predictive framework".

Due to the limited literature available for cotton price prediction, the methods used for price prediction of other materials were also studied. For instance, price prediction for crude oil [9, 10] was reported by researchers who proposed a predictive model using 'Long Short Term Memory (LSTM)' in the deep learning domain to increase the accuracy of a large training set. Several forecasting-related studies report on the prediction of stock prices. In one such study, a 'Hybrid deep learning model' using 'LSTM' and 'Grated Recurrent Unit' for the prediction of stock prices was considered [11]. In this work, the investigators used traditional metrics including 'Mean Square Error – MSE', 'Mean Absolute Error – MAE' and 'Mean Absolute Percentage Error – MAPE' for evaluation of their proposed hybrid model. A known machine learning model, 'Support Vector Regression' was found effective in the prediction of stock prices if the model setting was updated repeatedly [12]. In another related study, a 'rough set' and 'Wavelet Neural Network' (WNN) were employed for the prediction of trends in stock prices [13]. In this study, the accuracy of the proposed integrated model was compared with other known methods such as 'Support Vector Machines-SVM' and 'Wavelet Neural Network – WNN when applied separately [13]'.

Several other forecasting models such as 'naïve methods' for three different settings including 'moving average', 'linear regression' and 'multiple regression', etc., were evaluated for an institutional food service facility. Among these, 'multiple regression' was found to be the best-suited model [14]. In another study, different forecasting methods were evaluated for hotel revenue management in which the most recommended methods were exponential smoothing, pick-up, and moving average models [15]. For the price prediction of gold, the application of 'The Autoregressive Integrated Moving Average Model' (ARIMA) has been reported in one study [16].

In one study about the price prediction of two different types of cotton yarn, researchers discussed the fluctuation in prices and the factors responsible for causing such fluctuations [17].

More specifically, 'Seasonality' and ARIMA Models were used to predict attribute prices and thus a composite model was formed by integrating Seasonality and ARIMA Models with the 'KNN Model' to forecast cotton yarn prices with improved accuracy. ARIMA model and time series analysis were utilized in one study about the prediction of Jute production in Bangladesh [18].

In another study, a 'composite' model for improved accuracy in the prediction of cotton prices has been reported [19]. In this study, monthly cotton price in two different periods namely the 'policy shock' period and 'normal market conditions' was predicted. Cotton price prediction in the policy shock period was done by 'vector auto-regressions' and in normal market conditions prediction was done using 'time series forecast'. In another study, researchers evaluated the 'ARIMA model', 'generalized autoregressive conditional heteroscedastic (GARCH) model' and 'exponential GARCH (EGARCH) model' for forecasting prices of edible oils (domestic and international) and cotton (international) [20]. EGARCH model outperformed the ARIMA and GARCH models in forecasting the international cotton price. This improved accuracy in forecasting by the EGARCH model was attributed primarily to its ability to capture asymmetric volatility patterns.

In light of the review of available literature presented above, the goal of this research was to analyse 'yarn sales price' while considering the variation in different components of the yarn manufacturing costs. To the best of our knowledge, in the available literature, yarn sales price has not been incorporated in various forecasting/prediction methods as the primary target variable. The significant factors responsible for volatility in various components of manufacturing costs were taken into account [21, 22]. Furthermore, the fact that short-term forecasting is known to be more accurate for commodities, was also considered [23]. Therefore, it is envisaged that the present study will provide a useful insight into effective methods for the analysis of yarn manufacturing business in particular. However, the findings can potentially be applied to other manufacturing and services concerns for which the datasets are similar to the one used in this study.

## METHODOLOGY

Based on the problem statement, certain steps were followed to build a prediction model for yarn sales price. In the first step, an evaluation of all the possible features that can create an impact on the manufacturing and selling of yarn was required. Secondly, features having the most pronounced effect on the performance of prediction models were identified. Lastly, effective algorithms for the dataset were investigated. The algorithms were decided based on seasonal and trend patterns in yarn sales prices, based on the influence of different features on the yarn prices and the basis of the relationship between yarn sales prices and the selected features.

### Data collection and pre-processing

For the present study, data in the form of time series from July 2016 to December 2018 of a textile spinning mill located in Karachi, Pakistan, was collected from the ERP system of the mill. The data about two types of yarn ('carded' and 'combed') being manufactured by the said textile spinning mill was considered to account for the total cost of production and total sales for the local market.

The purpose of pre-processing operations is to transform and clean raw data to bring it into a meaningful and understandable format [24]. Incomplete data can potentially yield incorrect and misleading results. In this context, the following pre-processing operations were performed in the present study. From the obtained data, the month-wise and lot-wise data was extracted in MS Excel sheets. Some of the variables/parameters of interest were already available in the data while the remaining features that were

Table 1

| COST COMPONENTS AND FEATURES CONSIDERED | | |
|---|---|---|
| **Data component** | **Abbreviation** | **Unit** |
| Yarn Sales Price | YSP | Rs/lb |
| USA Cotton Price | CP1 | Rs |
| Pakistani Cotton Price | CP2 | Rs |
| Yarn Production | YP | - |
| Cotton Consumption | CC | - |
| Raw Material Cost | RMC | Rs/lb |
| Electricity Cost | ELC | Rs |
| Salaries Cost | SC | Rs |
| Other Expenses Cost | EXC | Rs |
| Net Total Cost (per pound) | NTC | Rs/lb |
| Total Yarn Stock | TYS | lb |

required for the present study were calculated using the equations as provided in the supplementary data to this study. After these calculations, the data about local sales was separated followed by transformation into numeric data so that it could be subsequently modelled and trained by regression techniques. All the relevant cost components and features are tabulated in table 1 where Rs stands for Pakistani Rupee.

**Analysis performed on yarn sale price**

Graphical representation of data is often considered a preliminary step in data analysis. This approach is known to be helpful in the visualization of trends, seasonality, and cycles in the data as well as helps higher management to understand the inclination or declination of yarn sales prices in a better way. These features can then be incorporated into the forecasting methods described in the later section. Time series graphics are often regarded as the foremost method for this purpose [25]. In the present study, seasonal plot, time-series decomposition, and seasonal adjustment methods were employed to analyse the YSP.

- **Seasonal plots:** The available data was illustrated in the form of different formats of time series graphics. Firstly, a 'time plot' was constructed for the July 2016 to December 2018 period. The resulting plot is shown in figure 1. Secondly, a seasonal plot allows the underlying seasonal pattern to be seen more clearly and is especially useful in identifying seasons (for instance, 'years') in which the pattern changes [26]. In the present study, the seasonal plot of the data was constructed by setting the usual calendar year (Jan-Dec) as the 'season'. The resulting seasonal plot is shown in figure 2.
- **Time series decomposition:** It is a procedure where a single time series is broken down into its components, i.e., trend, seasonality, and error. In the present study, the available time series data was decomposed using two methods [27]; 'Seasonal and Trend Decomposition using Loess-STL' and 'Classical Decomposition' (both additive

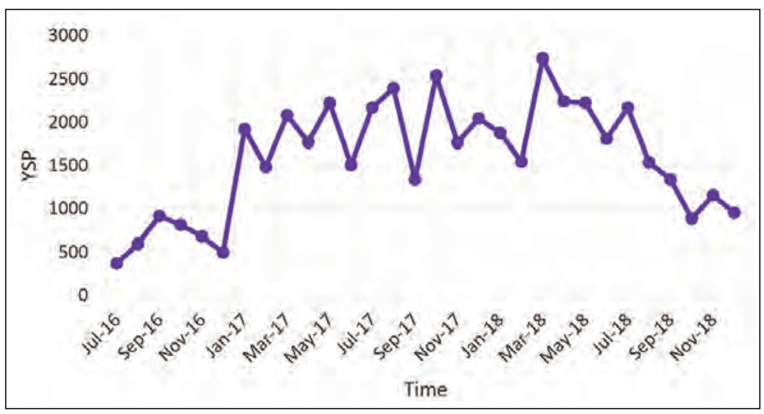


Fig. 1. Time plot of YSP

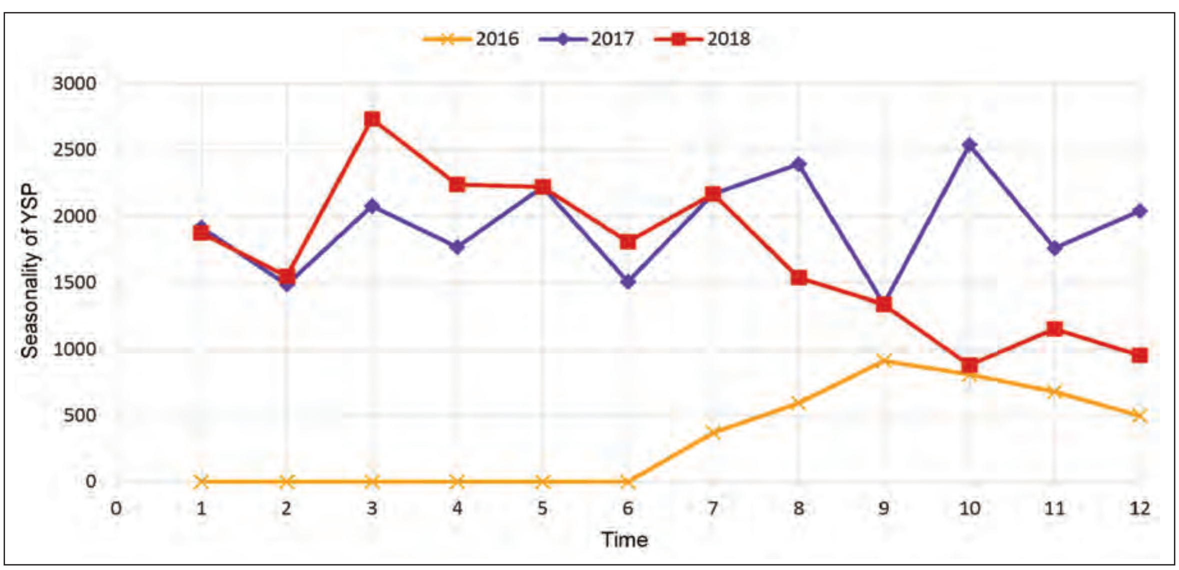


Fig. 2. Seasonal plot of YSP w.r.t year

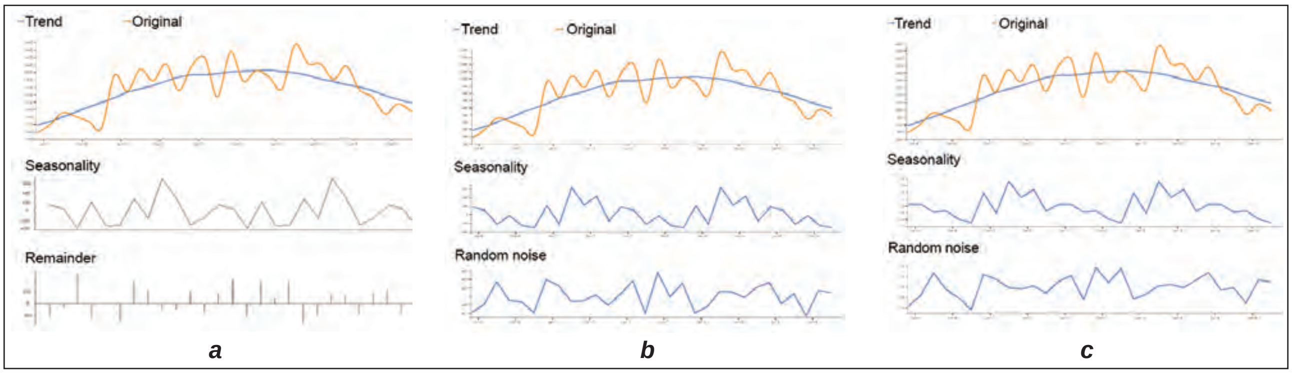


Fig. 3. Time-series decomposition using: *a* – STL; *b* – Classical decomposition (type; additive); *c* – Classical decomposition (type; multiplicative)

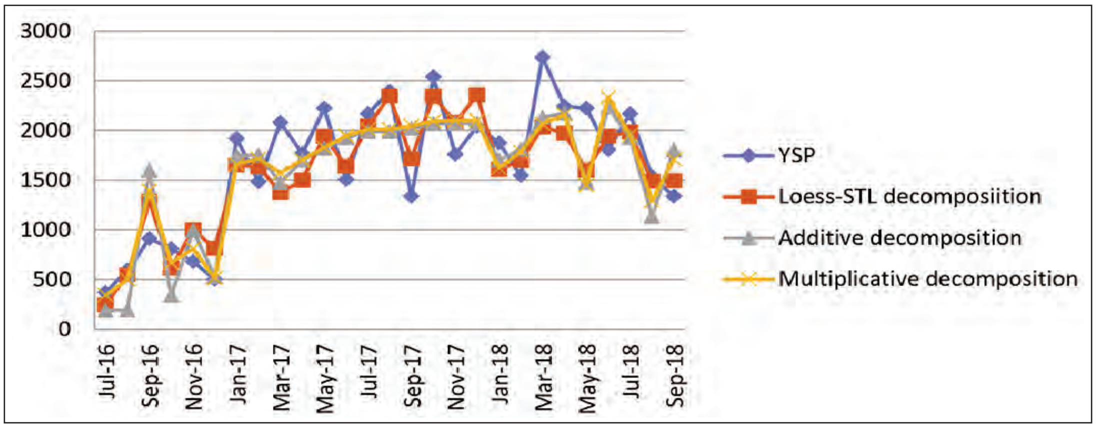


Fig. 4. Time series of the original data, seasonal adjustment using STL, seasonal adjustment using Additive decomposition and seasonal adjustment using Multiplicative decomposition

and multiplicative). The resulting graphs are shown in figure 3.

- **Seasonal adjustment:** It helps model the data without "seasonal effects" [28]. Seasonally adjusted data is obtained by "omitting" the seasonal component from the original data. In the present study, forecasting of YSP via the ARIMA Model was carried out using the original data and the data from which the seasonal component was removed as follows. Seasonal adjustment was done using all the decomposition methods as described in the previous section. The time series re-constructed after seasonal adjustment with Seasonal and Trend Decomposition, Additive Decomposition and with Multiplicative Decomposition is shown in figure 4.

After analysing YSP, the selected features affecting YSP were identified. The selection was based on the 'Adjusted R2' values calculated for the individual parameters and their combinations thereof. Table 2 provides the most significant (combination of) parameters and the associated Adjusted R2 value for YSP. Firstly, original data for the months of Oct-Dec 2018 were removed from the 29 months of data (i.e., July 2016 – December 2018) as discussed in the first and second sections. YSP original values are tabulated in table 3. These values were used for testing purposes to find out better accuracy in the predictions and for constructing the best-fit model. To analyse the model's scalability, the dataset is split for 26 months into training and testing datasets listed in table 4.

Table 2

SELECTED PARAMETERS FOR YARN SALES PRICE OF LOCAL MARKET

| Target variable | Parameters/Independent variables | Adjusted $R^2$ |
|---|---|---|
| YSP | CP1, CP2, YP, TYS | 13.30% |

Table 3

ORIGINAL VALUES OF YSP

| Month | YSP Original Value |
|---|---|
| Oct-18 | 881.965 |
| Nov-18 | 1154.398 |
| Dec-18 | 954.81 |

Table 4

DIVISION OF DATASET (DATA FOR 29 MONTHS)

| Training set (%) | Testing set (%) | Division |
|---|---|---|
| 60 | 40 | A |
| 70 | 30 | B |
| 75 | 25 | C |

Table 5

| YSP PREDICTIONS WITH ARIMA MODEL | | | |
|---|---|---|---|
| **Month** | **Predicted value for STL** | **Predicted value for Additive Decomposition** | **Predicted value for Multiplicative Decomposition** |
| Oct-18 | 1611.489 | 1564.422 | 1675.729 |
| Nov-18 | 1594.881 | 1478.75 | 1675.729 |
| Dec-18 | 1580.9 | 1478.75 | 1675.729 |

**Implementation of algorithms for prediction of YSP**

The first model that was considered to forecast YSP is the ARIMA Model. ARIMA model is a statistical analysis that is used for time series forecasting [29]. This model was built for both STL and classical decomposition (Additive/Multiplicative) methods. After the application of the ARIMA model, it was found that in comparison to the other methods, the YSP predicted using the additive decomposition was closer to the actual values for Oct, Nov, and Dec 2018. Values calculated for both cases (with and without seasonal component) were found to be the same for the dataset used in this research, as shown in table 5.

The second model that was applied is 'Multivarite Regression'. The predicted values of YSP obtained for different data set divisions are tabulated in table 6.

Table 6

| YSP PREDICTIONS WITH MULTIVARIATE REGRESSION MODEL | | | |
|---|---|---|---|
| **Month** | **Predicted value (Division A)** | **Predicted value (Division B)** | **Predicted value (Division C)** |
| Oct-18 | 1536.8049 | 1333.0258 | 1509.7648 |
| Nov-18 | 695.4393 | 490.4838 | 936.8201 |
| Dec-18 | 683.3659 | 497.5379 | 893.1763 |

Table 7

| YSP PREDICTIONS WITH KNN MODEL | | | |
|---|---|---|---|
| **Month** | **Predicted value (Division A)** | **Predicted value (Division B)** | **Predicted value (Division C)** |
| Oct-18 | 934.502 | 1127.998 | 1029.166 |
| Nov-18 | 908.404 | 890.2999 | 1029.166 |
| Dec-18 | 908.404 | 890.2999 | 1029.166 |

Table 8

| YSP PREDICTIONS WITH NN MODEL | | | |
|---|---|---|---|
| **Month** | **Predicted value (Division A)** | **Predicted value (Division B)** | **Predicted value (Division C)** |
| Oct-18 | 865.0542 | 882.95 | 882.85 |
| Nov-18 | 886.3313 | 881.22 | 881.29 |
| Dec-18 | 889.4591 | 880.9 | 881 |

The third model KNN was applied after data cleaning and partitioning as tabulated in table 4 and Euclidean distances were calculated for the predictors listed in table 2. The pair with the least distance is detected as the nearest neighbour and those pairs predicted the yarn sales price. After analysis, the results depicted that K = 5 resulted in minimum RMSE and maximum model accuracy.

The predicted values of YSP obtained for different data sets are tabulated in table 7.

Lastly, the 'Neural Networks' model was employed. Different layers of the neural network models were proposed based on different configurations and partitions (table 4). After analysis, it was concluded that the least SSE between training and testing results was found for Model 3 (NN3) because it has two hidden layers with a total of 5 neurons which gives less error in NN3. YSP-relevant prediction results are provided in table 8.

## RESULTS AND DISCUSSION

YSP predictions obtained from four models, as described in the preceding section, were analysed to identify the best-performing forecasting model for the dataset used in this research. This analysis was based on checking the error between the predicted and the actual values. For this purpose, the traditional metrics were considered, including 'Mean Absolute Error' (MAE) and 'Root Mean Square Error' (RMSE). The MAE and RMSE values for all models are tabulated in table 9 and table 10.

From these results, it is evident that for Division C of the dataset, the MAE and RMSE values are lower as compared to other Divisions and Methods.

Considering Division C, the MAE and RMSE values for the KNN Model were found to be lowest at 222.85 and 285.082, respectively. Thus, the optimal division of the dataset for all the models was KNN with Division C.

The previous studies used a combination of seasonality, ARIMA and KNN models to predict yarn prices [17]. However, this paper presents a new contribution to the literature. Firstly, the authors extended the features by including all possible data related to yarn sales prices. They evaluated each feature's impact on yarn prices using adjusted R2. Additionally, the authors analysed seasonal and trend patterns in yarn sales prices, which can assist higher management in making informed decisions in the textile industry.

Table 9

| MEAN ABSOLUTE ERROR (MAE) | | | |
|---|---|---|---|
| **Variable** | **Division A** | **Division B** | **Division C** |
| Multivariate Regression | 399.5926 | 397.3673 | 333.156 |
| KNN | 439.8063 | 327.1329 | 222.985 |
| Neural Network | 739.7477 | 572.9759 | 474.9306 |
| **Variable** | **STL** | **Additive Decomposition** | **Multiplicative Decomposition** |
| ARIMA | 598.699 | 510.249 | 678.671 |

Table 10

| ROOT MEAN SQUARE ERROR (RMSE) | | | |
|---|---|---|---|
| **Variable** | **Division A** | **Division B** | **Division C** |
| Multivariate Regression | 436.0006 | 438.623 | 398.502 |
| KNN | 571.7995 | 393.906 | 285.082 |
| Neural Network | 921.8554 | 740.0367 | 621.1331 |
| **Variable** | **STL** | **Additive Decomposition** | **Multiplicative Decomposition** |
| ARIMA | 610.524 | 530.868 | 688.37 |

Secondly, the authors utilized different machine learning algorithms to predict yarn sales prices. They used the ARIMA model to forecast prices based on historical trends and Multivariate Regression to get better results. To reduce errors, they also used the KNN model to predict sales prices. Additionally, they included neural networks in their study, as they are a widely studied tool for problem-solving in various fields and have previously been used to predict stock prices and yarn properties such as strength in the previous studies [8]. Finally, the authors evaluated the best-predicted model using traditional metrics that were not previously published in the literature.

## CONCLUSION

The methods presented in this study can be applied to similar datasets to predict other variables of interest and subsequently facilitate the management of an industry in decision-making. This paper introduces a new approach to predicting yarn sales prices by using advanced data mining techniques and deep learning algorithms. Furthermore, trends and seasonal patterns in the data were analysed to predict yarn sales prices which is a novel approach compared to previous studies that used traditional techniques. This study's unique combination of features and machine learning algorithms is expected to provide valuable insights for decision-makers in the textile yarn manufacturing industry.

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# Comprehensive assessment methods of environmental impacts during textile production

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**ABSTRACT – REZUMAT**

**Comprehensive assessment methods of environmental impacts during textile production**

*As an important part of textile production, the dyeing process not only makes the greatest contribution to water consumption and wastewater discharge, but its use of synthetic dyestuffs has a negative impact on all forms of life. To assess the environmental impact of textile production, it is necessary to assess the environmental impact of the dyeing process. Comprehensive assessment methods can convert multi-dimensional environmental impacts into unified quantitative indicators and enable comparisons between different products or environmental impact categories. In this study, five comprehensive assessment methods (i.e., ReCiPe, Eco-Indicator 99, Nike MSI, Environmental Price, and Environmental Profit & Loss) were applied to evaluate the environmental impact of the cotton fabric dyeing process. Furthermore, a preliminary assessment framework was constructed which could provide a reference for industry experts to establish uniform environmental assessment standards. The results indicate that diverse methods are recommended to be applied in parallel to analyse the environmental impact of textile products, and the use of individual comprehensive environmental assessment methods has its limitations and characteristics. Among the five methods, the ReCiPe method stands out as one of the most advanced LCA methodologies with the widest range of midpoint impact categories and a global-scale calculation mechanism. The scoring method offers sufficient possibilities to compare the severity of different environmental impacts caused by the dyeing process, and the monetary value model can be used as a more intuitive tool to characterize environmental impact no matter from the midpoint or endpoint.*

***Keywords:*** *comprehensive assessment methods, environmental impacts, textile production, single point, monetary valuation*

**Metode de evaluare a impactului asupra mediului în timpul producției materialelor textile**

*Ca parte importantă a producției materialelor textile, procesul de vopsire nu numai că are cea mai mare contribuție la consumul de apă și la evacuarea apelor uzate, dar utilizarea sa de coloranți sintetici are un impact negativ asupra tuturor formelor de viață. Pentru a evalua impactul asupra mediului al producției textile, este necesar să se evalueze impactul asupra mediului al procesului de vopsire. Metodele de evaluare pot converti efectele multidimensionale asupra mediului în indicatori cantitativi unificați și pot permite comparații între diferite produse sau categorii de impact asupra mediului. În acest studiu, au fost aplicate cinci metode de evaluare (cum ar fi ReCiPe, Eco-Indicator 99, Nike MSI, Environmental Price și Environmental Profit & Loss) pentru a evalua impactul asupra mediului al procesului de vopsire a materialelor textile din bumbac. În plus, a fost construit un cadru de evaluare preliminară care ar putea oferi o referință experților din industrie pentru a stabili standarde uniforme de evaluare a mediului. Rezultatele indică faptul că diverse metode sunt recomandate a fi aplicate în paralel pentru a analiza impactul asupra mediului al produselor textile, iar utilizarea metodelor individuale de evaluare a mediului are propriile limitări și caracteristici. Iar dintre cele cinci metode, metoda ReCiPe se evidențiază ca una dintre cele mai avansate metodologii LCA cu cea mai largă gamă de categorii de impact median și un mecanism de calcul la scară globală. Metoda de punctare oferă suficiente posibilități pentru a compara severitatea diferitelor tipuri de impact asupra mediului cauzate de procesul de vopsire, iar modelul valorii monetare poate fi folosit ca un instrument mai intuitiv pentru a caracteriza impactul asupra mediului, indiferent dacă este de la punctul median sau de la punctul final.*

***Cuvinte-cheie:*** *metode de evaluare, impactul asupra mediului, producția de textile, un singur punct, evaluarea monetară*

## INTRODUCTION

The textile industry is responsible for significant global environmental impacts [1]. Energies, freshwater, and chemicals are consumed in the textile production process, causing water scarcity, water pollution, air pollution, and other environmental impacts [2]. To quantify the negative environmental impact of the various production stages of the textile industry and analyse a single product's environmental impacts, life cycle assessment (LCA) is widely used in the carbon, water, and chemical footprint measurements applied in a cradle-to-grave or cradle-to-gate scenario [3]. These footprint indicators above focus on specific environmental impacts respectively. For example, carbon footprint is used to quantify the global warming potential impact of greenhouse gas emissions; water footprint is used to quantify the environmental impacts of water consumption and wastewater discharge. However, in the actual circumstances, textile production involves diverse kinds of environmental impacts. Correspondingly, the multi-dimensional indicators of environmental impact assessment can express multiple environmental impact categories simultaneously. For instance, Product Environmental Footprint (PEF), a multi-criteria measurement of the products' environmental performance throughout the life cycle, includes global warming potential, human toxicity, eutrophication, land use, etc. [4, 5].

From what has been clarified, a single environmental impact assessment indicator can only quantify the environmental impact of a certain aspect, and the multi-dimensional environmental impact assessment indicator integrates various environmental impacts with different quantification units. It is challenging to execute comparisons between different products or environmental impact categories without transforming the impacts into a uniform indicator [6]. Based on this relation, it is essential to use a simple procedure that can be ideally applied consistently to all pollutants emitted and give comparable results between products or environmental impact categories [7]. Several different comprehensive impact assessment methodologies have been proposed, and several of them have been implemented in software commercially available on the market [8].

Table 1

DEFINITION OF COMPREHENSIVE IMPACT ASSESSMENT METHODS

| Comprehensive impact assessment methods | Definition |
|---|---|
| Scoring | A scoring mechanism that incorporates different impact characteristics into its formula design aims to assess the comprehensive impact |
| Monetary valuation | Monetary valuation is the practice of converting measures of social and biophysical impacts into monetary units and is used to determine the economic value of non-market goods, i.e. goods for which no market exists |

Scoring and monetary valuation are common forms of comprehensive impact assessment methods, and the definitions of environmental impact assessment methods are detailed in table 1 [9]. The most typical scoring methods are Eco-Indicator 99 (EI99) and ReCiPe. Both of them are developed to determine the environmental impacts resulting from a product. EI99 is considered to be a comprehensive damage approach that is developed to simplify the interpretation and weighting of assessment results [7, 10]. ReCiPe, combining the advantages of the midpoint-based life cycle impact assessment approach and endpoint-based approach, has been thought to be one of the most advanced LCA methodologies around the world [11]. Another scoring method, the Nike Materials Sustainability Index (Nike MSI) was proposed in 2012 to evaluate the potential environmental impacts of materials in the product creation process, aiming to guide product creation teams in selecting materials that possess a lower environmental impact [12]. A comprehensive assessment method called Environmental Price and Environmental Gain and Loss (EP&L) is expressed in monetary values. Environmental prices are developed to express environmental impacts in monetary units at three levels: the pollutant level (a value for emissions of environmentally damaging substances), the midpoint level, and the endpoint level [13]. This method is used to assess the damage caused to the environment and humans by business activities, although many activities are not currently reflected in market prices [14].

Using different comprehensive assessments of the environmental impact of specific industrial processes would make the results more credible. Among textile production, the dyeing process makes the largest contribution to water consumption and wastewater discharge, and the use of synthetic dyestuffs has a negative impact on all forms of life [15, 16].

Therefore, the environmental impact analysis of the dyeing stage of cotton production can be a good case study for the comprehensive environmental impact assessment study of textile products. It can also provide data and scenarios for the comparative study of different comprehensive environmental impact assessment methods. In this paper, ReCiPe, EI99, Nike MSI, Environmental Price, and EP&L were applied to the environmental impact assessment of the cotton fabric dyeing process and a preliminary assessment framework was constructed. In addition, the methodological differences between these five methods as well as the practical implications were discussed. This study aims to serve as a reference for practitioners seeking to select suitable product environmental impact assessment methods and provide inspiration for the establishment of a unified environmental assessment mechanism.

## METHODOLOGY AND DATA

### Comprehensive assessment methodology

There are two mainstream ways to quantify the environmental impacts: problem-oriented (midpoint) and damage-oriented (endpoint). The definitions of environmental impact quantification methods are detailed in table 2 [17].

These two methods can be used to achieve a comprehensive evaluation through characterization, normalization, and weighting. The schematic diagram of the comprehensive environmental impact assessment related to the midpoint and endpoint approach is shown in figure 1. The two approaches are consistent models that can work together. The midpoint characterization is more directly linked to the environmental impacts and has relatively higher scientific

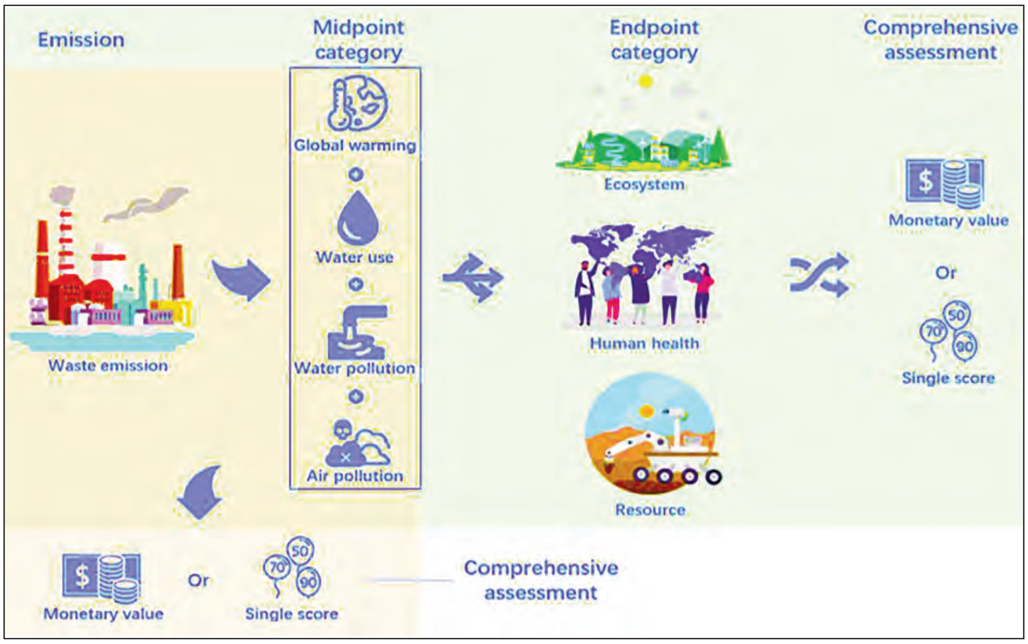


Fig. 1. Schematic diagram of comprehensive environmental impact assessment

Table 2

DEFINITION OF ENVIRONMENTAL IMPACT QUANTIFICATION METHODS

| Environmental impact quantification methods | Definition |
|---|---|
| Problem-oriented (midpoint) | The midpoint approach classifies impacts into different environmental themes in the underlying impact pathway such as global warming potential, water acquisition, water deterioration, air pollution, etc. |
| Damage-oriented (endpoint) | The endpoint approach transfers environmental impacts to concerning issues at the end of the impact pathway, such as human health, natural environment, and resource scarcity |

validity, while the endpoint indicators are more understandable because they show the outcomes of the environmental impacts. Both approaches can be expressed with monetary value or a single score [18, 19].

The construction of the comprehensive environmental impact assessment framework proceeded according to the following stages: (i) The definition of the comprehensive environmental impact assessment; (ii) the selection of the objective and scope of research work; (iii) the determination of the expression of impact categories; (iv) data search and collection; (v) the creation of a calculation model for the comprehensive environmental impact assessment results (equation 1). The methodology of comprehensive assessment methods can be expressed as:

$$F = \sum F_i = \sum E_i \times f_{c,i} = \sum W_i \times f_{e,i} \times f_{c,i} \qquad (1)$$

As shown in equation 1, the comprehensive environmental impact assessment results are composed of several impact categories. The comprehensive assessment result of environmental impact $i$ ($F_i$) is determined by multiplying the environmental damage value ($E_i$) with the comprehensively characterize factor ($f_{c,i}$). $E_i$ can be further expressed as the product of pollution emission equivalent ($W_i$) and environmental impact characterizes factor ($f_{e,i}$).

The characterize factors of comprehensive assessment approaches are different according to ReCiPe, EI99, Nike MSI, Environmental Price, and EP&L (as listed in table 3). In the ReCiPe and EI99 methodologies, $f_{e,i}$ are endpoint impact factors, and $f_{c,i}$ are expressed in single score Pt. One Pt can be interpreted as one-thousandth of the annual environmental load of one average European inhabitant [8]. In the Nike MSI assessment framework, $f_{c,i}$ is expressed in point. It is not a substitute for full LCA studies nor does it provide endpoint assessment data. In the Environmental Price and PwC-EP&L methodologies, $f_{c,i}$ is expressed in monetary value. The $f_{e,i}$ of Environmental Price is the midpoint impact factor, and the $f_{e,i}$ of PwC-EP&L is the endpoint impact factor.

There are some differences in the detailed classification of impact categories among these five methods, but the important midpoint impact categories such as global warming potential, water pollution, and air pollution are all included in these methods. In this paper, we classified the midpoint impact categories into four indicators according to the impact categories of PwC-EP&L to demonstrate the case study results (as shown in table 4).

**Data**

These five kinds of comprehensive assessment methods were adopted in the evaluation of the environmental impacts of the dyeing process of cotton

Table 3

| COMPARISON OF COMPREHENSIVE ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGY | | | | |
|---|---|---|---|---|
| **Comprehensive assessment approaches** | **Comprehensive impact assessment methods** | | **Environmental impact quantification methods** | |
| | Scoring | Monetary valuation | Problem-oriented (midpoint) | Damage-oriented (endpoint) |
| ReCiPe | $\surd(f_{c,i})$ | | | $\surd(f_{e,i})$ |
| EI99 | $\surd(f_{c,i})$ | | | $\surd(f_{e,i})$ |
| Nike MSI | $\surd(f_{c,i})$ | | | |
| Environmental Price | | $\surd(f_{c,i})$ | $\surd(f_{e,i})$ | |
| PwC-EP&L | | $\surd(f_{c,i})$ | | $\surd(f_{e,i})$ |

Table 4

| MIDPOINT IMPACT CATEGORIES SCHEME OF FIVE METHODS RELATED TO THE COTTON FABRIC DYEING PROCESS | | | | | |
|---|---|---|---|---|---|
| **Impact indicators** | **ReCiPe** | **EI99** | **Nike MSI** | **Environmental Price** | **PwC-EP&L** |
| Water consumption | Water consumption | – | Water use intensity | – | Water consumption |
| Greenhouse gases | Global warming | Climate change | Greenhouse gas intensity | Climate change | Greenhouse gases |
| Air pollution | Fine particulate matter formation; Photochemical ozone formation | Respiratory effects | Chemistry | Terrestrial acidification; Photochemical oxidant formation; Particulate matter formation | Air pollution |
| Water pollution | Freshwater ecotoxicity | Ecotoxicity; Carcinogens | | Human toxicity; Freshwater ecotoxicity | Water pollution |

fabric. The functional unit was defined as 1 kg of dyed cotton fabric. The data was collected from a textile-dyeing enterprise in Jiangsu Province (as listed in table 5) [20]. The characterize factors, normalization factors and weighting factors of ReCiPe, EI99 and Environmental Price were referred to the Simapro version 9.2.0.1. database. The data of PwC-EP&L and Nike MSI were obtained from PwC valuing

Table 5

| THE COMPREHENSIVE ASSESSMENT RESULTS OF THE COTTON FABRIC DYEING PROCESS BASED ON FIVE METHODS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Impact category** | | | **ReCiPe (Pt)** | | **Eco-indicator 99 (Pt)** | | **Nike MSI (point)** | **Environmental Price ($)** | **PwC EP&L ($)** |
| | | | Human health | Ecosystems | Human health | Ecosystem quality | | | |
| Water consumption ($m^3$) | Freshwater | 8.60 | 0.318 | 0.0314 | – | – | 8 | – | 3.55 |
| Greenhouse gases (kg) | $CO_2$ | 12.1 | 0.219 | 0.0107 | 0.129 | – | 3 | 0.909 | 1.10 |
| | $CH_4$ | 0.0576 | | | | | | | |
| | $N_2O$ | $2.44 \cdot 10^{-4}$ | | | | | | | |
| Air pollution (kg) | $SO_2$ | 0.01.34 | 0.0446 | $1.18 \cdot 10^{-4}$ | 0.0469 | – | 3.4 | 0.281 | $5.41 \cdot 10^{-4}$ |
| | NOx | 0.00337 | | | | | | | |
| | $NH_3$ | $2.10 \cdot 10^{-7}$ | | | | | | | |
| | NMVOC | $3.80 \cdot 10^{-5}$ | | | | | | | |
| Water pollution (kg) | Lead | $4.65 \cdot 10^{-8}$ | – | $9.62 \cdot 10^{-10}$ | $1.25 \cdot 10^{-4}$ | $9.36 \cdot 10^{-11}$ | | $6.37 \cdot 10^{-5}$ | 0.38 |
| | Mercury | $9.76 \cdot 10^{-10}$ | | | | | | | |
| | Cadmium | $1.73 \cdot 10^{-9}$ | | | | | | | |
| | Arsenic | $3.98 \cdot 10^{-8}$ | | | | | | | |
| Total | | | **0.62** | | **0.18** | | **14.4** | **1.19** | **5.04** |

corporate environmental impacts and Nike materials sustainability index methodology [12, 14].

## RESULT AND DISCUSSION

The comprehensive assessment results of the environmental impacts of the dyeing process are tabulated in table 5. It can be seen that greenhouse gas emissions and water consumption occupy a considerable proportion of the total environmental impacts. Water pollution has the least environmental impact.

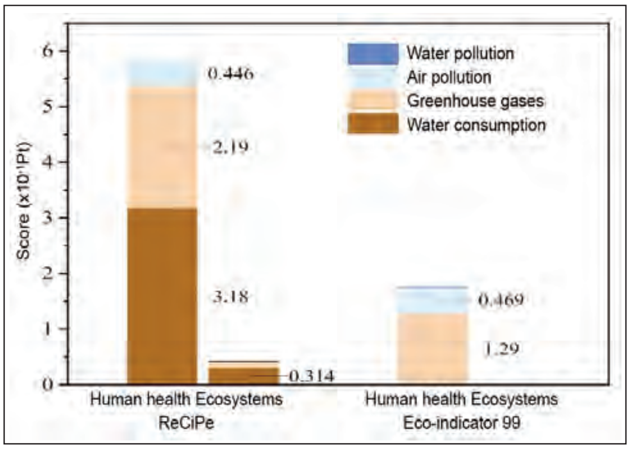


Fig. 2. Comparison of comprehensive assessment results between ReCiPe and EI99 method

At the endpoint level, the score gained according to the ReCiPe method is larger than that of the EI99 method (figure 2). This is because the EI99 method does not contain the impact category of water consumption, which leads to the underestimation of the total environmental impact. ReCiPe is suggested as a damage-oriented method better than EI99 because it expands the impact list of the ecosystem's damage category. In the resources damage category, the ReCiPe method provides more reliable cost parameters instead of the vague supplement of the energy requirement applied in EI99 [21].
Nike MSI evaluates the sustainability of products by assigning a numerical value to raw materials [22]. The base material score of cotton fabric is 26.8 points according to the Nike MSI scoring framework. In this study, we got a score of 14.4 points due to the environmental impact of physical waste was not included in the evaluation procedure (as shown in table 5). Nike MSI is not comparable with other methods because it is not based on life cycle assessment. It is a tool that engages designers to consider the sustainability issues of raw materials. Out of 100 points, a higher score means the material is more sustainable [12].
Environmental Price and PwC-EP&L express environmental impact in monetary value. From the results in table 5, it can be seen that the environmental impact monetary value of PwC-EP&L is larger than the Environmental Price (figure 3). The main difference between the two methods is that they are based

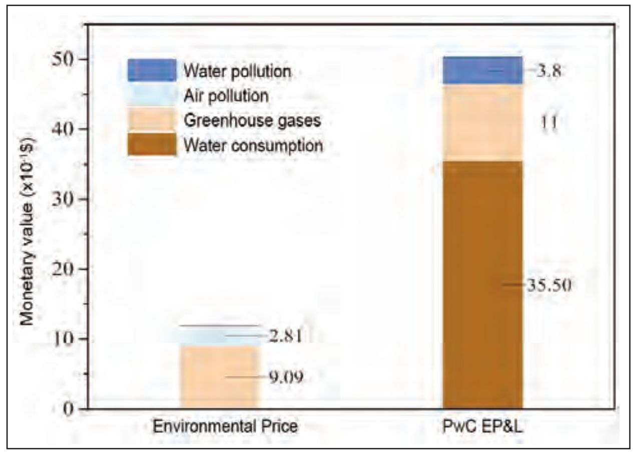


Fig. 3. Comparison of comprehensive assessment results between Environmental Price and PwC-EP&L method

on different study backgrounds. The Environmental Price was conducted in the Netherlands while the PwC-EP&L was conducted in the UK.
Besides, the impact category of water consumption in Environmental Price is not involved in the assessment system. It is the main reason that caused the gap between the two results.
Using the Recipe method in the scoring method and the PwC-EP&L method in the monetary valuation method to observe the environmental impact results, we found that water consumption accounts for 56.35% and 70.44% of the total environmental impact respectively. Therefore, we can formulate water-saving measures for the dyeing process in cotton fabric production from the perspective of water consumption. We can consider increasing the application of clean production technology to suppress wastewater discharge from the source. This includes adopting highly efficient and environmentally friendly dyes and chemicals and auxiliaries, adopting small bath ratio intermittent dyeing, pigment printing, digital ink-jet printing, transfer printing and other waterless printing and dyeing technical equipment. We can also adopt technologies such as condensed water reuse and reclaimed water reuse, counter-current rinsing by lattice, etc., to improve the water reuse rate.
Based on the above analysis, it is clear that both the scoring method and the monetary valuation method have their characteristics and limitations.
Scoring methods offer sufficient possibilities to analyse ecological impacts and make it relatively easy to compare different environmental impacts. The subjectivity of the weighting factors is one of the main weaknesses of this method because the weighting factors are often extracted from questionnaires with experts within the field [17]. As the uncertainty of different assessment systems is difficult to quantify, Goedkoop and Spriensma (2001). have developed three versions of eco-indicators, covering the perspectives of short-term (Individualist), long-term (Egalitarian) and balance (Hierarchist) effects. The three visions are applied in ReCiPe methods and EI99 methods, and the 'Hierarchist' version is often

the default option for environmental impact assessment [23].

The monetary valuation method provides a new option for assessing the environmental impacts of goods that are not on the market, such as clean atmosphere or freshwater [24]. It can simplify many complex environmental metrics into a single unit, enabling businesses to make comparisons and prioritize environmental impacts, and hence to reduce impacts in the most influential stage or develop environmental-friendly products. The limitation of monetary valuation is mainly due to the choice of monetary factor which will be affected by many elements, especially time and region. The monetarization of environmental impact is under development, and its suitability to provide information for specific business decisions still needs to be evaluated on a case-by-case basis [14].

The midpoint and endpoint environmental assessment mechanisms and weighting factors that make up the indicators were developed based on the social values, context, and environmental issues of a particular region [7]. Therefore, the discrepancy in spatial boundaries among these methods is obvious, some are global, whereas others are limited to a specific region or country [24, 25]. These methods are currently still partially under development and none of them is a perfect approach to fully contain all environmental impacts.

## CONCLUSIONS

This paper provided a review of existing comprehensive environmental impact assessment methods with a case study and constructed a preliminary assessment framework. Through decomposing impact pathways and highlighting their methodological discrepancy, this study could assist practitioners in choosing an appropriate method to implement comprehensive assessment according to their goals and data availability when conducting an environmental impact study. The assessment framework also provides a reference for industry experts to establish uniform environmental assessment standards. Among the five methods, the ReCiPe method finds its strength as one of the advanced LCA methodologies with the broadest categories of midpoint impact and a calculation mechanism with global scope. The monetary value model is easily understandable and can be used as a more intuitive tool to characterize environmental impact matter from the midpoint or endpoint. Assigning monetary value to the evaluation of environmental impacts allows companies to take sustainability into account when making decisions, thereby providing better outcomes for the environment and society. Additionally, this paper illustrates that these comprehensive assessment methods are not competitive absolutely because they provide distinct strengths and weaknesses and thus are recommended to be applied in parallel to analyse the environmental impact of textile products.


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# Different types of environmental regulations and carbon intensity: empirical analysis of China's garment industry

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**ABSTRACT – REZUMAT**

**Different types of environmental regulations and carbon intensity: empirical analysis of China's garment industry**

*Environmental regulation is an important tool to mitigate carbon emissions. To explore the relationships between different types of environmental regulations and carbon intensity (CI) of China's garment industry, this paper uses multiple econometric models to study the effects of command-and-control environmental regulation (CER), market-incentive environmental regulation (MER) and public-participation environmental regulation (PER) the carbon intensity of China's garment industry and analyses their regional heterogeneity. The results show that at the national level, both CER and MER have a green paradox effect on CI of China's garment industry, while the effect of PER is not significant. At regional level, in the eastern garment industry the influence of CER on CI is dominated by the forced emission reduction effect, while MER pushes up the emission intensity within a certain range. Increasing PER helps to reduce the CI of western and North-eastern garment industry. The potential for implications from the results and policy recommendations are also discussed.*

***Keywords:*** *China's garment industry, carbon intensity, environmental regulation, green paradox effect, forced emission reduction effect*

**Diferite tipuri de reglementări de mediu și intensitatea emisiilor de carbon: analiză empirică a industriei de îmbrăcăminte din China**

*Reglementarea mediului este un instrument important pentru atenuarea emisiilor de carbon. Pentru a explora relațiile dintre diferitele tipuri de reglementări de mediu și intensitatea emisiilor de carbon (CI) din industria de îmbrăcăminte din China, această lucrare utilizează mai multe modele econometrice pentru a studia efectele reglementării de mediu de comandă și control (CER), reglementarea de mediu care stimulează piața (MER) și reglementarea de mediu cu participarea publică (PER) privind intensitatea emisiilor de carbon din industria de îmbrăcăminte din China și analizează eterogenitatea lor regională. Rezultatele arată că, la nivel național, atât CER, cât și MER au un efect de paradox verde asupra CI a industriei de îmbrăcăminte din China, în timp ce efectul PER nu este semnificativ. La nivel regional, în industria de îmbrăcăminte din est, influența CER asupra CI este dominată de efectul de reducere a emisiilor forțate, în timp ce MER împinge în sus intensitatea emisiilor într-un anumit interval. Creșterea PER ajută la reducerea CI în industria de îmbrăcăminte din vest și din nord-est. Se discută, de asemenea, potențialul de aplicare a rezultatelor și recomandărilor de politici.*

***Cuvinte-cheie****: industria de îmbrăcăminte din China, intensitatea emisiilor de carbon, reglementarea mediului, efect de paradox verde, efect de reducere a emisiilor forțate*

## INTRODUCTION

Under the strategy of China's "carbon peaking and carbon neutralization", green development is the consensus of all industries of the national economy. As a major source of carbon emissions in China, the textile and garment industry has been under strict regulation. In recent years, the Chinese government has actively promoted energy saving and emission reduction in the textile and garment industry, and has formulated and implemented many laws, regulations and policies to drive the sustainable development of the industry. China's 14th Five-Year Plan for the Development of Textile and Garment Industry has proposed to "reach a new level of green development" and set a goal of 18% reduction in $CO_2$ emissions per unit of industrial value-added in China's textile and garment industry from 2021 to 2025. The garment sector is an important part of China's textile and garment industry and reducing carbon intensity (CI) of the garment industry is of great practical significance to achieve this green development goal.

As environmental quality and sustainable development have become a global concern, governments have been seeking instruments suitable for achieving the objectives. Three generations of tools within environmental policy: command and control, market-based or flexible instruments, and voluntary agreements were identified. Environmental regulation (ER) has been used to reduce the carbon emissions and carbon intensity, and promote effectively regional low-carbon development. However, extant empirical evidence on the relationship between environmental regulation and carbon emissions was inconsistent. Some studies showed that moderate environmental regulation could reduce CI and strictly and properly designed environmental regulation could stimulate business innovation, and the "compliance costs" due to environmental regulation could be effectively offset by the compensation effect of innovation, so the enterprises improved their productivity and competitiveness. Zhu and Ruth [1] studied the relationship between environmental regulations and carbon emissions using Tobit model. They found that environmental regulations played an important role in energy saving and emission reduction, and improving environmental standards could effectively reduce carbon emissions. On the contrary, some scholars believed that environmental regulation might not contribute to the reduction of carbon emissions, which was also known as the green paradox hypothesis [2]. Ritter and Schopf [3] concluded that green policies would accelerate the extraction of fossil energy, which would lead to a sharp increase in carbon emissions and was not helpful for the improvement of carbon efficiency. Schou [4] argued that environmental regulation could not mitigate carbon emissions, and as natural resources continued to be consumed and the emissions would automatically decrease. Some studies suggested that green paradox effect and forced emission reduction effect coexisted. Min [5] found that the impact of environmental regulation on carbon emissions showed a clear inverted U-shaped trend. Before and after the turning point, the green paradox effect and the forced emission reduction effect were observed, respectively.

As different types of environmental regulations differ in terms of regulatory efficiency, regulatory costs, penalties, and scope of application, scholars also compared the variability of the impacts of three environmental regulations on carbon emissions. Studies by Wang and Huang [6], Dong and Wang [7] and Almeida et al. [8] using Chinese and EU data confirmed that CER, MER and PER all could reduce total carbon emissions. Guo and Chen [9] observed that in China environmental regulation had a greater impact on carbon emissions in developed regions (i.e., eastern region) than in developing regions (i.e., central and western regions). Wu's [10] study revealed that environmental regulation could effectively curb carbon emissions in eastern and central regions, while it did not work as expected in the western region. Abbas et al. [11] used the data of BRICs to prove that MER played a mediating role in the impact of the renewable energy development on carbon emissions.

Research results on the relationship between environmental regulations and carbon emissions in China's garment industry are scarce. Published literature mainly estimated the total carbon emissions of the textile and garment industry [12] and analysed its influencing factors [13]. However, there was a lack of specialized research on the garment industry, and even less on carbon emissions of the industry. Can environmental regulation reduce carbon intensity of China's garment industry? What is the impact of different types of environmental regulations on the garment industry? Given the development level of China's garment industry varies from region to region, are there regional heterogeneities in the impact of various types of environmental regulations? Answering these questions will provide evidence suggesting specific policy recommendations targeting the sustainable development of China's garment industry.

This paper first measures carbon intensity of China's garment industry during 2005–2019, and analyses its trend nationally and by region. Then following the benchmark model and threshold regression model, this paper explores the linear or non-linear relationship between different environmental regulations and carbon intensity of the garment industry.

Furthermore, it examines the heterogeneous effects of various environmental regulations on carbon intensity across different regions. Finally, the potential for implications from the results and some policy recommendations are discussed. Compared with previous studies, the contribution of this paper is that it examines the impact of ERs on carbon intensity in China's garment industry for the first time. On the other hand, it provides a comprehensive analysis of the relationship between ERs and carbon intensity at national and regional levels.

## METHODOLOGY AND DATA SOURCES

### Estimation model

*Benchmark model*

In order to study the impacts of different environmental regulations on carbon intensity of China's garment industry, this paper constructs a benchmark panel model of the relationship between environmental regulations and carbon intensity according to the existing studies [14] as follows:

$$LnY_{it} = C_{it} + \beta LnXER_{it} + \theta LnX_{it} + \varepsilon_{it} \qquad (1)$$

where $Y_{it}$ represents carbon intensity of the garment industry of province *i* in year *t*. $XER_{it}$ denotes three kinds of environmental regulations: $CER_{it}$, $MER_{it}$ and $PER_{it}$. $X_{it}$ is the control variable and $\varepsilon_{it}$ is the residual. $\beta$ and $\theta$ represent the regression coefficients of independent variables and control variables.

*Threshold regression model*

It has been shown that there may be a nonlinear relationship between environmental regulations and carbon intensity. Most scholars used static panel threshold models to measure the nonlinear relationship between independent and dependent variables. Hansen [15] first proposed the threshold model to analyse the influence of independent variables on dependent variables under different threshold values. In the threshold model, each threshold value represents a point of transition. The relationship between variables varies in different ranges and single-threshold or multi-threshold models can be constructed according to the number of thresholds. To investigate whether different environmental regulations have a significant threshold effect on carbon intensity of China's garment industry, we construct the panel threshold model as described below following the study of Hansen:

$$LnY_{it} = C_{it} + \beta_1 LnXER_{it} \cdot I(XER_{it} \leq \gamma_1) +$$
$$+ \beta_2 LnXER_{it} \cdot I(\gamma_1 < XER_{it} \leq \gamma_2) + \ldots +$$
$$+ \beta_n LnXER_{it} \cdot I(\gamma_{n-1} < XER_{it} \leq \gamma_n) +$$
$$+ \beta_{n+1} LnXER_{it} \cdot I(XER_{it} > \gamma_{n+1}) + \theta LnX_{it} + \varepsilon_{it} \quad (2)$$

where *i, t* represent the region and year, respectively. $I(*)$ is the indicator function that takes the value of 1 when the condition in parentheses holds and 0 otherwise. $\gamma$ is the threshold value to be estimated. $\beta$ and $\theta$ denote the influence coefficients of independent variables and control variables in different ranges of threshold variables, respectively. The meanings of other variables are consistent with the benchmark model.

**Variables**

*Dependent variables*

Carbon intensity (CI) is the amount of $CO_2$ emissions per unit of gross output of China's garment industry. In general, CI decreases with the technological progress and economic growth.

*Independent variables*

Command-and-control environmental regulation (CER) is that the government makes laws and regulations to enforce against companies that destroy the environment. CER is expressed as the ratio of completed investment in industrial pollution control of each province to the gross industrial output of industries above the designated size.

Market-incentive environmental regulation (MER) is based on the "polluter pays" principle. The government does not intervene directly in the production of enterprises, but only guides them to reduce environmental pollution by the appropriate market regulation. This paper measures MER by the proportion of sewage charges in each province to the gross industrial output of industries above designated size.

Public-participation environmental regulation (PER), also known as informal environmental regulation exerts pressure on local governments and polluters through public environmental demands or environmental information disclosure. According to Pargal [16], here the entropy method is adopted to calculate the weighted values of residents' income, population density and education level in each province as a measure of PER.

*Control variables*

The structure of energy consumption (ES) can partly reflect the composition and structure of regional economies. It's measured by GDP per capita. If the energy consumption is mainly carbon-based, carbon emissions of the region are correspondingly higher. And if it is dominated by clean energy, the emissions are lower.

The level of urbanization (URB) is an important indicator of the degree of urban development and is estimated here by the ratio of the urban population to the total population. Urban expansion also brings increased energy consumption and more carbon emissions.

Foreign Direct Investment (FDI) provides a direct measure of a region's capability to attract capital, which is expressed as the total amount of foreign direct investment. Typically, investments often flow to areas where human resources costs are low. These areas, in comparison, are usually backward and have relatively high carbon emissions.

**Data sources**

All the data used in the empirical research are derived from the China Statistical Yearbook, China Industrial Statistical Yearbook and China Emission Accounts and Datasets (CEADs). CEADs have not yet published data on carbon emissions by sector for 2020 and beyond, and the statistical yearbook prior to 2005 did not have individual statistics on the garment industry. Due to the data availability the research periods cover from 2005 to 2019.

## THE CARBON INTENSITY OF CHINA'S GARMENT INDUSTRY

With the Chinese government's increasing emphasis on environmental protection, some industries, including the garment industry, have been subject to stricter regulations on carbon emissions. As a result, the CI of garment industry in China and all its four regions showed a fluctuating decline from 2005 to 2019, although in a different way across regions (table 1). The energy efficiency and environmental performance of the central garment industry have improved significantly. The CI of central garment industry had been decreasing year by year with a convergence trend, from 1.22 times of the national average in 2005 to 0.35 times in 2019. Central region had seen the significant reduction in CI. It is also worth noting that CI in the western region showed a gradual decreasing trend from 2005 to 2013, but then increased year by year from 2014, with recurrence and fluctuations. This resulted in the highest CI in the country, with 55.5 tons per billion CNY in 2019, which was 4.02 times the national average. From 2005 to 2019, its CI decreased by only 7.9 tons per billion CNY, with a decline of 12%, which was the smallest of the four regions. It showed the western garment industry was facing great pressure to reduce its CI. In addition, in the eastern region CI had also been declining, but at a slower pace. In 2019, CI of eastern garment industry was 1.19 times the national average, indicating the eastern region had to make more efforts to reduce CI and improve carbon emission efficiency.

Table 1

| CARBON INTENSITY OF GARMENT INDUSTRY IN CHINA AND BY REGION | | | | | |
|---|---|---|---|---|---|
| **Year** | **Carbon intensity (ton/billion CNY)** | | | | |
| | **China** | **Eastern** | **Central** | **Western** | **North-eastern** |
| 2005 | 74.4 | 72.0 | 90.7 | 63.4 | 245.4 |
| 2006 | 68.7 | 64.0 | 126.4 | 49.3 | 225.3 |
| 2007 | 58.8 | 56.8 | 75.6 | 20.9 | 210.9 |
| 2008 | 53.7 | 50.0 | 73.7 | 20.7 | 267.8 |
| 2009 | 44.5 | 42.1 | 47.7 | 15.9 | 204.5 |
| 2010 | 37.4 | 36.4 | 29.5 | 31.4 | 132.2 |
| 2011 | 29.7 | 28.8 | 21.1 | 15.2 | 122.0 |
| 2012 | 24.5 | 24.5 | 16.6 | 14.9 | 82.5 |
| 2013 | 18.2 | 19.4 | 10.6 | 12.2 | 46.7 |
| 2014 | 16.9 | 18.2 | 7.6 | 15.3 | 50.2 |

## THE IMPACTS OF ENVIRONMENTAL REGULATIONS ON CARBON INTENSITY OF CHINA'S GARMENT INDUSTRY

This paper firstly examines the threshold effects of three environmental regulations on CI of China's garment industry. The test results (table 2) show that CER has a significant double threshold effect on CI of eastern garment industry, but the single threshold effect is not significant. The same results are observed for MER's influence on CI of national and eastern garment industry, respectively. The significant single threshold effect of PER on CI exists in the western garment industry, while its double threshold effect is not significant. The others don't pass the threshold effect test (due to the limited space, only the significant test results are listed in table 2). Then the Hausman tests (not presented here for the same reason) show that the fixed effect model should be used for the estimation. The regression results are shown in table 3, which again only lists the impact coefficients of core independent variables.

### At national level

The impact coefficient of CER on CI of China's garment industry is significantly positive (0.134), which indicates a green paradox effect. This means that tighter CER causes higher CI in the garment industry, which is contrary to the results Wu's [17] research on China's iron and steel industry. The reason may be that the garment industry is typically labour-intensive, rather than capital-intensive, and it is more sensitive to the changes in production cost. The increase in environmental protection costs due to CER had a crowding-out effect on the investment of technological innovation in clothing enterprises, which was negative for the improvement of carbon efficiency. MER shows a double threshold effect on CI, but its coefficient is significant (0.693) only between the two thresholds. It suggests that within this range MER also has a green paradox effect on CI, and the use of MER tools such as transactional emission permits increases CI of China's garment industry instead of reducing it. It may likewise be due to the crowding-out effect of ER costs on technological innovation inputs. The regression coefficient of PER is positive, but not significant.

### At regional level

In the eastern region, CER has a double threshold effect on the CI of the garment industry. The impact coefficients (table 3) are both significantly negative, –0.507 and –2.161 when CER is less than the first threshold and between the two, respectively. It demonstrates that CER's impact on CI is dominated

Table 2

| THE THRESHOLD EFFECT TEST RESULTS | | | | | | |
|---|---|---|---|---|---|---|
| **Regions** | **Dependent variables** | **Number of thresholds** | **P-value** | **Threshold values** | **Lower** | **Upper** |
| China | MER | Double | 0.000 | –3.459 | –3.466 | –3.433 |
| | | | | –3.339 | –3.318 | –3.229 |
| Eastern | CER | Double | 0.000 | 1.236 | 1.234 | 1.318 |
| | | | | 1.261 | 1.229 | 1.306 |
| MER | Double | 0.000 | –3.408 | –3.459 | –3.361 | |
| | | | | –3.229 | –3.318 | –3.207 |
| Western | PER | Single | 0.000 | –3.883 | – | – |

Table 3

THE REGRESSION RESULTS OF GARMENT INDUSTRY IN CHINA AND BY REGION

| Region | ER | CI | | |
|---|---|---|---|---|
| China | CER | $0.134^{*}$ | | |
| | MER | | –0.052 (MER ≥ –3.459) | |
| | | | $0.693^{***}$(–3.459 < MER ≤ –3.229) | |
| | | | –0.167(MER > –3.229) | |
| | PER | | | 0.273 |
| Eastern | CER | $-0.507^{*}$(CER ≤ 1.236) | | |
| | | $-2.161^{***}$(1.236 < CER ≤ 1.261) | | |
| | | 0.014 (CER > 1.261) | | |
| | MER | | –0.106 (MER ≤ –3.408) | |
| | | | $0.653^{***}$(–3.408 < MER ≤ –3.229) | |
| | | | –0.302 (MER > –3.229) | |
| | PER | | | $1.125^{***}$ |
| Central | CER | 0.110 | | |
| | MER | | –0.173 | |
| | PER | | | $0.671^{*}$ |
| Western | CER | 0.160 | | |
| | MER | | –0.160 | |
| | PER | | | –0.494(PER ≤ –3.883) |
| | | | | $-0.628^{*}$(PER > –3.883) |
| North-eastern | CER | –0.329 | | |
| | MER | | $-0.534^{***}$ | |
| | PER | | | $-0.978^{*}$ |

Note: ***, **, * represent significance levels of 1%, 5% and 10%, respectively.

by a forced emission reduction effect and increasing formal environment regulation helps reduce CI of eastern garment industry. A double threshold effect is also observed between MER and CI, but the regression coefficient is only significant (0.653) between the two thresholds. This means that within a certain range MER pushes up CI of eastern garment industry. The coefficient of PER is significantly positive (1.125), showing a green paradox effect.

In the central region, the impact coefficient of PER is also significantly positive (0.671), showing a green paradox effect, similar to that in the eastern region. The other coefficients are not significant and will not be discussed here.

In the western region, there is a single threshold effect between PER and CI. The impact coefficient is only significant (–0.628) when PER is greater than the threshold. It indicates that PER can effectively reduce CI only when the intensity of PER exceeds a certain threshold, contrary to the results in the eastern and central regions.

Similar to the western region, PER also has a forced emission reduction effect (–0.978) on the CI of North-eastern garment industry. Therefore, enhancing public participation in environmental protection can help reduce CI in the Western and North-eastern garment industry, but not curb the growth of CI in the Eastern and central. In addition, the coefficient of MER is also significantly negative (–0.534), which means MER can be used as effective tool to supervise and force companies to reduce the CI of North-eastern garment industry.

## CONCLUSIONS AND POLICY RECOMMENDATIONS

This paper uses multiple econometric models to study the impacts of three different types of environmental regulations on carbon intensity of China's garment industry and explore their regional heterogeneity. The research results are as follows:

- At national level, CER has a green paradox effect on CI of China's garment industry and increasing formal environment regulation is not beneficial to the reduction of CI of garment industry. The relationship between MER and CI is also dominated by a green paradox effect. The impact coefficient of PER is not significant.
- At regional level, the empirical results indicate a significant heterogeneous effect of environmental regulations on CI in different regions. Specifically, in eastern garment industry CER shows a forced emission reduction effect on CI, whereas MER has a significant positive effect which means MER has increased CI of eastern garment industry within a certain range. A forced emission reduction effect of MER on CI exists in the North-eastern region. The impact of PER on CI is found to be different among

four regions: enhancing public participation in environmental protection can help reduce CI of the western and North-eastern garment industry, but it is not helpful in the eastern and central regions.

Based on the findings above, this paper provides the following policy recommendations to promote the green and low-carbon development of China's garment industry. (1) Environmental policies or measures in China's garment industry should be gradual and not simply pursue excessive regulatory intensity. They should keep CER and MER within reasonable limits to avoid putting too much pressure on garment companies in environmental protection. (2) The eastern region should continue to advance the innovation of CER methods, set stricter environmental standards and strengthen policy implementation. In the Northeast area, a combination of CER and MER should be adopted. Local government should implement a tougher environmental enforcement and accelerate the widespread application of MER. On the other hand, as in the western region, it is necessary to raise public awareness, encourage the public to actively participate in environmental protection and improve the supervision and disclosure requirements for enterprises.

Despite the contributions, this study also has limitations. Due to data availability, the data of China's garment industry from 2005 to 2019 is used as the research sample. More information may be revealed in the future if the data in 2020–2022 is available.

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# Developing a zero-waste pattern drafting method suitable for mass production

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**ABSTRACT – REZUMAT**

**Developing a zero-waste pattern drafting method suitable for mass production**

*The fashion industry is well known for being one of the most polluting industries worldwide, and its contribution to textile waste and apparel consumption has grown in significance over the years. The development and integration of zero-waste patterns in designing sustainable apparel represent a promising approach that supports reducing pre-consumer textile waste and optimizing fabric consumption. Moreover, it encourages society to step into a new era of the garment industry, by shifting the regular way in which consumers are currently perceiving apparel items: a trend, rather than a need – based on a survey conducted in 2023 by the author. The study focuses on the design principles and techniques of zero-waste patterns and their impact on fabric utilization. For this study, the patterns have been digitally drafted and nested, testing the requirements given by the chosen fabric and waste minimization. To acquire a specific image of the result, consisting of the garment item, has been virtually simulated. This method of obtaining the product's prototype aims to highlight and encourage the paradigm shift concerning digitalization that needs to take place within the manufacturing industry. The results of the study demonstrate that zero-waste patterns can reduce fabric consumption and significantly reduce pre-consumer waste, but their drafting methods are highly related to the design process and the chosen fabric's characteristics, such as usable with or print artwork.*

***Keywords:*** *apparel industry, pre-consumer fabric waste, sewing patterns, size set, sustainability*

**Dezvoltarea unei metode de proiectare a tiparelor zero-waste aplicată pentru producția în masă**

*Industria modei este renumită ca fiind una dintre cele mai poluante industrii la nivel mondial, contribuind în mod semnificativ, în ultimii ani, la producerea deșeurilor textile, precum și la dezvoltarea consumului de îmbrăcăminte. Dezvoltarea și integrarea tiparelor zero-waste în procesul de proiectare a articolelor vestimentare sustenabile reprezintă o abordare promițătoare, ce susține reducerea deșeurilor textile pre-consum, precum și optimizarea consumului de material textil. În plus, încurajează tranziția spre o nouă eră în cadrul acestui domeniu, prin modificarea modului prin care consumatorii percep la momentul actual produsele vestimentare: drept o modă, și nu o necesitate – bazat pe un sondaj de opinie efectuat în anul 2023 de către autor. Cercetarea realizată se concentrează asupra principiilor de design, precum și a tehnicilor de proiectare a tiparelor zero-waste, și în consecință asupra impactului pe care acestea îl au asupra consumului de material textil. Pentru acest studiu, tiparele au fost proiectate și încadrate digital, ținând cont atât de cerințele impuse de material, cât și de minimizarea deșeurilor textile. Cu scopul obținerii unei imagini reprezentative a produsului vestimentar analizat, a fost realizat prototipul virtual al acestuia. Prin această metodă s-a urmărit evidențierea și încurajarea schimbării de paradigmă în ceea ce privește digitalizarea proceselor din cadrul acestei ramuri industriale. Rezultatele studiului demonstrează faptul că tiparele zero-waste pot reduce consumul de material textil, minimizând în mod semnificativ cantitatea de deșeu textil pre-consum, însă metodele de proiectare a acestora sunt în strânsă legătură cu caracteristicile materialului ales, precum lățimea utilă sau direcția imprimeului.*

***Cuvinte-cheie:*** *industria produselor de îmbrăcăminte, deșeu textil pre-consum, tipare, gamă de mărimi, sustenabilitate*

## INTRODUCTION

The fashion industry has become well known for its glamour and ability to express the wearer's social status, preferences, and personality, in a way that does not imply using words. Through clothing items, people can adorn themselves, which also plays an important role in shielding one's body from outside threats. Apart from the representative assets that the fashion industry possesses, there is an opaque side to it, that goes hand in hand and shares simultaneous progress with the former aspect previously presented, given the increased consumption of apparel items [1]. Thus, the attention can be directed toward the negative side of the fashion industry. Even though its effects are not as visible or obvious to the naked eye of the regular consumer, they are present and ever-growing [2, 3]. The fashion industry is known for its high fabric consumption and pre- or post-consumer textile waste that's generated throughout the product's life cycle. Traditional garment production methods often result in the production of pre-consumer textile waste due to the inefficient use of fabric. Oftentimes, the unused fabric scraps are destroyed, either by incineration or landfill disposal. Both methods have a major impact on the environment (air, water, and land pollution), thus directly threatening human health. Considering the production process of textile fabric, as well as the polluting implications that are generated during the making process, one can appreciate the need to develop and adopt systems that capitalize on these textile resources. The generation of material losses during tailoring is a predictable and imminent factor that takes shape in the pattern design process [4].

Since the amount of textile material included in the composition of an article of clothing exceeds 50% of the total garment item, it is particularly important to develop practices and methods that ensure the most efficient utilization of the fabric.

Due to the current socio-cultural diversity, clothing is presented in a very wide range of shapes, sizes, and shades, designed to meet all the demands and needs addressed by consumers.

The apparel market has seen growth over the years [4], and it is expected to grow even further, in the upcoming years [5, 6], with a remarkable global rate of 63% by 2030 [7]. Those increasing tendencies include generating significant amounts of pre-consumer fabric waste, contributing to the expanding climate crisis [8]. On the European level, the policy of the 3R, which encourages the reduction, re-usage, and recycling of solid waste, was first integrated and promoted within the Waste Framework Directive (WFD, 2008/98/EC), in 2008.

Reusing and recycling are two processes on their own, that require resources needed to reintegrate solid waste back into the life cycle. Given the ongoing war in Ukraine, the prices for energy, transport, and raw materials have increased [9], thus emphasizing the prevention principle as being the most preferred outcome.

Within manufacturing factories, the pre-consumer waste mostly consists of leftover fabric or fabric scraps generated during the cutting process. If collected separately, those are then either incinerated, reused, or recycled, based on the profile of the collectors. Thus, the result can be translated as either air pollution or resource consumption. The resolution which enables the minimization and prevention of solid pre-consumer textile waste generation consists of using geometrical sewing patterns, which ensure the complete usage of the fabric, within the given usable width of the textile material. Such patterns caught the public eye in the last decade, despite being a popular technique of tailoring back in ancient times [10]. Recent studies have analysed the process of engineering clothing items, by using zero waste patterns (ZWP), developing new approaches as well as identifying several limits [11, 12].

Considering the complexity of drafting a ZWP set, the process of developing a technique that can be applied in the apparel industry may seem problematic [13]. In some cases, the seam allowances can be altered, to ensure the coverage capacity of the pattern's cutting perimeter [14], whereas, in other given circumstances, the unused fabric pieces can be attributed to aesthetic or practical value, by integrating them into the garment item as pockets or other decorative accessories [15]. It is important to mention the mass production that can be obtained, by using a ZWP set, for making multiple production units. The method implies generating different pattern sets, following the size range for which the units are produced [16].

## METHODOLOGY

The development of the ZWP drafting technique is based on drafting the initial set of classic patterns, which represent the base, shape, and dimensional-wise, on which the ZWP will be shaped. Nonetheless, the existence of a classic pattern set (CPS) will help in obtaining a concluding comparison regarding fabric usage and marker efficiency between the two types of patterns. The CPS has been obtained by shaping the base patterns following the design particularities of the chosen style.

The patterns have been drafted and developed using the Gemini Pattern Editor (GPE) software, and the layplans have been generated using the Gemini Nest Expert (GNE) system, which automatically generates the marker efficiency, as well as the fabric usage. The garment item has been virtually generated, using CLO 3D.

This research is based on reducing the pre-consumer textile waste that may be generated during cutting, by recovering potential scrap fabric and identifying a way through which it can be integrated into the value chain. The object of this study consists in optimizing fabric consumption, by drafting new pattern pieces. The starting point is the layplan initially generated to nest the existing classical pattern pieces for a women's dress item. The areas of unused fabric have been repurposed, to create a new set of patterns. Thus, a second apparel item (blouse) has been created.

The study employs practical research, which began with the extraction of the most important body measurements, provided by a physical avatar (mannequin). The measurements collected (table 1) correspond to the size S range, based on the international sizing system (table 2). The measurements were used to dimension the virtual avatar, in accordance with the physical one (figure 1), and also served in drafting the base patterns, as well as the CPS for the initial dress.

Table 1

MEASUREMENTS COLLECTED FROM THE PHYSICAL MANNEQUIN

| Measurement | Value (cm) |
|---|---|
| Chest perimeter | 85 |
| Waist perimeter | 68 |
| Hip perimeter | 92 |

Before proceeding with the pattern drafting, the first step is implied opting for the fabric from which the

Table 2

| INTERNATIONAL SIZING SYSTEM CHART [17] | | | |
|---|---|---|---|
| Chest perimeter (cm) | Waist perimeter (cm) | Hip perimeter (cm) | International System |
| 74 | 58 | 80 | XXS |
| 74-77 | 58-61 | 80-84 | XS |
| 78-81 | 62-64 | 85-89 | XS |
| **82-85** | **65-68** | **90-94** | **S** |
| 86-89 | 69-72 | 95-97 | S |
| 90-93 | 73-77 | 98-101 | M |
| 94-97 | 78-81 | 102-104 | M |
| 98-102 | 82-25 | 105-108 | L |
| 103-107 | 86-90 | 109-112 | L |
| 108-113 | 91-85 | 113-116 | XL |
| 114-119 | 96-102 | 117-121 | XL |
| 120-125 | 103-108 | 123-128 | XXL |
| 126-131 | 109-114 | 129-134 | XXL |

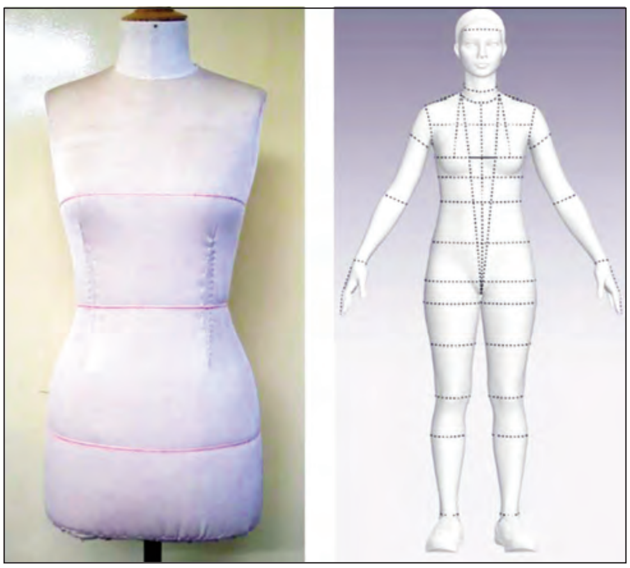

Fig. 1. The physical mannequin (left) and the virtual avatar (right)

clothing items will be manufactured. For this particular research, the velvet fabric has been chosen, because its structural surface requires the pattern pieces to be placed in one direction only. The width of this fabric is 141 cm.

Once the CPS for the dress item have been drafted, the initial layplan has been generated. By placing the pattern pieces for the initial garment, it was able to identify the fabric waste areas that could potentially be generated (hatched areas depicted in figure 2).

To make the best use of the potential waste fabric, a pattern library has been established, containing several CPS for the most common women's garment styles (mainly consisting of front, back and sleeve panels). Thus, a series of classical patterns sets previously drafted have been collected (figure 3). These will serve as a starting point based on which new ZWP will be developed.

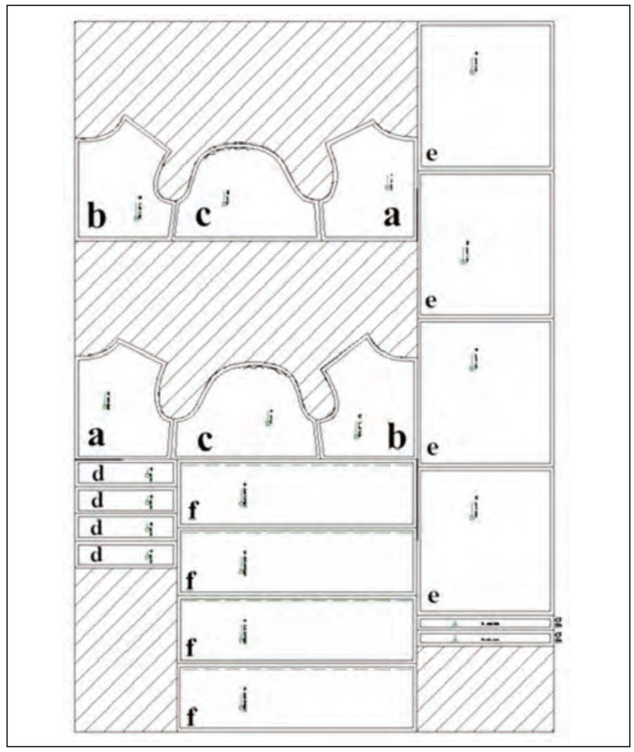

Fig. 2. Placing the dress CPS within the simulated fabric perimeter: *a* – front bodice; *b* – back bodice; *c* – sleeve; *d* – cuff; *e* – skirt panels; *f* – hem frill panels; *g* – neckline facings

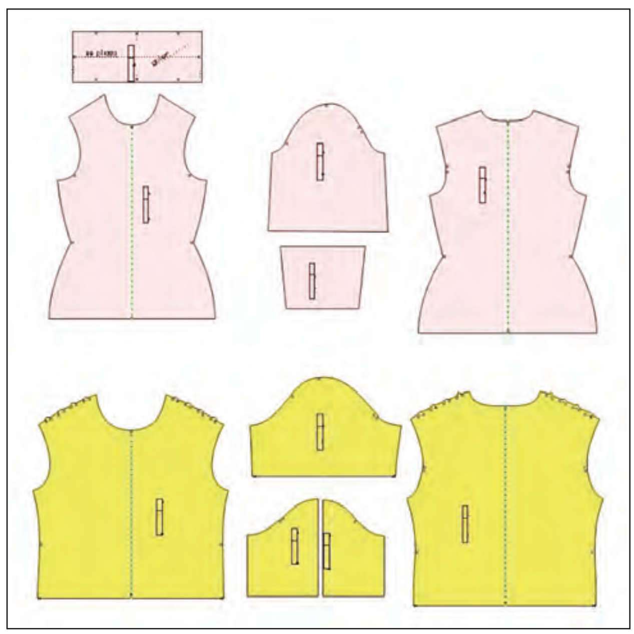

Fig. 3. Classical pattern library: example of two distinct women's blouse styles

The cutting surface for each pattern piece has been measured, using the Surface Measure option provided by the GPE software. The same method has been applied to the available unused fabric pieces in the marker previously simulated. The purpose of this operation is to facilitate the process of assimilating the available fabric surface to a feasible pattern piece. This is possible by using the format conditioning functions, which are available in spreadsheet software.

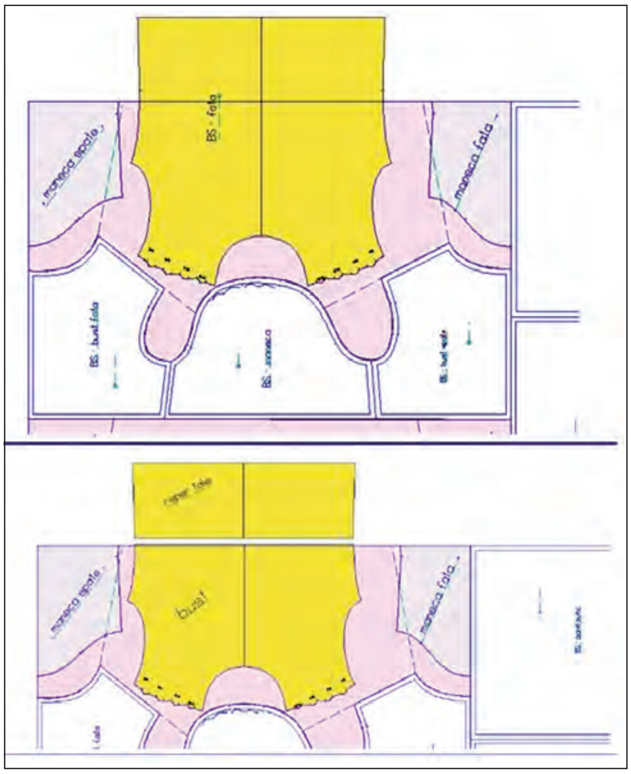

Fig. 4. Identifying the geometric similarity between the available surface and the potential surface – this highlights the need for pattern transverse sectioning around the waistline

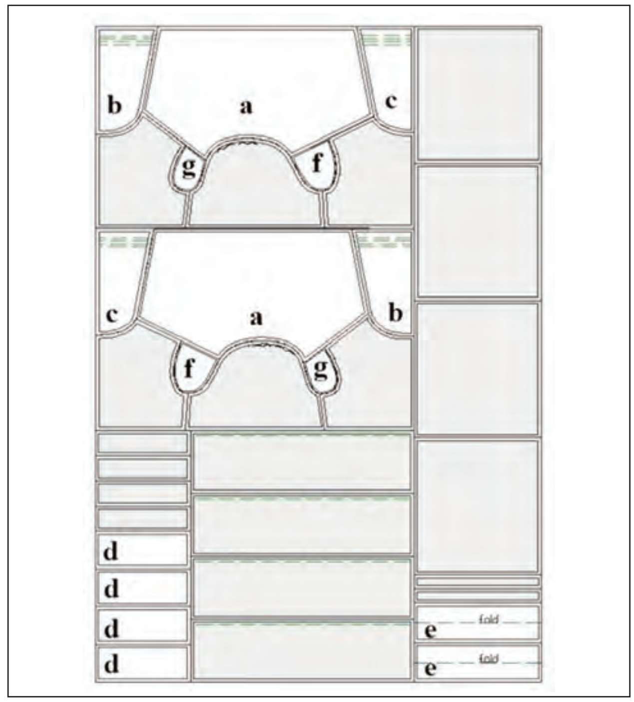


Fig. 5. Unused area converted into ZWP: *a* – front/back bodice; *b* – front sleeve panel; *c*–back sleeve panel; *d* – waistline panels (with centre front and centre back seam); *e* – collar panels (front and back); *f* – front sleeve head reinforcement; *g* – back sleeve head reinforcement

After analysing the shape-wise possibilities provided by the available fabric surface, the shape of a bodice was straightforwardly identified. Thus, the area has been sectioned (as depicted in figure 4), to define the shape that has been identified.

It's worth mentioning the fact that this process of altering the classical pattern pieces, to generate ZWP is, in its essence, a design process, in the sense that during this phase, the style features are being established, based on the restrictions encountered. Using the surface comparison method previously established, the possible pieces that fit within the given area were effortlessly identified (figure 5).

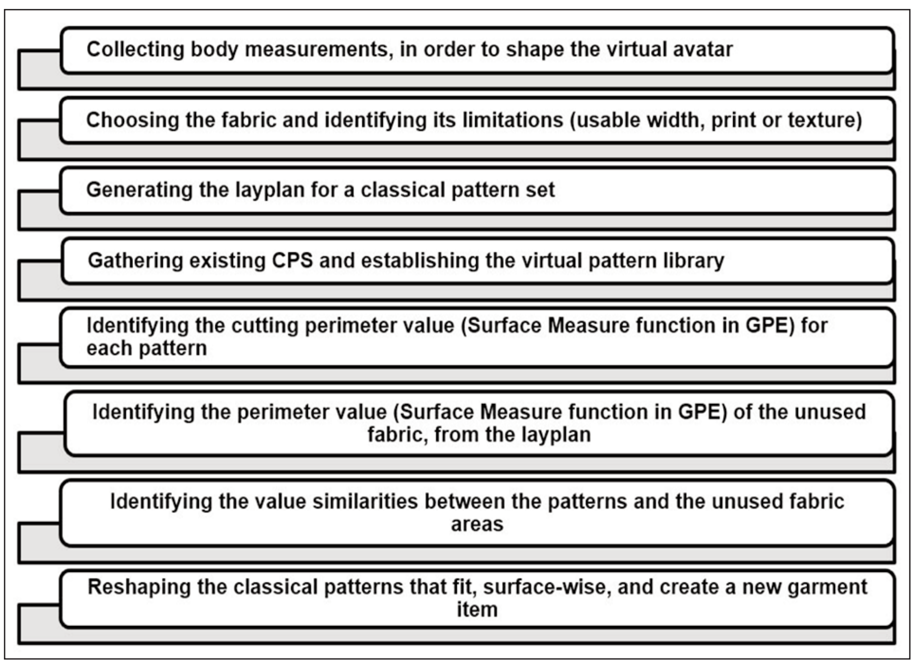


Fig. 6. The stages for developing the ZWP

For a clearer comprehension, the steps that have been taken within the design process have been summarized, as depicted below in figure 6.

The limitations that have been encountered during the design process were given by the fact that velvet is a pile fabric, and thus its surface has a certain one-direction orientation, mostly visible when a source of light is directly pointed on the fabric [18]. Thus characteristic has a great effect on the final product's aesthetic value, and for that instance, the pattern sets had to be placed by following only one specific orientation. Apart from that, the fabric width is a general restriction regarding the process of drafting the ZWP, because its value determines the width of the layplan.

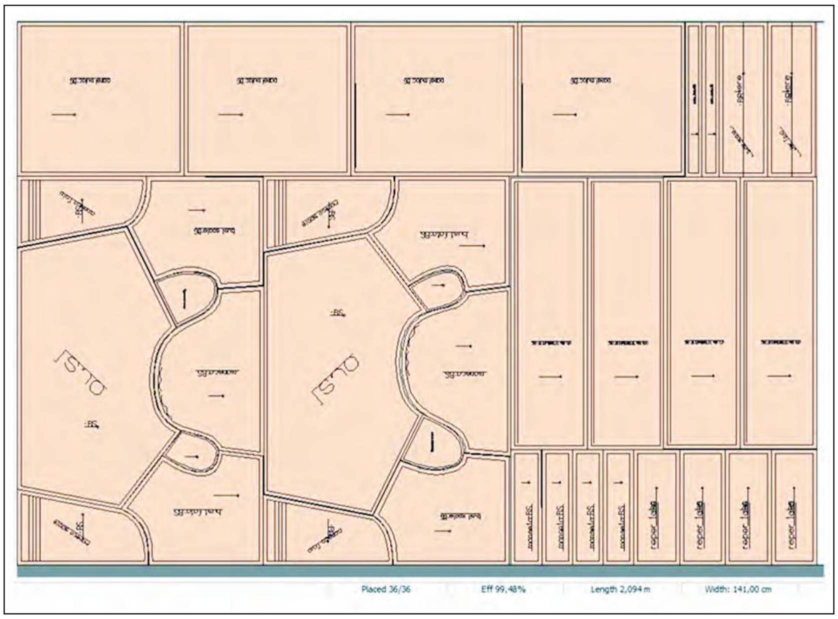


Fig. 7. ZW marker: 99.48% efficiency, 2.09 m rating and 141 cm width

Fig. 8. The virtual prototype for the blouse: raw aspect (left) and finished (right)

Fig. 9. ZW blouse fitted on a size S avatar (left) and size XL avatar (right)

## RESULTS

### Fabric rating and marker efficiency

Once the pattern modelling, the final marker has been made, using the GNE software. The program can provide the marker efficiency [%], as well as the length of the final layplan in cm. Through this, it was possible to test the conformity of the patterns to the initially imposed restrictions, given by the fabric and the ZW principle itself. Thus, the pieces were nested on a 141 cm usable width, with a 99.48% efficiency (figure 7). Those values confirm that the ZWP meets the initial requirements. The fabric rating for the two garment items is 2.09 m (without technological losses). In comparison, the fabric rating for the initial clothing item (using the CPS) was 1.6 m, with an 84.5% marker efficiency.

### The virtual prototype

The new pattern pieces have been assembled within the virtual space, in order to obtain a general first image of the product. Given the loose and asymmetrical cut of the patterns, the garment has been fitted on the avatar by using shirring as a modelling technique. This method not only added value to the final product but also allowed for a dimensional reshaping of the main measurement points. At this point, the initial body measurements have been used as a guideline (figure 8).

Nonetheless, it is worth emphasising the fact that by using virtual prototyping, instead of physical sampling, the benefits consist of reducing the usage of electricity (considering the plotter, sewing machines and ironing), as well as paper (used for printing the patterns). Also, trial and testing the pattern sets in a virtual environment prevents the usage of fabric, and also inhibits the manufacturing of pilot prototypes.

### Mass production opportunities

Drafting ZWP by exploiting the unused fabric surface as a guideline, and with the help of a pattern library, has proven to be efficient in diminishing the time needed to draft patterns from scratch. Nonetheless, since the patterns are drafted on the cut line, it creates a wider range of technological possibilities within the manufacturing process, because the seam allowances are lastly traced as a contour offset at a given distance. Depending on the assembling, the seam allowance values can vary, without affecting the cutting perimeter of the ZWP. The ZWP set obtained as a result of the exploitation of the unused fabric surface can be used in mass production

– albeit not graded, the product dimensions on the main points can be adapted from size to size by altering the gathering dimensions (shoulder line, cuff, waistline, and neckline).

The blouse can be classified as a one-size product, which can be altered from a dimensional perspective on the neckline and waistline, by adjusting the gathering dimensions. Given the loose fit, is not mandatory for the shoulder line, sleeve length, or bust line to present a significant increase from one size to another. The product fit for the extreme sizes of the range is depicted in figure 9.

The results of the study demonstrate that ZWP, not only can significantly reduce fabric consumption but also sustain the achievement of a high maker efficiency, which translates itself as zero pre-consumer textile waste generated during cutting.

## CONCLUSIONS

By analysing the framework of the research, it can be concluded that drafting ZWP represents a design process of its own, during which, the pattern maker has to adopt the designer and technician roles as well. The framework of the drafting process has been analysed

These three aspects intertwine and have no limited time correspondence throughout the process, as they are simultaneously present within the procedure. As an example, from a pattern-maker perspective, the pattern pieces must be joined perfectly on the assembling lines, whereas from a technician's point of view, the seam allowance values must correspond to the types of finishing that suit the chosen fabric. Lastly, the designer is rather interested in an aesthetically pleasing product. Therefore, it is clear to estimate a gap in communication between at least two of the mentioned characters. To ensure an efficient and optimal drafting process, these three aspects should all be present within the thinking process of the engineer.


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# Design of an interactive fashion recommendation platform with intelligent systems

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**ABSTRACT – REZUMAT**

**Design of an interactive fashion recommendation platform with intelligent systems**

*With the increase in customer expectations in online fashion sales, greater integration of fashion recommender systems (RSs) allows more personalization. Design decisions rely on personal taste, as well as many other external influences, such as trends and social media, making it challenging to adapt intelligent systems for the fashion industry. Different methods for recommending personalized fashion items have been proposed, however, the literature still lacks an approach for recommending expert-suggested and personalized items. In this research, an interactive web-based platform is developed to support personalized fashion styling, focusing on users with diverse body shapes. To merge the user's taste and the expert's suggestion, the proposed methodology in this research combines genetic algorithms and machine learning techniques allowing the system to access expert knowledge (including external influences) and incremental learning capability, by adapting to the user preferences that unfold during interaction with the system.*

***Keywords:** fashion styling recommendation, personalisation, female body shapes, web-based platform, genetic algorithms, artificial neural networks, incremental learning*

**Proiectarea unei platforme interactive de recomandare a articolelor de modă cu sisteme inteligente**

*Odată cu creșterea așteptărilor clienților în vânzările de modă online, integrarea sistemelor de recomandare a articolelor de modă (RS) facilitează procesul de personalizare. Deciziile de design se bazează pe preferinţele personale, precum și pe multe alte influențe externe, cum ar fi tendințele și rețelele sociale, ceea ce face dificilă adaptarea sistemelor inteligente pentru industria modei. Au fost propuse diferite metode de recomandare a articolelor de modă personalizate, cu toate acestea, în literatura de specialitate lipsește încă o abordare pentru recomandarea articolelor sugerate și personalizate de experți. În cadrul acestui studiu, este dezvoltată o platformă interactivă web pentru a sprijini stilul personalizat de modă, concentrându-se pe utilizatorii cu diverse forme ale corpului. Pentru a îmbina preferinţele utilizatorului și sugestia expertului, metodologia propusă în acest studiu combină algoritmi genetici și tehnici de învățare automată, permițând sistemului să acceseze cunoștințele de specialitate (inclusiv influențe externe) și capacitatea de învățare incrementală, prin adaptarea la preferințele utilizatorului care se desfășoară în timpul interacțiunii cu sistemul.*

***Cuvinte-cheie**: recomandare de stil de modă, personalizare, forme ale corpului feminin, platformă web, algoritmi genetici, rețele neuronale artificiale, învățare incrementală*

## INTRODUCTION

Despite the specific challenges involved, fashion products constitute a major category for e-shopping. Within current circumstances in the e-commerce sector, customers expect both personalized experiences and expert opinions regarding fashion trends [1]. With the dramatic increase in online sales in recent years, intensified by the COVID-19 pandemic, it is increasingly important to offer styling recommendations and options for interaction with customers on virtual platforms. In a personalized virtual platform, virtual tools and assistants take on the role held by sales advisors in a physical store [2]. They can provide both design/technical and social/service support based on customers' unique needs [3].

Integration of artificial intelligence (AI) in fashion includes multifold levels in the supply chain [4]. Virtual assistance and fashion styling purposes at online retail points are commonly provided by Recommender Systems (RSs) to improve user satisfaction through personalization and interaction.

Most current online styling recommendation platforms use fashion recommendations from human agents, such as online stylists, friends, and celebrities, and data is provided based on the user's input. There are some examples with automatic system recommendations using machine agents, but the number of these examples is limited, and they are generally based merely on user history data [5]. There is a gap in the literature concerning fully personalized fashion recommendation systems merging user's taste and expert's suggestion, and there are few commercial examples of such a system.

The main aim of our research, therefore, was to develop an interactive web platform for fashion styling recommendations. The unique approach in this research aims at developing a fully personalized method that fuses users' fashion preferences with a mix of human and machine experts' recommendations employing intelligent decision-making systems. The system learns progressively about the users' preferences based on their evaluation of expert-approved styles and updates the recommendations in line with the user's tastes.

## LITERATURE REVIEW

Research studies have been conducted for fashion styling recommendation, and a range of commercial systems for fashion recommendation have been implemented on various scales and for various purposes. The styling and/or fashion recommender systems in the market can be categorized considering several parameters, such as recommendation agents, system types, data collection and application types [5].

Systems such as Outfittery.com and Wishe.me gather information about the customer's style, size and price preferences, and personal style services recommend items of clothing based on these needs. In these systems, the stylist can choose from a range of brands. Some other systems that use recommendations provided by online stylists are Glamour Ask a Stylist, Nordstrom Stylist Services and The Chapar [5]. Some of these platforms are web-based, others are mobile applications.

Stitch Fix.com is one particular example of an online personal styling service that uses recommendation algorithms to make recommendations based on size, budget and style [6]. Styling recommendations evolve with greater information on the customer's taste, needs and lifestyle; the system uses personal stylists to uncover pieces that suit to personal taste, size and price range [7]. Trufit.com is one well-known example offering a personalized platform focusing on fit in addition to style. The system finds the best size and then recommends styling from among the garments provided by the brands covered by the platform.

Intelistyle.com provides personalized styling with the use of machine learning by analysing the latest catwalk photography and social media. Dressipi.com is a similar technology support for retailers providing personalized shopping experiences. Nosto.com and Stylebookapp.com provide personalized recommendations based on machine agents. Amazon.com uses an automatic system as a recommendation agent [5], providing personalized recommendations of items based on user history data [8]. Additionally, Amazon launched a camera-based personal fashion style assistant device called "Echo Look" in 2017, giving fashion styling advice on fit, colour and current trends using a combination of machine learning algorithms and fashion specialists' advice [9], however, Amazon withdrew this system shortly after its launch. These platforms offer a customization experience in terms of various parameters such as body type, occasion, colour code, etc. StyleUp.clothing has another unique approach, allowing a personal avatar to be created by entering body measurements into the system. The system can calculate the body type and recommends styling options for specific body shapes. Asos.com offers a visual search technology called "Style Match" as a mobile application. When the user uploads an image, the system searches their brand database for the most similar products [10].

A survey of such existing fashion recommendation platforms reveals that some online recommendation systems are start-ups, which turn into big businesses, while others fade away or switch to another retail strategy. Despite various possibilities for fashion styling recommendations from the consumer and retail perspective, such systems are not widely applied. About the 'perceived ease of use' and 'perceived usefulness', consumers' acceptance of information technology is strongly correlated with perceived usefulness, and the prominence of usefulness is over ease of use [11]. All other factors being equal, users are more likely to adopt a user-friendly technology. Adopting the Theory of Planned Behaviour [12], Innovation Diffusion Theory [13], and Technology Acceptance Model [11], a new model is developed and tested to evaluate the effects of mobile recommendation agents [14]. According to these results, product purchases increase with the perceived usefulness of the mobile recommender agent, additionally, recommender agents help to predict usage intentions and influence consumer shopping preferences. New retail business models should meet both the information and communication demands of customers.

Recommender agents are useful tools from the customer perspective for decision-making, and have some obvious advantages, such as enormous data processing capacity and almost unlimited memory, allowing for smarter and more interesting results with less effort, powerful search engines [15], and the ability to create an enjoyable experience, especially for the customers who seek comfort [6]; however, major obstacles of these systems are the unnatural processes, the lack of emotional and social intelligence, and the practical difficulties in applications.

Consumer participation is a factor to increase satisfaction and create a joyful experience in online product recommendation services, while decreasing perceived ease of use, especially for purchases with high financial risk [16]. The recommender systems currently take time to use, so improving the simplicity with which customers can express their preferences will pave the way for more widespread use of these systems [15].

Based on the survey of current fashion recommendation platforms and within the theoretical framework given above, an innovative approach in this field is the integration of an interactive customer interface with an automatic system styling providing recommendations in a user-friendly and pleasurable way. The creative merging of the customer's taste with the expert's opinion, and developing these styling options further with the machine learning capabilities is an underexplored area and our contribution to this gap in the field. Another difficulty in current online garment sales is achieving a good fit due to the challenges of dealing with personalized data such as body shapes [2], therefore, we considered applying fashion styling recommendations for female body shapes.

## OBJECTIVES

With this context, this research aims to integrate RS for fashion styling, which recommends expert-approved items in line with user preferences. The specific objectives are as follows:
1. To develop a personalized interactive web platform for fashion styling recommendations based on female body shapes and with the use of intelligent decision-making systems.
2. To develop a novel methodology and framework to merge expert and user aspects in recommended items.
3. To show that Interactive GA can be used as the RS's central instrument to provide the critical capabilities of incremental learning, adaptation and creativity in fashion recommendation solutions.

## METHODOLOGY/APPROACH

### Development of the database for the web-based platform

In this research, to create personalized fashion styling suggestions, a female body shape classification was devised based on the proportions of the front view silhouette, identified and coded using figures based on letter shapes [17]. Styling recommendations were provided for the following body shapes: V (inverted triangular), A (triangular), H (rectangular) and O (oval)-shapes. To create an aesthetic relationship between the shape of the body and the garment for fashion styling, we assembled combinations of top and bottom garment pieces or dresses with several attribute categories. The attribute categories included garment details such as waistline, hem and flare for pants and skirts; collar type, sleeve length and garment length for tops; and colour and pattern design for all garment types.
A knowledge base is built consisting of fashion styling recommendations for these four female body shapes. The design recommendation system was achieved through a garment design archive consisting of 2310 2-dimensional technical drawings. Additionally, styling suggestions for each specific body shape were generated by three experts in fashion design. One expert has 21 years, the other has 35 years of experience in the field of clothing production and fashion design. The third expert is a PhD candidate in fashion design.
Initially, 700 styling suggestions were provided across all four body shapes. Basic principles of design, such as contrast, balance, emphasis, proportion, hierarchy, repetition, rhythm, pattern, movement, variety and unity were considered for creating an aesthetic relationship between a specific body type and the styling suggestion. Balancing a specific part of the body by drawing attention to the contrary; playing with proportions to elongate the body; repeating of body shape on the garment silhouette; and emphasizing parts of the body with colours and patterns are some examples of applying design principles for styling suggestions.

### Development of the algorithm

The proposed algorithm assumes that the expert has more mechanic-like and static principles so that the expert opinion can be modelled by formal methods for automation, whereas the user's taste is based on human subjectivity which will be inferred by interacting with the user. The expert opinion is modelled by a formal fitness function such that given the attributes of an item, it returns a numerical value indicating the level of approval of the expert. To construct such a fitness function, one can apply any artificial intelligence techniques or ontology-based approaches; or construct a decision tree with fitness outputs, depending on the application domain. The steps of the two-stage methodology are listed below and sketched as a diagram in figure 1.
The first stage is called the expert stage, where the candidate items that the expert approves are generated. The second stage is called the true personalization stage, where the idea is to use human evaluation as the fitness function, the so-called Interactive Genetic Algorithm [18]. In the proposed methodology, the sequential nature of the steps guarantees that the user evaluates only the expert-approved items, as in Steps 2-3-4. Also, the expert opinion has priority over the user's taste in fashion since the expert is the first to evaluate and generate candidate solutions. Thus, the proposed methodology permits searching for solutions that reflect the user's taste in the expert-approved space of solutions. In Step 5, the user's opinion is embedded into the fitness values of the top-N items as the weighted average. Next, in Step 6, GA operators run on this new list to fuse the user's taste into the population. This newly created population is then used as the new initial population in the second round of Step 2, where the newly constructed population will now breed. As this sequence is repeated, the system continually recommends expert-approved items and adapts to the user's taste. So, it is expected that the task of recommending expert-approved and personalized items could be accomplished.

## RESULTS AND DISCUSSION

### Website design

Considering the difficulties associated with the applications of recommender agents, it is important to improve the interactivity and usability of RSs [15]. Based on the suggested algorithm, the expected major outcome of this research was the development of an apparel recommendation system featuring a web-based platform with a contemporary, easy-to-use, and interactive interface. A detailed visual brand

Stage 1: The Expert Stage

0. Construct a fitness function that imitates the expert.
1. Randomly generate initial chromosomes each corresponding to an item/solution.
2. Apply GA to create a pool of creative items/solutions by iterating enough ($m_i$) steps using the fitness function of expert from Step 0. $m_i$ can be customized in each $i^{th}$ iteration, since every iteration is an optimization problem of its own.

Stage 2: The True Personalization Stage

3. Offer the user the top-N (e.g. top-20) elite creative solutions/items from the pool, which reflects the expert opinion.
4. Let the user evaluate the top-N items as such giving numerical values, for instance ranking over 5, or binary 0-1 etc.
5. Update the fitness values of top-N as the weighted average of the artificial expert's and user's evaluations.
6. Combine the list of top-N and other chromosomes (i.e. binary coded items), then apply GA operators such as mutation and cross-over to the combined list for one iteration and generate a new population.
7. Using the generated new population in Step 6 as the initial population, repeat steps 2-6 for the next sessions.

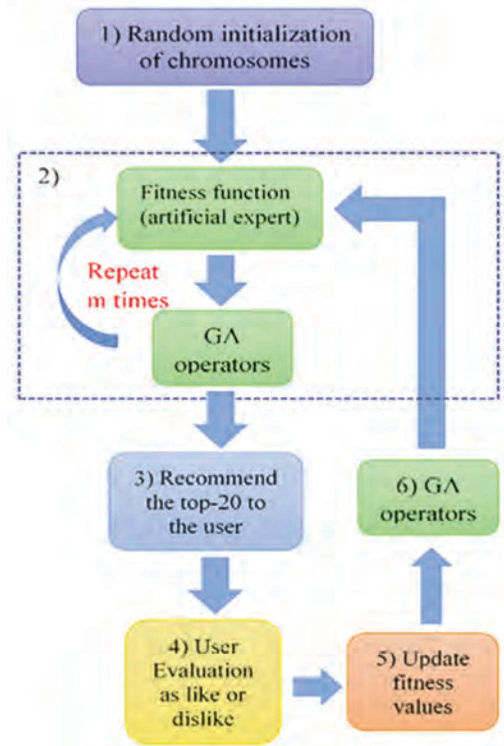


Fig. 1. Proposed recommendation methodology for suggesting expert-approved items that the user is likely to prefer

identity was created for the development of the website. Figures 2 and 3 illustrate some screenshots from the website. Initially, the platform shows some introductory photos, drawings, and videos, and explains the body shape terminology used in the platform. For the suggested flow, the user needs to log in to the system. The system gives three options for identifying the body shape: (1) by entering body dimensions from the front view (the platform provides detailed photos and instructions for measurement taking), (2) by allowing the user herself to select the shape (providing detailed visual and written information introducing the body shapes), and (3) by allowing the user to upload a front view photo (figure 2, *c*).

Based on the identified body shape, 700 styling suggestions were provided by fashion experts, however, the intelligent system provides unlimited suggestions. The user interacts with the system, making choices from alternatives, such as a combination of pants/skirts and tops, or dresses as a single look (figure 3, *a*). When making choices, the user selects from a moving card system showing styling suggestions, based on complete visuals, which provides users with both an expert-informed and a trend-informed experience; thus, this solution contributes to improving the ease of use of the proposed system. To test the platform, three imaginary brands were created and real garment photos were uploaded to the system. As a final step, the system suggests a selected garment from one of these brands and shows an image of it (figure 3, *b*).

Taking an interdisciplinary approach, the development of the platform involved integrating design and engineering perspectives to offer customers an extended service with options. Therefore, the uniqueness of this suggested platform, in contrast to competitors such as StyleUp, StitchFix, and Truefit, is the integration of a machine agent for styling recommendations providing unexpected and more creative styling options, in a continual development based on the customer's taste and expert's opinion.

### Stereotype modelling: artificial users

Customer choices depend on rational factors and those that are irrational, arising from human subjectivity, and thus impossible to exactly replicate through computer simulations. Nevertheless, it is possible to create artificial stereotype users who prefer certain features in recommended garments, and this system can be tested, at least for the rational aspects. The idea of stereotyping relies on the presumption that user interests are reflected in the attributes of the preferred items, and are also influenced by attributes of the visual components of the recommended styles [19]. Thus, for a more precise quantitative evaluation of the proposed methodology, before testing with real users, we carry out mass experiments on 20 different artificial stereotype user models and plot the average performance of the implemented methodology to provide insights on its effectiveness (figure 4, *a*). In the Stage-1 of figure 4, *a*, the artificial expert alone is used as the fitness, and at , a local optimum of average fitness chromosomes (around 0.86) is reached. As can be seen, at the user's first evaluation of the top-20 chromosomes, the average fitness values of the population decrease due to the cold start problem. However, as the new sessions are attained, the average fitness values begin to increase, which indicates


Fig. 2. Sample cut-out screenshots from the online fashion styling platform where information is provided regarding the system: *a* – About ShopShape; *b* – Initial styling combinations in the system provided by experts; *c* – What's my body shape


Fig. 3. Photos of: *a* – styling suggestions and user interaction in the web platform; *b* – suggested garment belonging to one of the brands in the platform

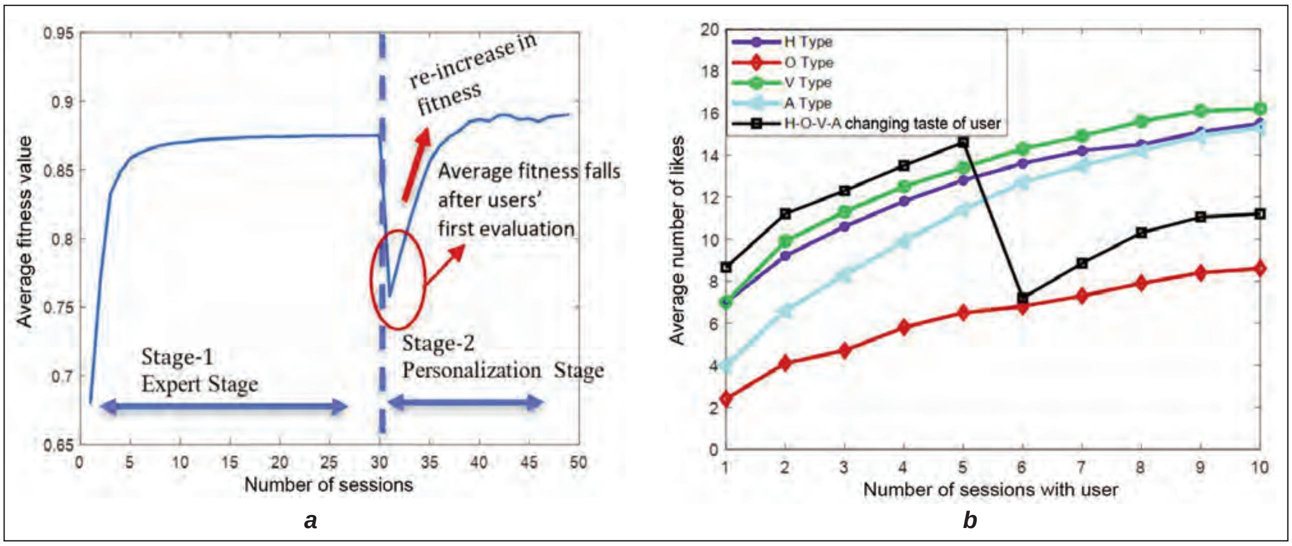


Fig. 4. Graphs of: *a* – fitness values of the candidate solutions in the population-averaged over 20 stereotypes; *b* – for each body shape category the average number of likes in each session, found by averaging over 10 different artificial experts over 20 stereotype users. The black line with square symbols: average number of likes through sessions 1 to 10 in case of change in user's taste

greater satisfaction for both the user and the artificial expert.

We propose two criteria for the success of the algorithm: 1) the more the user interacts with the algorithm, the number of likes in each session should increase correspondingly (the running of the algorithm from steps 2 to 6 is considered as one session); 2) this rising trend should be independent of the artificial expert, stereotype or body shape category. Figure 4, *b* shows an increasing trend for each body shape category in an average number of likes per artificial expert, per stereotype number with an increasing number of sessions. Thus, the results indicate that the algorithm is effective, on average, for all body shape categories (figure 4, *b*), and, on average, for the stereotype users (figure 4, *a*).

**Adaptation of the proposed system to the changing taste of artificial users**

To test our system's performance in matching the changing tastes of users, we implemented the following test: we defined 5 stereotypes with changing tastes, each defined by two constituent stereotype models symbolized by stereotype-i-j, where the user with stereotype-i-j behaves as stereotype-i in the first 5 sessions, and as stereotype-j in the last 5 in a 10-session experiment. We experimented on arbitrarily chosen models of stereotype 1-5, stereotype 2-19, stereotype 8-13, stereotype 9-14, and stereotype10-15 for each body shape category. The line with square symbols in figure 4, *b* summarizes the number of likes for changing stereotypes. A fall in the average number of liked items is seen in the 6th session due to changing taste, however, increases again after this session through the 10th session. Such adaptation is a manifestation of incremental learning capability.

**Results with real users**

For experimenting with real users, the web-based platform allowed the evaluation via a simple button click to indicate whether the recommended style is liked or disliked. The system was tested with 50 women participants. Participants indicated their positive remarks for the recommendations provided by the intelligent fashion styling platform. Unlike the synthetic users' results, which can only be interpreted based on the number of likes, the real users' results can be interpreted with additional data from their perceptual impressions obtained using a questionnaire. This impression of the system was positive (about 4 over 5).

## CONCLUSIONS

The new approach in our research to online shopping supports the tendency towards increasingly personalized services for online users. This paper contributes to the literature in four main respects: 1) by introducing the proposed intelligent system to enable fashion styling for diverse female body shapes; 2) by developing an automatic adaptive web-based apparel design and recommendation platform for online use; 3) by incrementally enhancing the performance of the proposed intelligent system based on the user interaction, thus obtaining a person-specific design recommendation system; 4) creating a digital dataset for fashion styling considering female body shapes, initially constructed by human experts, and developed in line with the user's taste.

The evaluation of the fashion items reflects the way that the user evaluates a photo on social media, suggesting that the algorithm is compatible with social media, one of the most effective communication methods in fashion [20]. In this very competitive market, it is important to differentiate the service add value to consumers' shopping experience and bring a competitive advantage. This can be done with small changes, such as integration with social media embedding an expert view, and providing an easy-to-use interactive interface with many visuals rather than text. In addition to the possibilities in current platforms existing in the market, this new approach allows the integration of machine agents complementing the styling recommendations from experts and underlines the simplicity for the customers via providing a sample platform designed for the implementation of the suggested algorithm. In parallel to the theory for a new retail model to meet customers' demands for both information and communication [14], our system offers such an interactive online retail model with a personalised shopping experience, which could add value to online shopping, in the face of the major challenges caused by a lack of real touch and fit issues.

The proposed online platform is shown to be appropriate for use in e-commerce for fashion styling and can be adapted to various other fields. Its two main advantages are the simple, customizable web-based platform, and the convenience of the recommendation algorithm, which simply involves a yes (like) or no (dislike) button. However, in real-world cases, the satisfaction of a given user depends on many factors, including irrational ones. When features above and beyond the body types are involved, the problem becomes more complex, requiring more powerful methods for expert modelling. Recently, deep convolutional neural networks have gained attention due to their success in learning in complex situations [21]. The large databases required by such studies can be obtained by implementing recommendation systems such as those developed in this paper. Such studies will allow the full assessment of the accuracy of the algorithm, and discuss its various impacts.

As further work, 3D visuals and virtual fit opportunities will be integrated as complementary functions. These steps will be conducted in collaboration with a company, and include a wide range of product categories. Such a shopping experience could inform developments in omnichannel marketing, which is a contemporary retailing setting. Such a channel leads to personalization, and also to a more environmentally friendly approach by decreasing product returns and increasing digital communications.

The use of intelligent systems in the fields of fashion and apparel design, in which creativity is a key concept, is an innovative and challenging area. In a field in which practical and commercial applications are currently rare, the encouraging results of these preliminary experiments demonstrate the feasibility of applying intelligent systems to fashion styling. This application, which integrates intelligent systems into design fields, may become an inspiration for similar platforms in other areas of design.


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# Research on the bending and tensile mechanical properties of ceramic yarns

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**ABSTRACT – REZUMAT**

**Research on the bending and tensile mechanical properties of ceramic yarns**

*Ceramic yarns play an important role in the aerospace sector, aviation, military, shipbuilding and nuclear industry, they have some advantages of high-temperature resistance, high specific strength and high specific modulus. However, almost no one studies the bending properties of ceramic yarns. To explore the influence of the degree of bending of ceramic yarn on its mechanical properties, three kinds of ceramic yarns (silicon carbide, silicon nitride and alumina) were knotting, bending and checking tensile tests. The retention rate of silicon nitride yarn after bending, checking and knotting tensile tests was 81.9%, 3.39% and 0.17%. The retention rate of silicon carbide yarn after bending, checking and knotting tensile tests was 95.1%, 4.88% and 0.09%, respectively. After bending, checking and knotting tensile tests, the fracture strength retention rate of alumina yarn was 91.8%, 0.39% and 0.04%. It was proved that the retention rate of breaking strength of ceramic yarn decreases seriously under different forms of bending. As a result, ceramic yarns should not be used under bending conditions.*

***Keywords:*** *ceramic yarn, kinking property, knotting property, entanglement property, retention rate of fracture strength*

**Studiu privind proprietățile mecanice de rezistenţă la încovoiere și tracțiune ale firelor ceramice**

*Firele ceramice joacă un rol important în sectorul aerospațial, aviație, sectorul militar, construcții navale și industria nucleară, având unele avantaje de rezistență la temperaturi ridicate, rezistență specifică ridicată și modul specific ridicat. Cu toate acestea, aproape nimeni nu studiază proprietățile de rezistenţă la încovoiere a firelor ceramice. Pentru a explora influența gradului de încovoiere a firelor ceramice asupra proprietăților sale mecanice, trei tipuri de fire ceramice (carbură de siliciu, nitrură de siliciu și alumină) au fost supuse la încercări de rezistenţă la înnodare, încovoiere și verificare la tracțiune. Rata de retenție a firelor de nitrură de siliciu după încercările de rezistenţă la încovoiere, verificare și înnodare la tracţiune a fost de 81,9%, 3,39% și 0,17%. Rata de retenție a firelor de carbură de siliciu după încercările de rezistenţă la încovoiere, verificare și înnodare la tracţiune a fost de 95,1%, 4,88% și, respectiv, 0,09%. După încercările de rezistenţă la încovoiere, verificare și înnodare la tracţiune, rata de retenţie a rezistenței la rupere a firului de alumină a fost de 91,8%, 0,39% și 0,04%. S-a dovedit că rata de retenție a rezistenței la rupere a firelor ceramice scade foarte mult sub diferite forme de încovoiere. Prin urmare, firele ceramice nu trebuie folosite în condiții de încovoiere.*

***Cuvinte-cheie****: fire ceramice, proprietate de rezistenţă la încovoiere, proprietate de rezistenţă la înnodare, proprietate de rezistenţă la încurcare, rata de retenţie a rezistenței la rupere*

## INTRODUCTION

The rapid development of aerospace, aviation, military, shipbuilding and the nuclear industry has promoted the research and development of continuous ceramic yarns, and some new continuous ceramic yarns such as $Si_3N_4$ yarn, SiC yarn and $Al_2O_3$ yarn have appeared in public view [1–3], which have excellent properties such as high-temperature resistance, high elastic modulus, high strength, high rigidity, light specific gravity and corrosion resistance [3–6]. In addition, the ceramic yarn can overcome the sensitivity of ceramic to crack and thermal shock effectively, especially since it has a non-failure fracture mode which is different from ordinary ceramics [7].

At present, the United States, Europe, Japan and other countries have invested a lot of energy in the research and production of ceramic yarns. A series of studies on the mechanical and thermal properties of ceramic yarns show that ceramic yarns will usher in a brand-new era. The mechanical properties of ceramic yarns include many aspects (tensile, compression, bending, torsion, impact, alternating stress), but there is a lack of comparative analysis of various experimental data [8]. However, ceramic yarns are mostly used in various products as soft braided bodies, which are in bending, folding, twisting and other states. Studying the mechanical properties of ceramic yarns in a bending state can more effectively reflect the properties of composite materials [9–11].

In this paper, the tensile test, bending test, knotting test and beading test of ceramic yarns are studied at first, and then the strength retention rate of ceramic yarns is observed to judge the strength loss of yarns with different bending degrees. Secondly, to further explore the influence of different radius of curvature on the strength of $Al_2O_3$ yarn, alumina yarn in ceramic yarn was selected to explore the influence of bending of $Al_2O_3$ yarn under different radius of curvature on mechanical properties. Finally, through data processing and statistical analysis, the basic mechanical properties of continuous ceramic yarn such as load, strength, stress, modulus and tensile strain are comprehensively evaluated [11–15].

## BENDING FRACTURE MECHANISM OF CERAMIC YARNS

### Bending stiffness of yarn

The bending stiffness of yarn determines its ability to resist bending deformation. The bending stiffness is large, the yarn is not easy to bend and deform, and the fabric is stiff. According to material mechanics, the bending stiffness of yarn is:

$$R_B = EI \tag{1}$$

where $R_B$ is the bending stiffness of yarn (cN·cm$^2$); $E$ is the elastic modulus of yarn (cN/cm$^2$); $I$ is the sectional inertia moment of yarn (cm$^4$), a moment of inertia of circular section axis: $I_0 = \pi r^4/4$. However, the cross-section shape of the yarn is generally non-circular. To simplify the calculation, the sectional inertia moment of the yarn is usually calculated by equation 2:

$$I_f = \frac{\pi}{4}\eta_f \cdot \bar{r}^4 \tag{2}$$

Where $I_f$ is the sectional inertia moment of yarn (cm$^4$); $\bar{r}$ is the equivalent radius when the yarn section is converted into a circle according to the equal area (cm); $\eta_f$ is the section shape coefficient and the actual section axis inertia moment of the yarn $I_f$ and the moment of inertia when converting to a regular circle $I_0$ ratio. Therefore, the actual bending stiffness of the yarn is:

$$R_f = \frac{\pi}{4}\eta_f \cdot E \cdot \bar{r}^4 = EI_0 \cdot \eta_f \tag{3}$$

Assume that the yarn density is $\gamma$ (g/cm$^3$), and the linear density is $N_{dt}$, from the conversion formula of yarn linear density and radius:

$$\bar{r}^2 = (N \cdot d_t/\pi\gamma) \times 10^{-4} \tag{4}$$

$$R_f = \frac{1}{4\pi}\eta_f \cdot E \cdot (N_{dt}/\gamma^2) \tag{5}$$

The bending stiffness is proportional to the square of the linear density when the yarn thickness is different. To compare yarns with each other, the unit thickness is usually adopted (tex) yarn bending stiffness $R_{fr.}$ Therefore:

$$R_{fr} = \frac{1}{4\pi}\eta_f \cdot E \cdot (Nt/\gamma^2) \times 10^{-10}\ (\text{cN} \cdot \text{cm}^2/\text{tex}) \tag{6}$$

When a specific modulus is adopted (cN/tex), the formula is converted to:

$$R_{fr} = \frac{1}{4\pi}\eta_f \times (E \cdot \frac{Nt}{\gamma^2}) \times 10^{-5}\ (\text{cN} \cdot \text{cm}^4/\text{tex}^2) \tag{7}$$

### Bending failure of yarn

When the yarn is bent, the deformation on the bending layer is different, as shown in figure 1, *a*. The neutral surface is stretched above *OO′*; the neutral plane below *OO′* is compressed. The greater the bending curvature, that is, the smaller the radius of curvature *r*, the greater the deformation difference of each layer. $I_f$ the radius of curvature is too small, the outer layer will crack and the inner layer will extrude until it breaks, as shown in figure 1, *b*.

When the yarn diameter is *d*, the strain of the outermost layer $\varepsilon$ for:

$$\varepsilon = \frac{\overline{34} - \overline{12}}{\overline{12}} = \frac{d}{2r} \tag{8}$$

Where $\overline{34} = \left(r + \frac{d}{2}\right)\gamma$; $\overline{12} = r\gamma$, with the decrease of the curvature radius *r* of the yarn bending deformation, the elongation of the outer layer of the yarn increases. When $\varepsilon$ to the tensile breaking strain of the yarn $\varepsilon_b$, the outermost layer starts to fracture, and then is

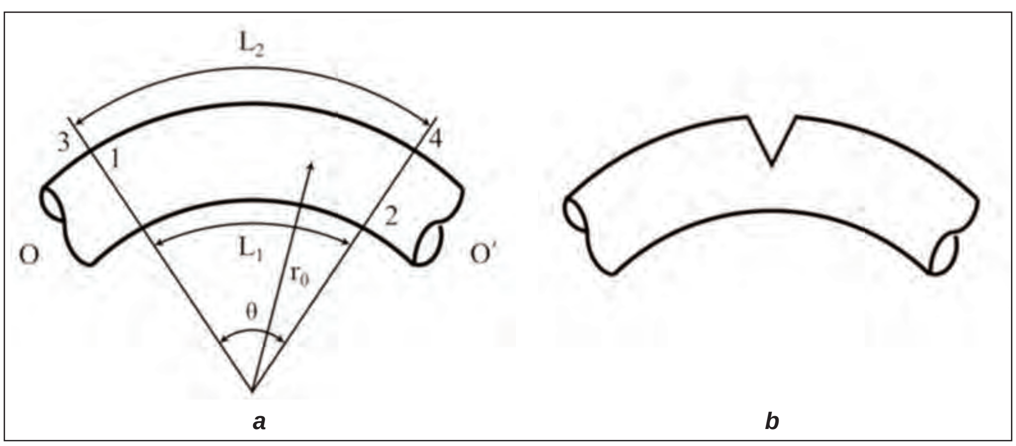


Fig. 1. Deformation and damage of yarn during bending

fractured by crack propagation. Therefore, the minimum curvature radius $r$ of yarn surface fracture is:

$$r \geq \frac{d}{2\varepsilon_b} \tag{9}$$

The thinner the yarn, and $d$ is smaller, the tensile breaking strain $\varepsilon_b$ the bigger the harder it is to break. Glass, metal, carbon, ceramics and other rigid and brittle yarns $\varepsilon_b$ less than 1%, but cotton, wool, hemp and silk are common $\varepsilon_b$ is greater than 10%, so common ceramic yarn and its stiffness.

## MATERIAL AND METHODS

### Materials and instruments

Materials: $Si_3N_4$ yarn (201 tex, Shandong Dongheng Co, Ltd., China), SiC yarn (202 tex, Shandong Dongheng Co, Ltd., China), $Al_2O_3$ yarn (198 tex, Shandong Dongheng Co, Ltd., China) (figure 2).

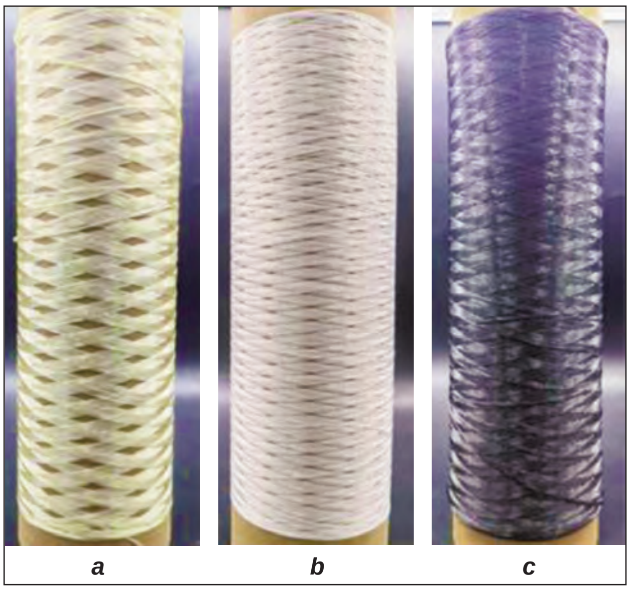


Fig. 2. Studied yarns: *a* – $Si_3N_4$ yarn; *b* – $Al_2O_3$ yarn; *c* – SiC yarn

Instruments: Electronic strength universal testing machine (INSTRON 5967, USA), Precision balance (SaiDolis, Germany), Scanning electron microscope (S-4800, Japan).

According to the national standard IOS/T 7690.1, take a certain length of yarn, weigh it with a precision balance (accuracy 0.0001 g), and calculate the linear density of the yarn:

$$N_t = \frac{G_k}{L} \times 1000 \tag{10}$$

where $N_t$ is the linear density of yarn (unit: tex); $G_k$ is yarn weight (unit: g); $L$ is the yarn length (unit: m).

### Yarn bending tensile strength test

For the following four tensile tests, the experimental conditions are as follows: clamping distance of 100 mm, stretching speed of 20 mm/min, pre-tension of 0.1–0.2 cN, room temperature of 17°C and relative humidity of 60%.

*Testing of tensile properties of ceramic yarns*

Sample preparation: cut out 5 yarns of $Si_3N_4$, SiC and $Al_2O_3$ each with a length of 150 mm, and fix the two ends of the yarn sample with cardboard to ensure that the yarn does not slip off. When both ends of the sample are clamped, make sure that the test distance of the middle part of the sample is 100 mm, as shown in figure 3, *a*.

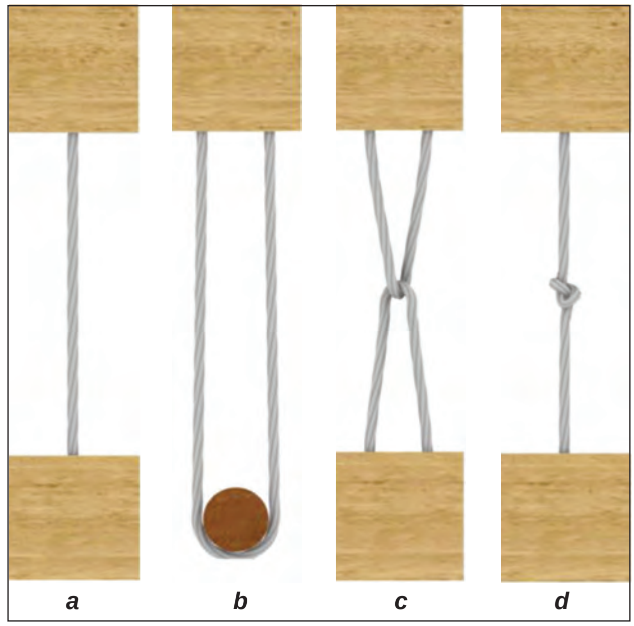


Fig. 3. Graphical representation of: *a* – tensile simulation diagram of ceramic yarn; *b* – simulation diagram of ceramic yarn bending; *c* – simulation diagram of ceramic yarn checking; *d* – simulation diagram of ceramic yarn knotting

*Testing of bending tensile properties of ceramic yarn*

Sample preparation: use a 3D printer to make a cylindrical mould with a radius of 10 mm and a height of 8 mm, as shown in the third mould in figure 3, *b*; cut out five yarns of $Si_3N_4$, SiC and $Al_2O_3$, each 300 mm long, make the yarns into a circle, and use lapels to clamp one end of the yarns together and stick them together, which is conducive to clamping the pattern. When the collar is turned on the end of the sample, the measured sample length is 100 mm, as shown in figure 3, *b*.

*Testing of Checking tensile properties of ceramic yarn*

Preparation: cut five yarns of $Si_3N_4$, SiC and $Al_2O_3$, each of which is 150 mm long, and hook them. Both ends of the yarn are fixed with cardboard to ensure that the yarn does not slip. When both ends of the sample are clamped, make sure that the test distance of the middle part of the sample is 100 mm, as shown in figure 3, *c*.

*Testing of knotting tensile properties of ceramic yarn*

Sample preparation: cut five yarns of $Si_3N_4$, SiC and $Al_2O_3$ each with a length of 150 mm, tie them, and fix the two ends of the yarn sample with cardboard to ensure that the yarn does not slip. When the two ends of the sample are clamped, the test distance of the middle part of the sample is 100 mm, as shown in figure 3, *d*.

To further analyse the relationship between stretching and bending of ceramic yarn, the formula is used to calculate the breaking strength retention ratio $W_1$ (%) after bending, and the formula is used to calculate the breaking strain retention ratio $W_2$ (%) after bending:

$$W_1 = \frac{P_f}{2 \times P_y} \times 100\% \quad (11)$$

Where $P_f$ for yarn strength after bending (unit: N), $P_y$ for yarn stretching strength (unit: N).

$$W_2 = \frac{Q_f}{2 \times Q_y} \times 100\% \quad (11)$$

Where $Q_f$ for yarn strength after bending, $Q_y$ for yarn stretching strength.

**Yarn fineness tensile strength test**

Experimental conditions: room temperature of 17 °C and relative humidity of 60%.

In the experiment above, only the effect of bending on the strength of ceramic yarns($Si_3N_4$ yarn, SiC yarn, $Al_2O_3$ yarn) was explored, did not explore whether the fineness of ceramic yarn affects strength, three different ceramic yarns are stranded, three and five pieces of three ceramic yarns were paralleled, they tested their tensile breaking strength. After parallel treatment of 3 and 5 pieces of three ceramic yarns, test their tensile breaking strength. The sample preparation is shown in figure 4.

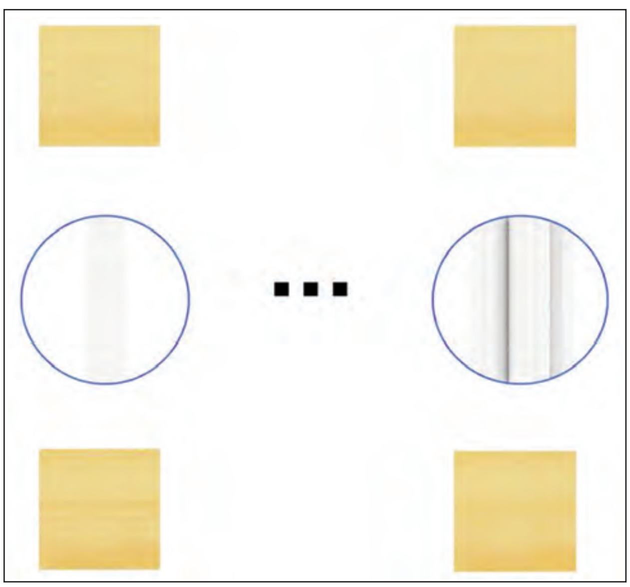

Fig. 4. Schematic diagram of ceramic yarn strand simulation

**Yarn surface topography test**

Experimental conditions: room temperature of 17 °C and relative humidity of 60%.

Sample preparation: in the experiment, the ceramic yarns before and after breaking were shear treated, and the samples were made from the shear yarns, which were pasted on the sample table with conductive adhesive and sprayed with gold. Scanning electron microscopy was used to observe the surface morphology characteristics of the three ceramic yarns ($Si_3N_4$ yarn, SiC yarn, $Al_2O_3$ yarn) and the microstructure of the fracture incision before and after stretching.

## RESULTS AND ANALYSIS

### Mechanical properties of ceramic yarn

*Testing of tensile properties of ceramic yarns*

To explore the mechanical properties of different yarns after stretching, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius.

Table 1

SPECIFICATION PARAMETERS AND TENSILE PROPERTY OF THE CERAMICS YARNS

| Category | Fineness (tex) | Stain (%) | Strength (N) |
|---|---|---|---|
| SiC | 200 | 1.12 | 122.38 |
| $Si_3N_4$ | 200 | 0.88 | 44.89 |
| $Al_2O_3$ | 200 | 0.96 | 73.01 |

As shown in table 1, the linear density of $Si_3N_4$, SiC and $Al_2O_3$ is the same, Judging from the number of strands, all three kinds of ceramic yarns are composed of single yarn; the tensile breaking strength of SiC yarn is 122.38 N, which is the highest among all yarns, about 1.5 times that of $Al_2O_3$ yarn and about 3 times that of $Si_3N_4$ yarn.

As shown in figure 5, *a*, three different bending methods, the bending angle increases sequentially, and the strength decreases sequentially due to the high stiffness of the ceramic yarn, the peak of the image is the breakage of the yarn, which is also the maximum strength of the yarn. In addition, as can be seen from figure 6, the fracture mode of ceramic filaments is not brittle fracture like most filaments, but explosive fracture and the fracture opening is shower-shaped.

*Testing of bending tensile properties of ceramic yarn*

To explore the mechanical properties of different yarns after bending, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius, as shown in table 2.

After the bending test, the retention rate of mechanical properties is one of the important indexes to

Table 2

TENSILE PROPERTY OF THE CERAMICS YARNS AFTER BENDING

| Category | Strength (N) | Stain (%) | Retention rate (%) |
|---|---|---|---|
| SiC | 234.2 | 1.35 | 95.7 |
| $Si_3N_4$ | 85.7 | 0.77 | 95.5 |
| $Al_2O_3$ | 134.4 | 1.12 | 92.1 |

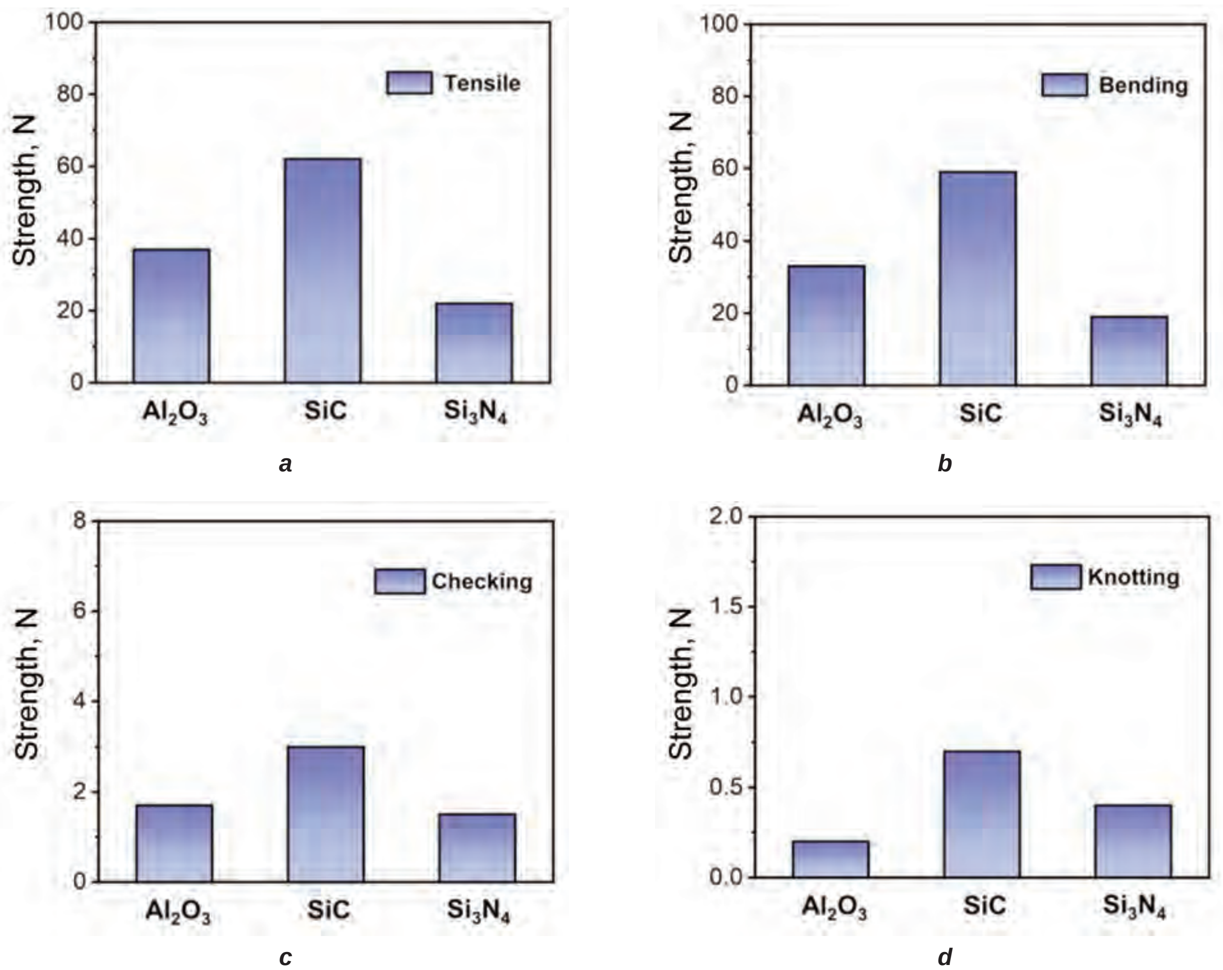


Fig. 5. Graph of: *a* – tensile strength strain curve of ceramic yarn; *b* – bending strength strain curve of ceramic yarn; *c* – checking strength strain curve of ceramic yarn; *d* – knotting strength strain curve of ceramic yarn

valuate the bending resistance of ceramic yarns. To explore the bending resistance of ceramic yarn, a rubber mould with a radius of 10 mm and a height of 8 mm is made, and the ceramic yarn is wound on the mould, and then the tensile test is carried out on the Instron electronic universal testing machine. Table 2 for specific data on bending and tensile mechanical properties of ceramic yarns. It can be seen that the fracture strengths of SiC and $Si_3N_4$ after bending are 234.2 N and 85.7 N. Respectively, the breaking strength and strain of $Al_2O_3$ after bending are 134.40 N and 1.12%. Therefore, the breaking strength retention ratio $W_1$ and breaking strain retention ratio $W_2$ can be calculated.

After bending the tensile properties of the ceramic yarns are shown in table 2. After bending, the breaking strength and breaking strain of the three kinds of ceramic yarns show a downward trend. It can be seen that the breaking strength retention rate of SiC and $Si_3N_4$ yarns is between 95% and 96%, and the yarn strength is partially lost. The breaking strength retention rate of alumina yarn is about 92%, and the breaking strength retention rate of $Al_2O_3$ yarn is the lowest. It can be seen that the breaking strength loss of $Al_2O_3$ yarn after bending treatment is the largest.

*Testing of checking tensile properties of ceramic yarn*

As shown in table 3, to explore the mechanical properties of different yarns in checking, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius.

Table 3

TENSILE PROPERTY OF THE CERAMICS YARNS AFTER BENDING

| Category | Strength (N) | Stain (%) | Retention rate (%) |
|---|---|---|---|
| 5.97 | 1.12 | 4.92 | 95.7 |
| 1.68 | 0.88 | 7.53 | 95.5 |
| 1.56 | 1.96 | 4.37 | 92.1 |

After the ceramic yarn is crosslinked, the breaking strength and breaking strength of the yarn decrease obviously. The breaking strength of SiC is 5.97 N, and the breaking strength retention rate is 4.92%, which is the highest among the three yarns. The fracture strength of $Si_3N_4$ is 1.68 N, and the fracture retention rate is 7.53%. The breaking strength of $Al_2O_3$ is 1.56 N, and the breaking retention rate is 4.37%. As can be seen from figure 6, *a–c*, in the process of series-parallel drawing, the yarn also explosively breaks, and it also has some basic characteristics such as different breaking times.

*Testing of knotting tensile properties of ceramic yarn*

To explore the mechanical properties of different knotted yarns, this section tests the mechanical properties of three kinds of ceramic yarns under the same curvature radius, as shown in table 4.

Table 4

| TENSILE PROPERTY OF THE CERAMICS YARNS AFTER KNOTTING | | | |
|---|---|---|---|
| **Category** | **Strength (N)** | **Stain (%)** | **Retention rate (%)** |
| SiC | 0.12 | 4.34 | 1.06 |
| $Si_3N_4$ | 0.08 | 6.99 | 2.01 |
| $Al_2O_3$ | 0.03 | 2.22 | 0.61 |

After the ceramic yarn is knotted, the breaking strength and breaking strength of the yarn decrease more obviously. The fracture strength of SiC is 0.12 N, and the retention rate of fracture strength is 1.06%. The breaking strength of $Si_3N_4$ is 0.08 N, and the breaking retention rate is 2.01%, which is the highest among the three yarns. The breaking strength of $Al_2O_3$ is 0.03 N, and the breaking retention rate is 0.61%.

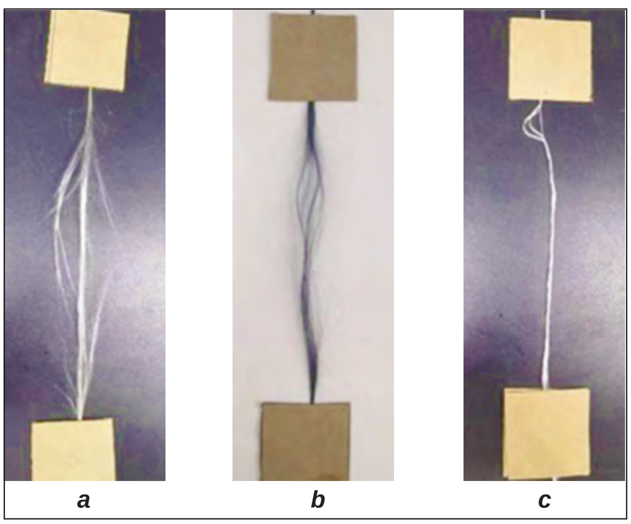


Fig. 6. Graphical representation of: *a* – fracture morphology of $Si_3N_4$ yarn; *b* – fracture morphology of SiC yarn; *c* – fracture morphology of $Al_2O_3$ yarn

**Mechanical properties of ceramic yarn fineness**

As the fineness of the ceramic yarn increases, the loss of tensile strength becomes greater after bending, as shown in figure 7. The reason for the analysis is that the ceramic yarn is a leather core structure [16–22], from formula 1, it can be seen that as the fineness becomes larger, its stiffness also increases, so it is not easy to bend and deform, from equations 3 and 6, it can also be seen that the linear density and stiffness of the yarn are directly proportional, the linear density increases, the greater the stiffness, so the strength loss is greater when bending; from formulas 8 and 9, it can be seen that the smaller the radius of the yarn, the smaller the number of broken fibers in the outer layer, and with the larger the radius, the number of broken fibers increases, so the strength loss is large.

**Surface microtopography of ceramic yarn**

SEM photos of three kinds of ceramic yarns (SiC, $Si_3N_4$, $Al_2O_3$) are displayed, as shown in figure 8. Figure 8, *a–c* is the schematic diagram of the morphological characteristics of SiC, $Si_3N_4$ and $Al_2O_3$ yarns in turn. It can be seen that the surface of the three ceramic yarns is very clean, there are almost no particles on the surface of the fibres, and the fibre thickness is relatively uniform. This is because the composition of the yarn is micron or submicron particles, which will not cause obvious agglomeration.

The fracture notch image of single SiC, $Si_3N_4$ and $Al_2O_3$ fibres under 6000 times electron microscope, as shown in figure 8, *g–i*. It can be seen that the fracture notch section presents an irregular fracture, in which the fracture notch section of $Si_3N_4$ fibre is more regular and neat than that of the other two fibres. However, a little debris can be seen at the fracture section of $Al_2O_3$ and $Si_3N_4$ fibres, which is sufficient to show that its agglomeration effect is not as strong as that of SiC fibre, which also verifies the conclusion in figure 6, *a, b*. The tensile and bending breaking strength of SiC yarn is higher than that of $Al_2O_3$ and $Si_3N_4$ yarn.

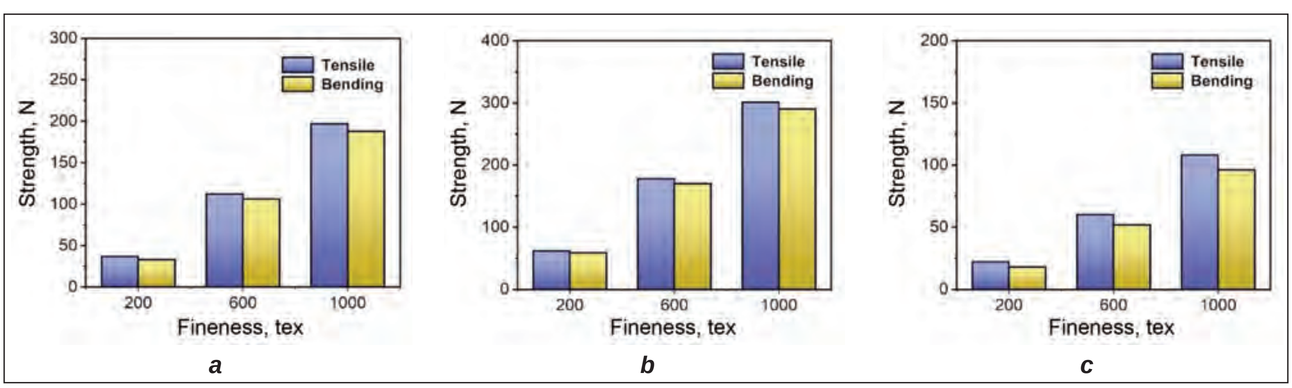


Fig. 7. Graphs of: *a* – fracture morphology of $Al_2O_3$ yarn; *b* – fracture morphology of SiC yarn; *c* – fracture morphology of $Si_3N4$ yarn

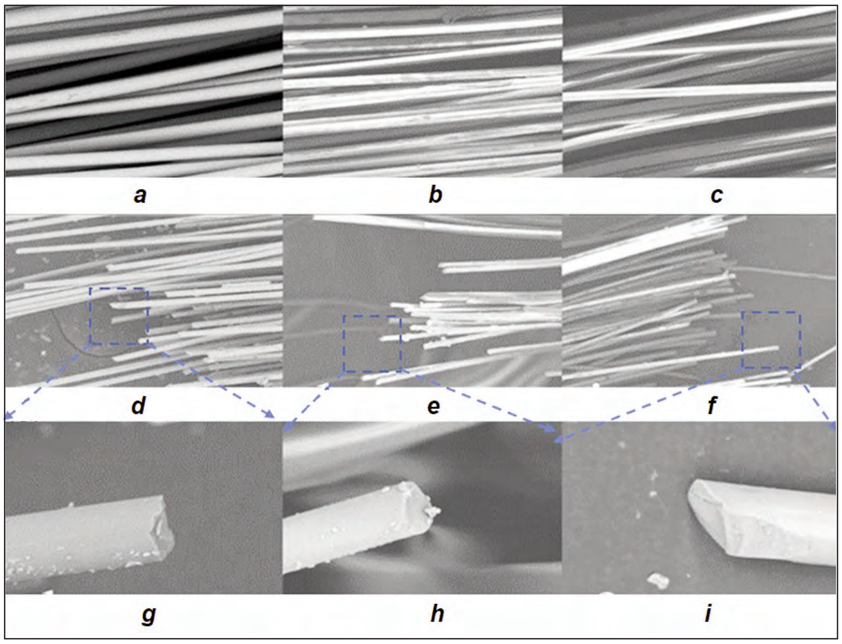


Fig. 8. Graphical representation of: *a–c* – morphological characteristics of ceramic yarn; *d–f* – fracture notch morphology of ceramic yarn; *g–i* – fracture notch of ceramic fibre

The schematic diagram of the morphological characteristics of the fracture notch of SiC, $Si_3N_4$ and $Al_2O_3$ yarns in turn, as shown in figure 8, *d–f*. It can be seen that the fibres in the three kinds of ceramic yarns are distributed in parallel, and the fibres at the fracture notch are uneven, which can verify the different fracture timing of the ceramic yarn in figure 8, *a–c*. The yarn is a parallel bundle of fibres, when bending and breaking, the outer fibre breaks first, as shown in figure 1, and according to the analysis of formula 1–7, it can be seen that the greater the rigidity of the yarn, the faster the external fibre breaks, and after the internal fibre is completely broken, it will lead to different yarn fracture lengths and unevenness, as shown in figure 8, *d–f*.

**Ceramic yarn sizing treatment**

To solve the problem of strong loss of ceramic yarn, it can be seen from consulting the literature method that there are currently three methods on the market to change the strength of ceramic yarn:

- Passivate the ceramic fibre structure by high temperatures, such as increasing the density and graphitization degree of the surface layer, thereby increasing the difficulty of oxygen diffusion to the inside, achieving the purpose of oxidation resistance, and increasing its fracture strength [19].
- Through physical or chemical methods, prepare a high-temperature resistant coating on the surface of the fibre to block the direct contact between oxygen and the fibre, thereby reducing the weight loss rate of ceramic fibre at high temperatures and increasing the strength of the yarn [20].
- Through the method of surface coating, will not only reduce the loss of fibre mechanical properties but also improve the interface adhesion with the substrate material. We use a surface coating method to optimise the strength of the ceramic yarn [21].

Adding 4 g of melamine to 200 ml of deionized water and stirring at 85°C to dissolve; weighing 2 g boric acid dissolved in 50 ml of deionized water and adding melamine aqueous solution; the mixed solution was reacted at 85°C for 1 h, and the h-BN precursor was obtained by rotary evaporation at 95°C. Weighing 2.5 g ammonium molybdate and 3 g PVP-K30 dissolved in 30, in 20 ml of deionised water, 2.5 ml of 1 mol/l Hcl was added after mixing the two solutions well, and irradiated under 365 nm ultraviolet light for 30 minutes, and the prepared 2 g h-BN precursor was added to it, and coated after ultrasound Layer solution [22, 23]. To obtain the coating solution, the ceramic yarn is sized by the method shown in figure 9, *a*, and after cooling, the bending and tensile strength test is carried out, and the test results are

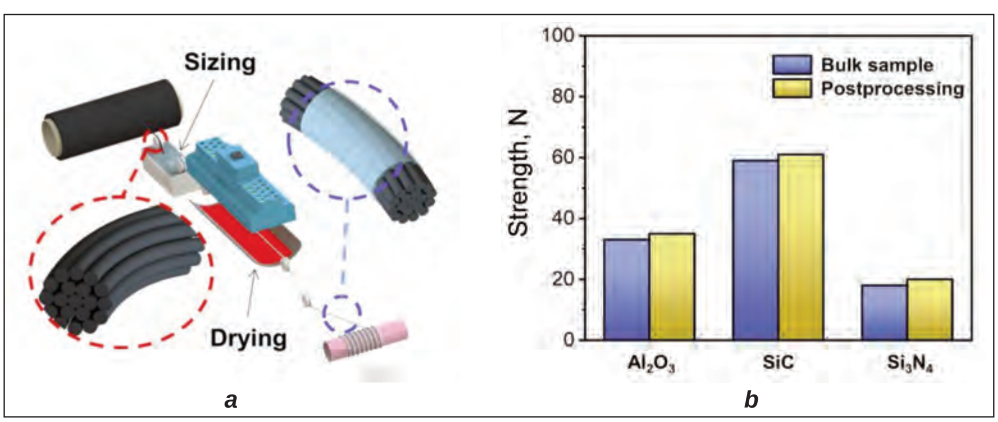


Fig. 9. Graphical representation of: *a* – ceramic yarn sizing simulation diagram; *b* – ceramic yarn bending and stretching strength diagram after sizing

shown in figure 9, *b*. After sizing, ceramic yarns bend strongly, which is significantly better than unsizing ceramic yarns.

## CONCLUSIONS

This work mainly explores the influence of bending degree on the tensile breaking strength of ceramic yarn. The tensile test of SiC, $Si_3N_4$ and $Al_2O_3$ ceramic yarns with different bending degrees is carried out by using the INSTRON 5967 yarn strength tester. The following conclusions are obtained:

- The strength of SiC yarn is higher than that of $Al_2O_3$ yarn and $Si_3N_4$ yarn in turn, and $Si_3N_4$ yarn is the weakest when the three kinds of ceramic yarns are not bent and then tested for tensile fracture. In addition, the fineness of the yarn affects the bending strength of the ceramic yarn, and the greater the fineness, the greater the strength loss rate when bending the application.
- Fracture test shall be conducted for three kinds of ceramic yarns with different bending degrees. It was found that the tensile strength of SiC yarn decreased by 4.3%, $Si_3N_4$ yarn by 4.2%, and $Al_2O_3$ yarn by 7.9% under bending. In the colluded state, the SiC yarn decreased by 95.1%, silicon nitride decreased by 96.6%, and $Al_2O_3$ yarn decreased by 99.6%. In the knotted state, the $Si_3N_4$ yarn decreases by 99.9%, the $Si_3N_4$ yarn decreases by 99.8%, and the $Al_2O_3$ yarn decreases by 99.8%.

To sum up, it can be seen that the inherent tensile breaking strength of the ceramic yarn is high, but after bending treatment, that is, the smaller the curvature radius of the yarn is, the higher the loss rate of tensile breaking strength is. Therefore, ceramic yarn is not easy to apply in bending, so how to improve the transverse shear force of ceramic yarn is also a challenge in the field of textile mechanics.

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# Development of antimicrobial hydrogels for burn wound treatment

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**ABSTRACT – REZUMAT**

**Development of antimicrobial hydrogels for burn wound treatment**

*To obtain biomaterials with the potential for use in the treatment of first-burn injuries, this study focused on the development of several polymeric systems based on collagen-polyvinyl alcohol-active principles. The hydrogels were prepared using polymeric matrices formers (collagen and polyvinyl alcohol), water, and glycerol in the presence of the nonionic surfactant polysorbate 80 (Tween 80®) under proper homogenization. For the development of multifunctional textile materials designed for topical application, ciprofloxacin, chlorhexidine, tea tree essential oil, and curcumin were used as active principles. The obtained hydrogels were then immobilized by the padding method on 100% plain weave cotton. The functionalized textile materials were characterized in terms of their physico-mechanical and comfort characteristics, hydrophilicity, and antibacterial activity. The mass of all the functionalized textile materials increased compared to that of the untreated fabric, due to the amount of polymeric systems remaining after the functionalization process. The water vapour permeability and air permeability of the functionalized materials were lower than those of the untreated samples. Antibacterial activity was observed for all analysed samples, with inhibition zones between 14 mm (CUC-11 code in the presence of S. aureus) and 27 mm (CUC-1 code in the presence of E. coli), obtained for the textile materials treated with the hydrogels containing ciprofloxacin, exhibiting the most pronounced antibacterial effect compared to analogous samples containing chlorhexidine. The obtained experimental data suggest that these hydrogels are appropriate candidates for application in burn wound management.*

***Keywords:*** *cotton, antibacterial activity, drugs, curcumin, tea tree essential oil*

**Dezvoltarea de hidrogeluri antimicrobiene pentru tratamentul arsurilor**

*Pentru a obține biomateriale cu potențial de utilizare în tratamentul arsurilor de gradul I, acest studiu s-a concentrat pe dezvoltarea mai multor sisteme polimerice pe bază de colagen-alcool polivinilic-principii active. Hidrogelurile au fost preparate folosind formatori de matrici polimerice (colagen și alcool polivinilic), apă și glicerol în prezența surfactantului neionic polisorbat 80 (Tween 80®) sub omogenizare corespunzătoare. Pentru dezvoltarea materialelor textile multifuncționale destinate aplicării topice au fost folosite ca principii active ciprofloxacina, clorhexidina, uleiul esențial de arbore de ceai și curcumina. Hidrogelurile obținute au fost ulterior imobilizate prin metoda fulardării pe o țesătură din 100% bumbac. Materialele textile funcţionalizate au fost caracterizate din punct de vedere al caracteristicilor fizico-mecanice şi de confort, al hidrofiliei şi al activității antibacteriene. Masa tuturor materialelor textile funcţionalizate a crescut faţă de cea a ţesăturii netratate, datorită cantităţii de sisteme polimerice rămase după procesul de funcţionalizare. Permeabilitatea la vapori de apă și permeabilitatea la aer a materialelor textile funcționalizate au fost mai mici decât cele ale probelor netratate. Pentru toate probele analizate a fost observată activitate antibacteriană, cu zone de inhibiție între 14 mm (CUC-11 în prezența S. aureus) și 27 mm (CUC-1 în prezența E. coli), obținute pentru materialele textile tratate cu hidrogelurile care conțin ciprofloxacină și care prezintă cel mai pronunțat efect antibacterian în comparație cu eșantioanele analoge care conțin clorhexidină. Datele experimentale obținute sugerează că aceste hidrogeluri sunt candidați adecvați pentru aplicații în managementul rănilor cauzate de arsuri.*

***Cuvinte-cheie:*** *bumbac, activitate antibacteriană, medicamente, curcumină, ulei esențial de arbore de ceai*

## INTRODUCTION

The antibacterial property is one of the most frequently desired properties from a wound dressing, as the growth of microorganisms is controlled or eliminated by the presence of antimicrobial agents that are embedded into the textile material`s structure. Incorporating antimicrobial agents into wound dressings has been the most effective way to control the spreading of bacteria from wound sites. Different antimicrobial materials, which include chlorhexidine, hydrogen peroxide, chitosan, essential oils, honey, proflavine, iodine and silver have been in use in different wound dressings [1, 2].

Hydrogels are polymers designed to retain up to 96% water [3]. They possess a 3D network structure formed through chemical or physical cross-linking. The mechanism of water retention is based on the hydrophilic nature of the functional groups present in the polymer, such as -OH, -COOH, $NH_2$, -CONH, and $SO_3H$. Hydrogel fabrication is achieved by either physical cross-linking (through ionic interactions, crystallization, hydrogen bonding between chains, amphiphilic block copolymer combination, and protein interactions) or chemical cross-linking (through chain-growth polymerization, reactions of complementary groups, or thiol-alkene reaction or by using high energy radiation) [4]. The most common hydrogels used are polyacrylamide, polyvinylpyrrolidone, polyvinyl alcohol, polyethylene glycol, polyethylene oxide, and their derivatives [5].

Natural hydrogels consist of polypeptides (such as collagen, fibrin, gelatine, etc.) or polysaccharides (e.g., cellulose, chitosan, alginate, hyaluronic acid, etc.) and present advantages in biocompatibility and biodegradability. However, synthetic hydrogels are more versatile since they possess tunable properties by design, such as elasticity, porosity, viscosity, and swelling [6]. Hydrogel dressings are used in burn injury treatment because they are biocompatible materials, exhibit good oxygen and water permeability, are able to adhere to tissues and protect them from harmful environmental factors, absorb wound exudates, and even contribute to pain relief [7].

Research on improving hydrogel performance has led to the promotion of multifunctional hydrogels that minimize infections and maximize healing by delivering antimicrobial and antiseptic agents [8]. Moreover, engineered hydrogels with different scaffolds can be used for tissue regeneration in skin repair strategies [9, 10].

The enrichment of hydrogels with antimicrobial compounds has led to many studies advancing the field of burn wound management. Furthermore, the progress in manufacturing multilayer hydrogel dressings has enabled improvements in healing properties. Additionally, drug-loaded hydrogels provide controlled drug release for longer durations, reducing the need for frequent changing of wound dressings [11]. Tamahkar et al. reported the antibacterial efficiency of a multilayer hydrogel dressing loaded with ampicillin that exhibited antibiotic release for seven days [12]. Another wound-healing dressing was produced by encapsulating cefazoline into coaxial polylactic acid (PLA)-based electrospun nanofibers. Using this material, Hajikhani studied the rate of wound closure for samples containing 10% and 20% collagen [13]. Similarly, Shi studied the healing properties of a wound dressing based on a dual-release system for gentamycin sulphate and platelet-rich plasma. The release of the active components was achieved by loading gelatine microspheres with covalent bonding to carboxymethyl chitosan in the matrix of carboxymethyl chitosan [14]. The most recent studies aimed to use different *green* antimicrobial agents, such as herbal extracts [15] or essential oils [5,16], for loaded hydrogel construction.

Despite their reported activity against both gram-positive and gram-negative bacteria, the main disadvantage of essential oils is their high volatility and susceptibility to degradation under different mild conditions (such as temperature, light, or oxidation) [17]. Hence, the integration of essential oils into hydrogel matrices constitutes an attractive approach for maintaining their properties and controlling their release [18]. Wang and collaborators reported using eucalyptus essential oil, ginger essential oil, and cumin essential oil to prepare effective antibacterial hydrogels physically cross-linked by carboxymethyl chitosan and carbomer 940. They demonstrated that burn wound repair in a mouse model was significantly accelerated when the developed hydrogel dressing was applied [19]. Huma Mahmood performed the co-encapsulation of tea tree or lavender with oil ofloxacin in gellan gum-based hydrogel films as wound dressings [20]. Lu also used thyme oil to manufacture an antibacterial-loaded zwitterionic hydrogel [21]. Other essential oils incorporated into hydrogel dressing systems for their antimicrobial properties include *Hypericum perforatum* oil [22], *Eupatorium adenophorum* essential oil [23], clove essential oil [24], *Galium verum* essential oil [25], and chamomile oil [26].

Another active component used in hydrogel enrichment is curcumin due to its antimicrobial, antioxidant, and anti-inflammatory properties [27, 28]. Wafa Shamsan Al-Arjan developed a pH-responsive dressing material capable of curcumin release for burn and chronic wound healing [29]. Babaluei also formulated a hydrogel dressing based on sodium carboxymethylcellulose, polyacrylamide, and mussel-inspired polydopamine containing vitamin C and curcumin to promote full-thickness burn regeneration [30].

In the field of smart textile research, there are only a few publications regarding the use of hydrogels for burn wound management. Michael Rodrigues tested a textile-based hydrogel dressing containing usnic acid for its antimicrobial and antibiofilm properties. The material has up to 99.9% microbial reduction percentages against *Staphylococcus aureus*, *Listeria monocytogenes*, *Enterococcus faecalis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Candida albicans*, and *Aspergillus niger* [31]. Türkoğlu et al. also reported the development of textile-based sodium alginate and chitosan dressings and investigated the physico-mechanical properties of the resulting products [32].

Given the progress in research on the use of hydrogels for burn wound management, the further application of these materials in textiles is worth exploring. This study aimed to develop textile materials with functional properties by applying bioactive polymeric systems based on collagen-polyvinyl alcohol-active principles (ciprofloxacin, chlorhexidine, curcumin, and tea tree essential oil) that have been tested on textile fabrics for their antimicrobial and drug-releasing properties as potential candidates for first-degree burn treatment. Ciprofloxacin is an antibiotic from the fluoroquinolone class, patented by Bayer [33], while chlorhexidine is an antiseptic widely used as a disinfectant in oral hygiene [34]. The polyvinyl alcohol was selected as a polymeric matrix due to its biocompatibility and ability to undergo self-crosslinking due to the high density of hydroxyl groups on its side chains

Table 1

| BIOACTIVE PRINCIPLE CONSTITUENTS FOR EACH EXPERIMENTAL HYDROGEL | | | | | | |
|---|---|---|---|---|---|---|
| **Code** | **PVA** | **Collagen** | **Ciprofloxacin** | **Chlorhexidine** | **Essential oil** | **Curcumin** |
| CUC-0 | * | * | | | | |
| CUC-1 | * | * | * | | * | * |
| CUC-2 | * | * | * | | * | |
| CUC-3 | * | * | * | | | * |
| CUC-4 | * | * | | | * | * |
| CUC-5 | * | * | * | | | |
| CUC-6 | * | * | | | * | |
| CUC-7 | * | * | | | | * |
| CUC-8 | * | * | | * | * | * |
| CUC-9 | * | * | | * | * | |
| CUC-10 | * | * | | * | | * |
| CUC-11 | * | * | | * | | |

[35]. Moreover, collagen was incorporated to provide regenerative properties, along with improving biocompatibility. For this purpose, formulations of different hydrogels have been carried out. The aim was to identify the main factors influencing the formulation process and the most appropriate composition for developing textile materials designed for the treatment of first-degree burns.

## MATERIALS AND METHODS

### Materials

Collagen (ZENYH, Romania) and polyvinyl alcohol (87-90% hydrolyzed, average mol wt 30,000–70,000, Sigma Aldrich) were used as embedding agents for the bioactive principles. Ciprofloxacin (Sigma Aldrich), chlorhexidine digluconate (Sigma Aldrich), tea tree essential oil (Mayam, Romania), and curcumin (PuraSana, Romania) were used as bioactive principles. Polysorbate 80 - Tween 80® (Sigma Aldrich) was used as a nonionic surfactant, and glycerol (Riedel-de haën|Honeywell, USA) was used as a solubilizing agent. Glutaraldehyde (Sigma Aldrich) was used as a cross-linking agent for the polymeric systems. Bleached 100% cotton woven fabric with a weight of 168 g/m$^2$ was used for the functionalization processes.

### Synthesis of the hydrogels

First, stock solutions of 5% collagen and 10% PVA were prepared and mixed through continuous stirring at 600 rpm for 30 minutes at room temperature. The collagen-polyvinyl alcohol mixture ratio (by volume) was fixed at 1:1 (20 ml of collagen and 20 ml of PVA) (*Solution 1*). To obtain the essential oil/curcumin system, 10 mg of curcumin was mixed under continuous stirring with 2.4 ml of tea tree essential oil until complete homogenization (*Solution 2*). Afterwards, over the previously prepared polymeric matrix (*Solution 1*), 0.2 g ciprofloxacin or 4 ml chlorhexidine (20 µl/ml) was added, and magnetic stirring was continued for another 30 minutes. To improve the flexibility of the hydrogels, 10 ml of glycerol was added to the resulting mixture, and after homogenization, 4 ml of Tween 80 was added. Furthermore, the oil/curcumin system (*Solution 2*) was added dropwise to the above polymeric mixed solution under continuous stirring for 30 minutes. Then, 0.2 ml of glutaraldehyde was added as a cross-linking agent as the final step of hydrogel synthesis. The succession of PVA-collagen hydrogel preparation stages is presented in figure 1, and the selected experimental variants are presented in table 1.

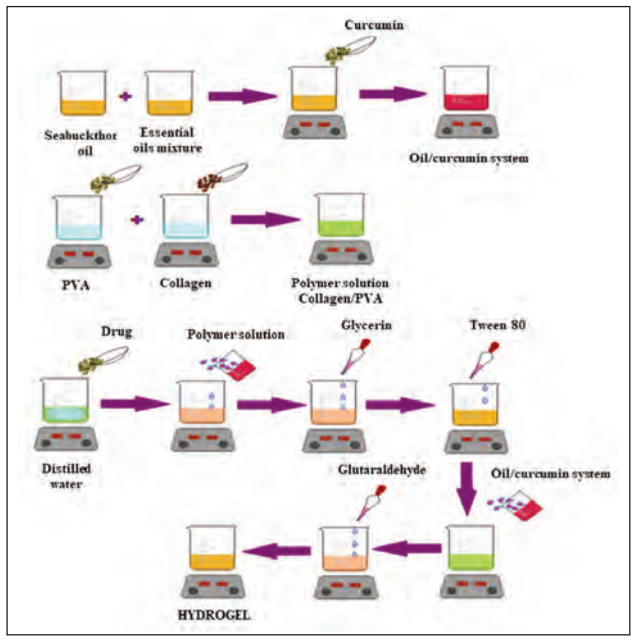


Fig. 1. The succession of PVA-collagen hydrogel preparation stages

### Methods

*Dynamic light scattering – DLS*

The hydrogel samples (CUC-0 – CUC-10) were analysed using Zetasizer Nano ZS equipment (Malvern) by dynamic light scattering (DLS) technique. For each sample, three measurements were made to determine the particle size and the zeta potential. All eleven samples were measured without any further preparation at 25°C using specific standard operating procedures (SOPs) and disposable folded capillary cells (DTS 1070).

*Physico-chemical and physico-mechanical characteristics*

The treated woven fabrics were characterized in terms of the main physico-chemical and physico-mechanical characteristics, respectively: mass per unit area (SR EN 12127-2003), water vapour permeability (STAS 9005:1979), permeability to air (SR EN ISO 9237:1999) and hydrophilicity based on wettability (measured by the drop test method according to the Romanian Standard SR 12751/1989 standard).

*Assessment of antibacterial activity*

The antibacterial activity of the functionalized samples was qualitatively assessed by the agar diffusion method according to the SR EN ISO 20645:2005 standard – Determination of antibacterial activity-agar diffusion plate test, by using liquid cultures of the ATCC 6538 *Staphylococcus aureus* and ATCC 11229 *Escherichia coli* test strains replicated at 24 h. Inhibition zones were calculated using the following formula:

$$H = (D - d)/2 \tag{1}$$

where $H$ is the inhibition zone diameter (mm), $D$ – the total diameter of the specimen and inhibition zone (mm) and $d$ – the diameter of the specimen (mm).

After incubation, the obtained results were assessed based on the absence or presence of bacterial growth in the contact zone between the agar and the sample and based on the eventual appearance of an inhibition zone. Following the standard method, the inhibition zone was measured in mm, and the degree of bacterial growth was estimated in the nutrient medium under the specimen. The criteria for inhibition zones according to the standard SR EN ISO 20645:2005 are presented in table 2.

Table 2

CRITERIA FOR INHIBITION ZONES ACCORDING TO THE SR EN ISO 20645:2005 STANDARD

| Inhibition zone (mm) | Growth | Evaluation |
|---|---|---|
| >1 | absence | satisfactory effect |
| 1–0 | | |
| 0 | | |
| 0 | little | efficiency limit |
| 0 | moderately | unsatisfactory effect |

## RESULTS AND DISCUSSION

### Dynamic light scattering (DLS)

DLS is a suitable technique for the determination of the size distribution profile of particles in a dispersion. Although it is recommended for measuring molecules and particles typically in the submicron range, it has also been shown to be a useful tool for the characterization of hydrogels. The results obtained for the hydrogel samples are presented in table 3.

Hydrogel samples have different sizes, depending on their composition and component interactions.

Ciprofloxacin is a fluoroquinolone antibiotic used to treat many bacterial infections and contains a large molecule, which was also reflected in the DLS results, where samples that contained ciprofloxacin, CUC-1, CUC-2, CUC-3 and CUC-5, had large sizes. PdI represents the polydispersity of the sample, and values <0.2 are preferred. The obtained PdI values suggest that the samples had high polydispersity. The zeta potential is an indicator of sample stability. The values obtained for the hydrogel samples suggest a tendency for deposition and particle agglomeration and the sign represents the type of charge on the surface of the particles. From a stability perspective, the most stable dispersion seems to be CUC-5, with positively charged particles. The obtained hydrogels have good conductivity, which makes them feasible for applications in various other fields, such as soft electronics, sensor and actuator fabrics, and biomedicine.

Table 3

SIZE DISTRIBUTION AND ZETA POTENTIAL FOR HYDROGEL SAMPLES

| No. | Sample | Size (nm) | PdI | Zeta potential (mV) | Conductivity (mS/cm) |
|---|---|---|---|---|---|
| 1 | CUC-0 | 43.7 | 0.3 | –1.63 | 0.282 |
| 2 | CUC-1 | $3.4*10^4$ | 0.47 | –0.4 | 0.344 |
| 3 | CUC-2 | $2.9*10^4$ | 0.71 | –0.2 | 0.293 |
| 4 | CUC-3 | $5.1*10^4$ | 0.34 | –0.5 | 0.304 |
| 5 | CUC-4 | 163 | 0.71 | –0.5 | 0.331 |
| 6 | CUC-5 | $5.5*10^4$ | 0.14 | 25.1 | 0.297 |
| 7 | CUC-6 | 3.2 | 0.67 | –0.3 | 0.364 |
| 8 | CUC-7 | 38.63 | 0.43 | –1.44 | 0.317 |
| 9 | CUC-8 | 91.31 | 1 | 0.218 | 0.313 |
| 10 | CUC-9 | 620.9 | 0.91 | –0.522 | 0.268 |
| 11 | CUC-10 | 39.83 | 0.34 | –1.11 | 0.328 |

**Physico-chemical and physico-mechanical characteristics**

The obtained values for the main physico-chemical and physico-mechanical characteristics are presented in table 4.

According to the results presented in table 4, the mass of all functionalized textile materials increased compared with that of the untreated fabric, and the highest increase of 23.5% was observed for the textile material treated with the polyvinyl alcohol-collagen-chlorhexidine-tea tree essential oil-based hydrogel (code CUC-9). There was no distinct correlation between the number and type of hydrogel components and the value of the mass obtained for each functionalized textile material. Lower values were recorded for the air and water vapour permeability of the functionalized materials than for those of the untreated fabric due to the polymeric systems deposited at the surface of the fabrics, indicating a decrease in comfort for all experimental variants. The most pronounced decrease in air permeability (by 46%) was obtained for the textile material treated with the hydrogel based on polyvinyl alcohol-collagen-chlorhexidine-tea tree essential oil (code CUC-9), which was closely related to the increase in the mass of this sample. This indicates that the hydrogel deposited on the surface of the fabric in the form of a semipermeable film leads to an increase in the mass of the functionalized sample and implicitly decreases its air permeability. The performed functionalization treatments led to a decrease in the water vapour permeability for all functionalized samples, with small nonsignificant variations among the analysed variants. Analysis of the hydrophilicity values obtained for the textile biomaterials showed that they possessed excellent moisture absorption capacity, absorbing excess exudate while maintaining a moist environment that stimulated the wound-healing process.

Table 4

| PHYSICO-CHEMICAL AND PHYSICO-MECHANICAL CHARACTERISTICS | | | | |
|---|---|---|---|---|
| **Code** | **Mass ($g/m^2$)** | **Permeability to air ($l/m^2/s$)** | **Water vapour permeability (%)** | **Hydrophilicity (s)** |
| M | 204 | 223.4 | 35.3 | Immediate |
| CUC-0 | 247 | 126.8 | 31.2 | Immediate |
| CUC-1 | 243 | 121.2 | 33.1 | Immediate |
| CUC-2 | 249 | 119.4 | 31.7 | Immediate |
| CUC-3 | 249 | 109.1 | 29.5 | Immediate |
| CUC-4 | 239 | 109.0 | 25.8 | Immediate |
| CUC-5 | 248 | 120.0 | 30.1 | Immediate |
| CUC-6 | 229 | 123.9 | 29.0 | Immediate |
| CUC-7 | 241 | 120.1 | 31.4 | Immediate |
| CUC-8 | 249 | 115.3 | 30.4 | Immediate |
| CUC-9 | 252 | 102.8 | 32.1 | Immediate |
| CUC-10 | 244 | 104.9 | 33.3 | Immediate |
| CUC-11 | 250 | 125.2 | 31.9 | Immediate |

**Antibacterial activity**

Images of Petri plates after 24 h of incubation are shown in figures 2 and 3, and an assessment of antibacterial activity is shown in table 5.

By analysing the obtained results, it can be concluded that the textile materials treated with synthesized emulsions based on polyvinyl alcohol-collagen-active principles had an antibacterial effect against both test strains (*E. coli* and *S. aureus*), with inhibition zones between 14 mm (CUC-11 in the presence of *S. aureus*) and 27 mm (CUC-1 in the presence of *E. coli*). All textile biomaterials obtained by treating textile materials with hydrogels containing ciprofloxacin as an active principle (codes CUC-1, CUC-2, and CUC-3) had the most pronounced antibacterial effect compared to analogous samples containing chlorhexidine (CUC-8, CUC-9, and CUC-10).

Table 5

| EVALUATION OF THE ANTIBACTERIAL ACTIVITY | | | | |
|---|---|---|---|---|
| **Code** | ***E. coli*** | | ***S. aureus*** | |
| | **Inhibition zone (mm)** | **Evaluation** | **Inhibition zone (mm)** | **Evaluation** |
| M | 0 | Unsatisfactory effect | 0 | Unsatisfactory effect |
| CUC-0 | 16.0 | Satisfactory effect | 17.0 | Satisfactory effect |
| CUC-1 | 27.0 | Satisfactory effect | 20.0 | Satisfactory effect |
| CUC-2 | 23.5 | Satisfactory effect | 21.0 | Satisfactory effect |
| CUC-3 | 24.5 | Satisfactory effect | 24.0 | Satisfactory effect |
| CUC-4 | 20.0 | Satisfactory effect | 26.0 | Satisfactory effect |
| CUC-5 | 21.0 | Satisfactory effect | 17.0 | Satisfactory effect |
| CUC-6 | 22.0 | Satisfactory effect | 20.0 | Satisfactory effect |
| CUC-7 | 23.5 | Satisfactory effect | 22.0 | Satisfactory effect |
| CUC-8 | 15.5 | Satisfactory effect | 18.5 | Satisfactory effect |
| CUC-9 | 18.0 | Satisfactory effect | 20.5 | Satisfactory effect |
| CUC-10 | 16.0 | Satisfactory effect | 15.0 | Satisfactory effect |
| CUC-11 | 15.0 | Satisfactory effect | 14.0 | Satisfactory effect |

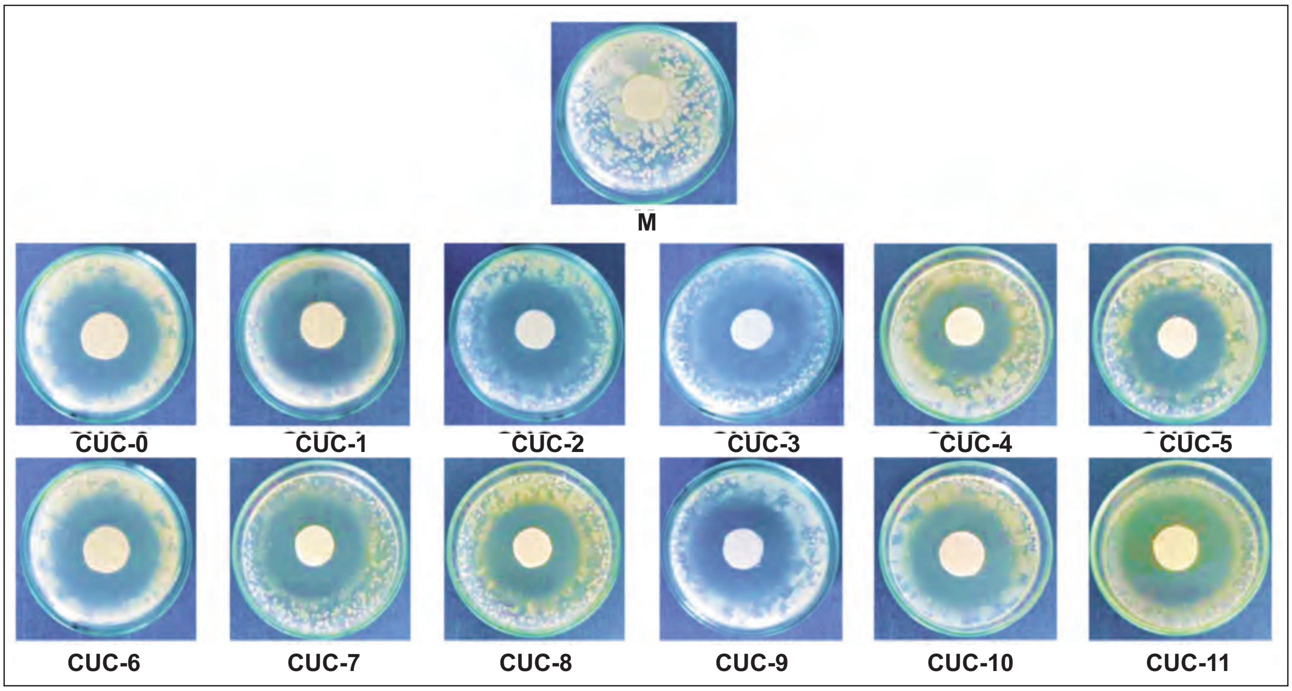


Fig. 2. Images of Petri plates showing an antibacterial effect after 24 h against the *E. coli* test strain

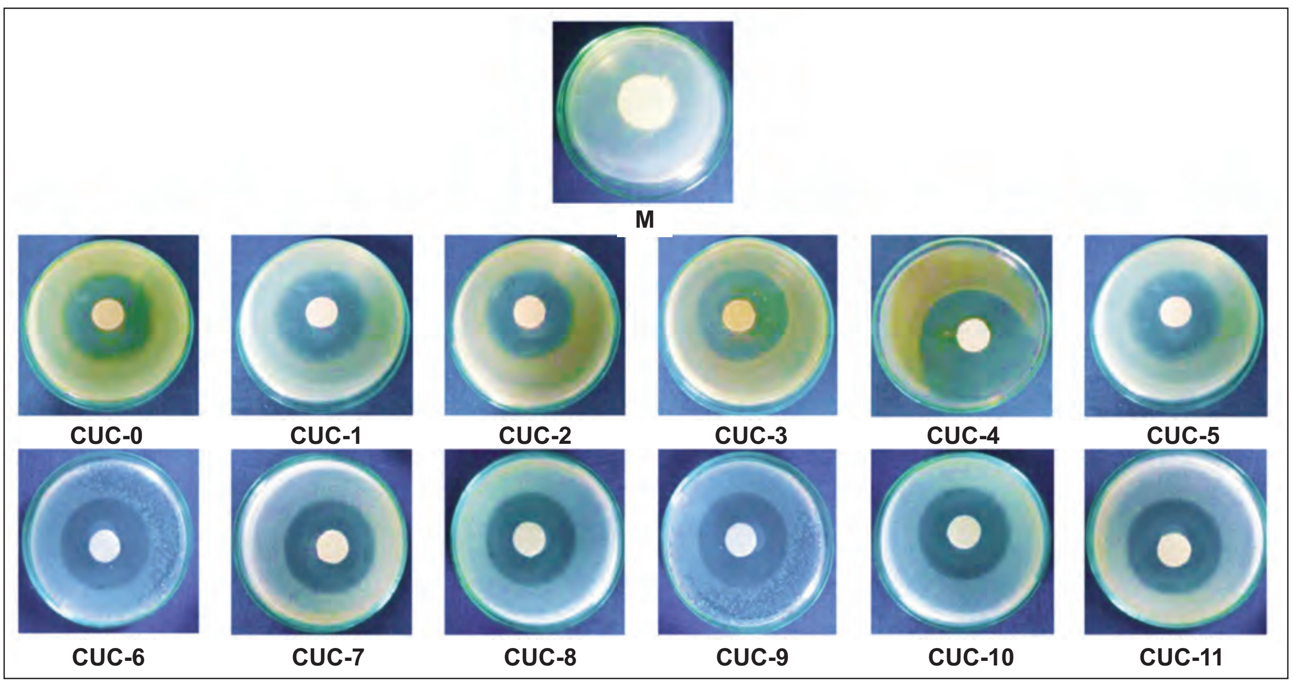


Fig. 3. Images of Petri plates showing an antibacterial effect after 24 h against the *S. aureus* test strain

Among samples treated with hydrogels based on ciprofloxacin and tested against *the E. coli* test strain, a slightly higher level of antibacterial activity was observed for the sample treated with a hydrogel containing all active principles (code CUC-1, inhibition zone = 27 mm) in comparison with samples treated with the hydrogels based only on ciprofloxacin (CUC-5, inhibition zone = 21 mm), tea tree essential oil (CUC-6, inhibition zone = 22 mm) or curcumin (CUC-7, inhibition zone = 23.5), highlighting the synergistic effect of the three active principles. However, the opposite behaviour was observed for these samples when tested against the *S. aureus* test strain, for which higher antibacterial activity was obtained for the sample treated with the hydrogel without ciprofloxacin, based on tea tree essential oil and curcumin (code CUC-4), with a 26 mm inhibition zone.

For both tested strains, the textile materials group which was treated with the hydrogels containing chlorhexidine (CUC-8 – CUC-11), showed a slightly lower antibacterial efficiency in comparison to the samples treated with hydrogels based on ciprofloxacin, the most evident antibacterial effect being obtained for the sample treated with the hydrogel based on polyvinyl alcohol-collagen-chlorhexidine-tea tree essential oil (code CUC-9, inhibition zone = 20 mm), tested against the *S aureus* test strain. Additionally, for all samples from this group, the inhibition zone diameter was higher than that for samples treated with hydrogel-based only on chlorhexidine.

## CONCLUSIONS

Textile materials with healing and antimicrobial properties were obtained by applying hydrogels containing ciprofloxacin, chlorhexidine, tea tree essential oil and curcumin on cotton fabric. In this context, several hydrogel formulations based on PVA and collagen, which were used as polymeric matrices, were prepared and evaluated. The developed hydrogels applied on cotton fabrics influence the comfort indices, decreasing the air and water vapour permeability due to the polymeric systems deposited at the surface of the fabrics. Textile materials treated with hydrogels based on PVA and collagen containing different bioactive principles showed antibacterial activity against both test strains (*S. aureus* and *E. coli*). Samples of textile material treated with hydrogels containing ciprofloxacin exhibited higher antibacterial activity than analogous samples treated with hydrogels containing chlorhexidine. From the results obtained, and taking into account that the developed polymeric systems contain the active principle designed for the treatment of first-degree burns, it can be concluded that through the application of hydrogels containing ciprofloxacin, chlorhexidine, tea tree essential oil and curcumin on cotton fabrics, it is possible to obtain a varied range of biomaterials with antibacterial properties that can be used for burn wound management. Research on potential bioactive systems based on PVA and collagen for obtaining multifunctional textile materials for topical application is in progress for studying the potential of biocompatibility in terms of skin irritation.

## ACKNOWLEDGEMENTS

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# Adsorption, kinetics, and thermodynamic study of dyeing the Scutellaria Orientalis L as an eco-friendly natural colourant on cotton fabric

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**ABSTRACT – REZUMAT**

**Adsorption, kinetics, and thermodynamic study of dyeing the Scutellaria Orientalis L as an eco-friendly natural colourant on cotton fabric**

*The adsorption isotherm, thermodynamic parameter, and kinetics study for dyeing without mordanting cotton fabric dyed with natural dye obtained from an aqueous extract of the Scutellaria Orientalis were investigated using, as optimal conditions, at pH of 5 a material to liquor ratio (MLR) of 1:100, an initial dye concentration of 1.0/l and contact time (20–90 min.). The effect of the temperature and dyeing time (from 20–90 min.) on dyeing was evaluated using three different temperatures (from 60, 80, and 90°C). Also, the adsorption isotherms have been analyzed by Langmuir and Freundlich models. It is revealed that the adsorption kinetics was found to follow the pseudo-first-order kinetic model, the obtained adsorption isotherm was found to be suitable for both Langmuir and Freunlich adsorption isotherm, and the dyeing process is exothermic. The rate of dye uptake and thermodynamic parameters have also been calculated and discussed.*

***Keywords***: *Scutellaria orientalist L, cotton, dyeing, adsorption, isotherm, thermodynamic*

**Adsorbția, cinetica și studiul termodinamic al vopsirii ţesăturii de bumbac cu colorantul ecologic natural Scutellaria Orientalis L**

*Studiul izotermei de adsorbție, al parametrului termodinamic și al cineticii pentru vopsirea fără mordansare a țesăturii de bumbac cu colorant natural obținut dintr-un extract apos de Scutellaria Orientalis a fost investigat folosind condițiile optime: la un pH de 5 un raport de flotă (MLR) de 1:100, o concentrație inițială de colorant de 1,0/l și un timp de contact de 20–90 minute. Influența temperaturii și al timpului de vopsire (de la 20–90 min.) asupra vopsirii a fost evaluată folosind trei temperaturi diferite (de la 60, 80 și 90°C). De asemenea, izotermele de adsorbție au fost analizate prin modelele Langmuir și Freundlich. S-a descoperit că cinetica de adsorbție urmează modelul cinetic de pseudo-ordin întâi, izoterma de adsorbție obținută s-a dovedit a fi potrivită atât pentru izoterma de adsorbție Langmuir, cât și pentru Freundlich, iar procesul de vopsire este exoterm. Rata de absorbție a colorantului și parametrii termodinamici au fost, de asemenea, calculaţi și discutaţi.*

***Cuvinte-cheie***: *Scutellaria orientalis L, bumbac, vopsire, adsorbție, izotermă, termodinamic*

## INTRODUCTION

The use of natural dyes to colour textiles (silk, wool, cotton, and leather) had been flourishing for thousands of years until the appearance of synthetic dyes in 1856. Since synthetic dyes have apparent advantages such as overall chromatography, good fastness, good colour reproducibility, and low costs, natural dyes almost disappeared after the discovery of synthetic dyes. However, recently there has been a revival of growing interest in the application of natural dyes on natural fibres due to worldwide environmental consciousness [1]. Moreover, compared with synthetic dyes, natural dyes exhibit some functions and better biodegradability and compatibility with the environment [2]. Thus, more and more natural dyes including Scutellaria Orientalis L have been reused in textile dyeing [3]. Scutellaria plants are known to contain large amounts of flavones. The main flavonoids of this genus are baicalein, wogonin, and chrysin [4]. Its chemical structure is shown in table 1 and figure 1. Chrysin (5,7-dihydroxyflavone), a natural flavonoid that is found in many plant extracts, honey, and propolis is reported to possess antioxidant property [5]. Chrysin possesses different biological activities such as antiviral anti-inflammatory and anti-diabetic antioxidant and anticancer properties. Wogonin is another flavour-noid-like chemical compound found in the dried root of Scutellaria. Baicalein, 5,6,7-trihydroxy flavone, is the main bioflavonoid found among other flavonoid derivatives in the roots of S. baicalensis. Numerous studies have demonstrated that it has a broad spectrum of bioactivity, including anti-oxidative [4].

Scutellaria is a genus of flowering plants belonging to the Lamiaceae family. They are known commonly as skullcaps and include about 350–400 species [5]. Most are annual or perennial herbaceous plants, and more rarely, subshrubs, worldwide, excluding South Africa [5, 6]. It has been widely used in different fields such as food additives, cosmetics, pharmaceuticals, colourants in textiles, and so on. However, it is rare for them to dye Scutellaria plants with cotton, silk,

Table 1

| COMPUNDS OF OF SCUTELLARIA ORIENTALIS L. | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Compounds** | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ | $R_6$ | **The molecular formula and Mol.Wt.** |
| Baicalein | - | - | - | OH | OH | OH | $C_{15}H_{12}O_5$, 272.25 g |
| Wogonin | $CH_3$ | - | - | OH | - | OH | $C_{16}H_{14}O_4$, 270.28 g |
| Chrysin | - | - | - | OH | - | OH | $C_{15}H_{12}O_4$, 256.25 g |

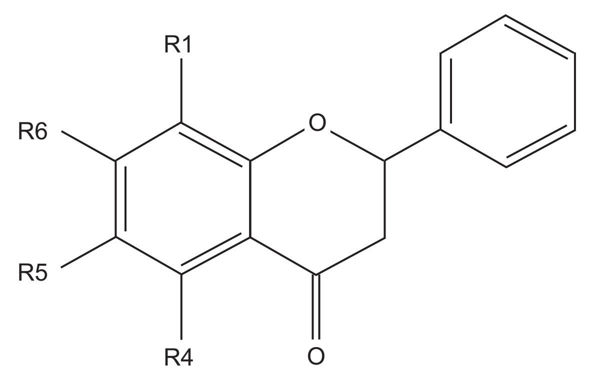



Fig. 1. Chemical structure of Scutellaria Orientalis L.

and wool fibres, they are generally widely used in medicinal fields. Whereas, there are a lot of thermodynamic and kinetics studies on natural dyes in the literature. Samanta and Agarwal investigated the Physicochemical studies on the dyeing of jute and cotton fabrics using jackfruit wood extract, dyeing kinetics, and thermodynamics [7]. Samanta et al reported the dyeing of jute fabric with tesu extract, thermodynamic parameters, and kinetics of dyeing [8]. In another study, thermodynamic and kinetic studies of the adsorption behaviour of the natural dye cochineal on polyamide66 were reported [9]. In another study, kinetics and thermodynamics studies of cationic dye adsorption onto carboxymethyl cotton fabric [10]. However, not much has been reported in the literature about the dyeing kinetics and thermodynamics for the dyeing of cotton fabric using Scutellaria Orientalis L. natural dyes. Hence, the main aim of this present work is to extract aqueous colourants of various shades from Scutellaria Orientalis L and to apply them in cotton fabric dyeing. On the other hand, the adsorption isotherms, kinetics, and thermodynamic parameters were studied in detail.

## MATERIALS AND METHODS

### Materials

A Commercially scoured, and bleached cotton fabric was received from Kipaş Co., Ltd., Turkey. Scutellaria Orientalist flowers were collected in the season in Van-Turkey. Plants collected were dried under shady and airy conditions, and for the preparation of the solutions Distilled water was used for the preparation of the dyeing solutions.

### Methods

*Dye extraction*

This study used the solid-liquid extraction method, and due to the evaporation of the solvent in the extraction process, the temperature was not increased above the boiling point of the solvent. About 5 g of dried Scutellaria Orientalist L. were weighed taken in the 500 ml beaker and dissolved in 300 ml of solvent ($H_2O$). After heating the beaker at 70–80°C for 1 h, the extract was filtered, and the solution was stored for later use as an aqueous dye extract.

*Dyeing process*

The natural dye extracted from Scutellaria Orientalist extracts dye onto cotton fabric was carried out through an exhaustion dyeing process, and the solution containing 100% o.w.f (on the weight of the fabric), and liquor ratio 50:1. The pH of the dye solutions was 7. Next, a steel cup with the dye solution and the fabrics were placed in the YK-12 dyeing machine (Atac Textile Machinery Co., Ltd. Turkey) for dyeing. The dyeing of fabrics was commenced at ambient temperature, and the dye solution was subsequently heated under a heating rate of 2°C/min to 60, 80, and 90°C, and maintained at this temperature for 40 to 90 min. for dyeing time.

*Effect of pH on dye extract*

The effect of pH on the colour value of the dye extract of Scutellaria orientalist was determined by recording the visible spectra (Optizen 3220 UV/Vis spectrophotometer) of the dye solution at different pHs (5, 7, and 9). Acetic acid buffer was used to maintain pH in range 5, and sodium hydroxide buffer was used to maintain pH 7–9.

*Dye exhaustion*

Dye exhaustion means the amount of dye adsorbed by the fibres, fabric, etc. Exhaustion percentage ($E$%) is determined by measuring the absorbance of extract Scutellaria Orientalis extracts dyebath before and after dyeing, respectively. After the dyeing process, the absorbance of the dyeing solutions was measured using a (Shimadzu UV-Vis 1240) spectrophotometer set at a wavelength of 410 nm, maximum absorbance. The exhaustion percentage ($E$%) was calculated using equation 1 [11].

$$E\% = \frac{A_0 - A_t}{A_0} \times 100 \tag{1}$$

where $A_0$ is the absorbance of Scutellaria Orientalist flower extracts dye solution before dyeing and $A_t$ – the absorbance of Scutellaria Orientalist flower extracts dye solution after dyeing.

The amount of Scutellaria Orientalist flower extracts dye adsorbed $[D]_{f,t}$ (g/g) by per unit weight of the cotton fabric at time t was calculated by using equation 2 [11]:

$$[D]_{f,t} = \frac{[C_0] - [C_t]V}{m} \quad (2)$$

where $C_0$ is the initial concentration (g/l) of Scutellaria Orientalist flower extracts dyebath, $C_t$ – the concentration (g/l) of Scutellaria Orientalist L extracts solution after time $t$ (min), $V$ – the volume of the Scutellaria Orientalist flower extracts dye solution (L), and $m$ – the weight of cotton fabric (g) used for dyeing in the dyebath. After completion of dyeing, the residual dye bath liquor was measured on a Shimadzu UV-Vis 1240 absorbance spectrophotometer, subsequently, the concentration of Scutellaria Orientalist flower in the extracts in the dyebath ($C_t$) was calculated using a linear regression equation of the standard curve. The amount of extracts dye adsorbed by per unit weight of the cotton fabric at equilibrium $[D]_e$ (g/g) was calculated using equation 3 [11, 12]:

$$[D]_e = \frac{(C_0 - C_e)V}{m} \quad (3)$$

Where $D_e$ is the amount of dye adsorbed (g/g), $C_0$ and $C_e$ are the initial and equilibrium dyebath concentrations of dye (g/g) respectively.

*Fourier Transform Infrared (FTIR) Analysis*

Fourier transform infrared (Bruker ALPHA model) dye and dyed cotton fabric were analyzed for dye interactions (with a resolution of 4 $cm^{-1}$). Bands in the FTIR spectra were analyzed by the literature data.

*Colourfastness properties*

The ability of the dye to be retained by the fabric during washing and on exposure to light was evaluated by the respective colourfastness tests. These were carried according to, ISO 105 C03, and ISO 105 BO2 for washing, and, light fastness, respectively.

Greyscale was used to rate the colour fastness between one and five.

## RESULTS AND DİSCUSSION

### Effect of dyeing time on the exhaustion percentage

The effect of dyeing time on the $E$% of Scutellaria Orientalist extract dye into the cotton fabrics at different temperatures (60, 80, and, 90°C) with an applied dosage of 1% o.w.f of dye is shown in figure 2. As can be seen in figure 2, the dyeing uptake of Scutellaria Orientalist dye on cotton fabrics increases with the extension of dyeing time, and the initial dyeing rate is faster. However, with time extension, the increase of the dyeing rate slows down and gradually reaches a stable state after 60 min, and the higher the dyeing temperature is, the higher the dyeing uptake is, and higher temperatures lead to shorter equilibrium time. Also, Scutellaria Orientalist extracts showed a thermal property against higher dyeing temperatures. The thermal stability of Scutellaria Orientalist extracts dye proves that when dyeing cotton fabric at high temperatures does not influence the detection of $E$%. These results showed that the $E$% increased with increasing dyeing time, and dyeing of equilibrium times was found to be 75, 60, and 55 min at 60, 80, and 90°C respectively. It is found that for Scutellaria Orientalist extract dyeing onto cotton fabric, 90°C is the optimal dyebath temperature to promote dye exhaustion into the fibre from the dyebath. This can be explained by the dye solution being more quickly transferred from the dyebath to the fabric [11]. Similar results have also been reported in the previous study [13–15].

### The substantivity of Scutellaria orientalist dye on cotton fabric

The substantivity is usually used to determine which dye the fibres prefer to the dye bath. It represents the relationship between substantivity, liquor ratio, and the percentage of exhaustion at equilibrium. The substantivity can be calculated using the following equation [11]:

$$K = \frac{\%E_e\,L}{100 - E_e} \quad (4)$$

where $K$ is the substantivity, $\%E_e$ – the percentage of exhaustion at equilibrium, and $L$ – the liquor ratio. The $K$ value indicates the efficiency of dye transferred from the dye bath to the substrate. A greater value of $K$ means that the dye is favoured to stay in the fibre. The parameters of substantivity of dyeing are presented in table 2. A higher $K$ value suggests higher substantivity of Scutellaria orientalist extracts

Table 2

PARAMETERS OF SUBSTANTIVITY OF DYEING

| Temperature (°C) | $\%E_e$ | L | K |
|---|---|---|---|
| 60 | 75.4 | 50 | 153 |
| 80 | 84.5 | 50 | 272 |
| 90 | 88.7 | 50 | 392 |

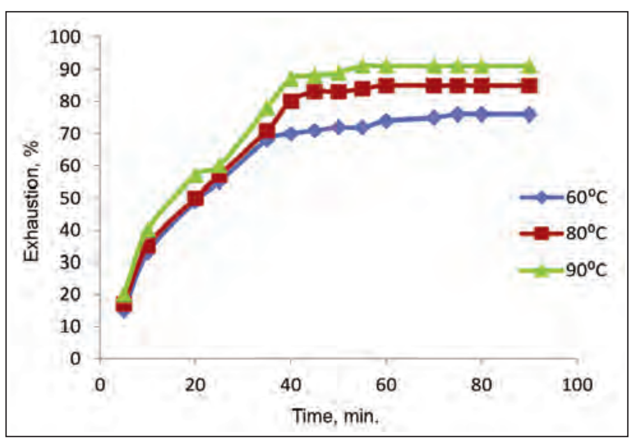



Fig. 2. The effect of of dyeing time on $E$% at different temperatures with 1% o.w.f Scutellaria Orientalist extract and a liquor ratio of 50:1

dye toward cotton fabric and also higher transport of the dye from the dyebath to the fibre. A higher *K* value specifies that more dye could remain inside the fibre than in the dye bath.

**Effect of dyeing temperature on the exhaustion percentage**

The effect of dyeing temperature on the exhaustion percentage was studied in the range of temperature between 60 to 90°C for Scutellaria Orientalis extracts 1% o.w.f of extract. The obtained results are shown in figure 3. As can be seen from the figure, the exhaustion percentage increased with temperature 60 to 90°C, the exhaustion percentage, but, the increasing rate of the exhaustion began to slow after 80°C which is almost close to that at 90°C.

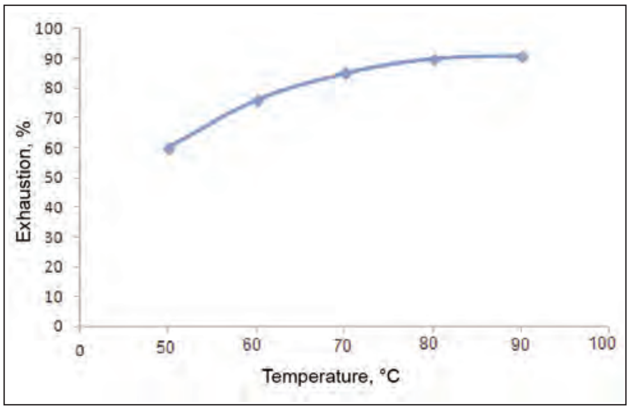



Fig. 3. The effect of dyeing temperature (60–90°C) on *E*% (conditions: with 1% owf of Scutellaria Orientalis extract dye for 90 min. dyeing time, liquor ratio: 50:1)

**Effect of pH on dye extract**

The visible spectra of the dye extract of Scutellaria Orientalis were measured at pH 5, 7 and 9. The spectra in figure 4 show that the absorbance value is low at pH 7. However, the absorbance value of the dye increases at pH 9, but the maximum absorbance was observed at pH 5, which may be attributed to the increased solubility of polyphenol and flavonoid groups at these values.

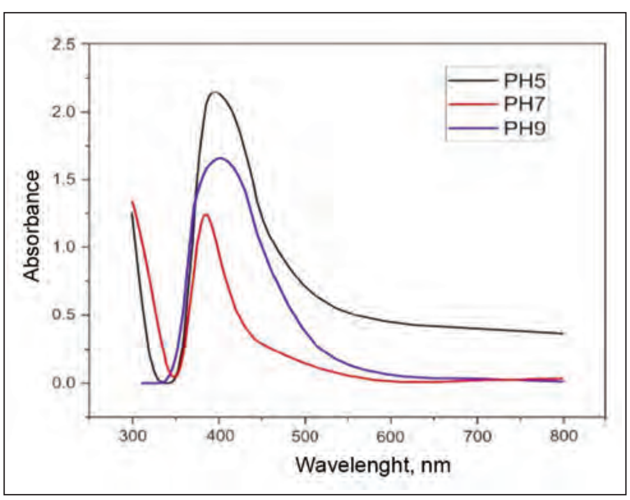



Fig. 4. UV-Vis spectra of the aqueous extracts of Scutellaria Orientalis plant at different pH

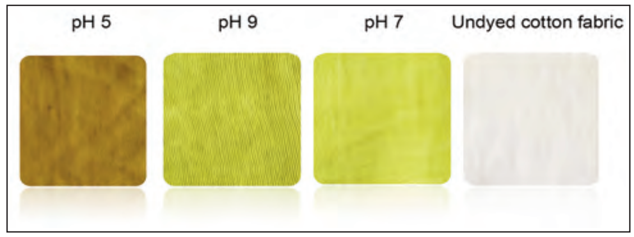



Fig. 5. Photos of cotton fabrics dyed with Scutellaria Orientalis Plant at different pH

It was observed that cotton is significantly attracted by the three different pH extracts This indicates the availability of studying the optimum condition of dyeing and the effect of different mordants

**Colourfastness properties**

The fastness properties of fabrics dyed with Scutellaria Orientalis with different pH were evaluated in terms of the fastness of washing, and fastness of the light colour alteration as shown in table 3. In the test for colour fastness to artificial light, it was found that all the samples showed a good light fastness rating of 4 and 5 on grayscale. Considering the fastness and properties of the cotton fabrics dyed with different pH extracts of the natural dye, it was observed that the pH 5 extract showed the best fastness properties compared to the other dye extract. This can be attributed to the fact the pH 5 dye extract was purified during the sequential extraction process which reduces the concentration of non-dye substances present in the extracted matrix allowing the dye molecules to bond with the cellulose on the fabric [16]. Similar results have been also observed in previous studies [17–19].

Table 3

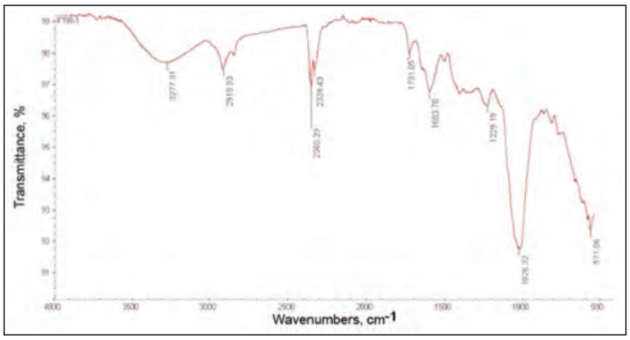
COLOUR FASTNESS FOR THE FABRİC DYED WİTH PH DİFFERENT DYE EXTRACT

| Samples code | Light fastness | Wash fastness CC | CS |
|---|---|---|---|
| (a) | 5 | 4–5 | 4–5 |
| (b) | 4 | 4 | 4 |
| (c) | 4 | 4 | 4 |

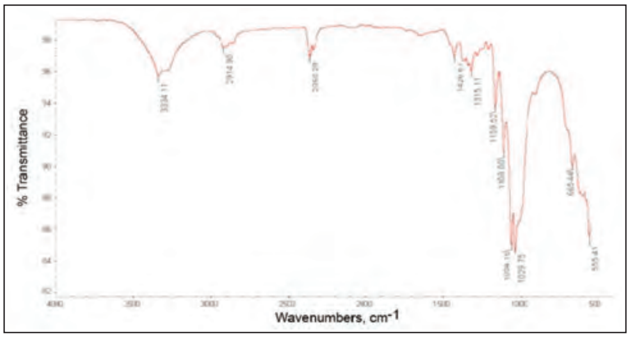
Note: *CC – colour change of the dyed fabric, CS – colour staining of the adjacent cotton fabric.

**Fourier Transform Infrared (FTIR) Analysis**

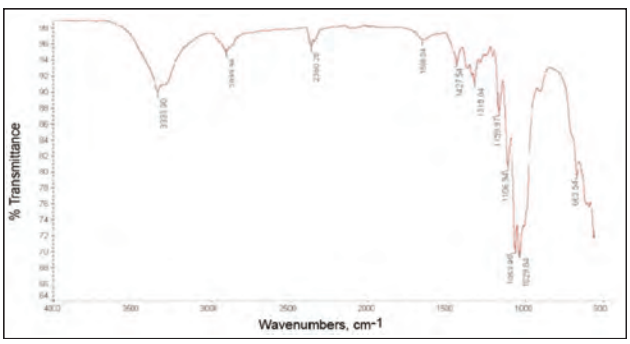
In figure 6, *a*, the FT-IR spectra showed a band at 2918 $cm^{-1}$ corresponding to the O–H bond stretching mode for carboxylic acid. The bands at 2300 $cm^{-1}$, 1700 $cm^{-1}$, 1600 $cm^{-1}$,1229 $cm^{-1}$, and 1026 $cm^{-1}$ correspond to C=C stretching mode, C–O–H bending mode, C=O bending mode, C–O stretching mode, and C–H out of plane bending mode for the aromatic ring, respectively. These observed peaks showed that the extracted dye contained polyphenols and flavonoids. According to Figure 5, *b*, the characteristic cellulose broad peak at 3334 $cm^{-1}$ is for the O–H




*a*




*b*




*c*

Fig. 6. FTIR spectra of: *a* – dye; *b* – cotton fabric; *c* – dyed cotton fabric

bond stretching mode, and that at 2914 $cm^{-1}$ corresponds to C–H bond stretching. C–O stretching mode and C–O–H bending mode was shown by the peaks at 1426 $cm^{-1}$, and 1315 $cm^{-1}$, respectively. All these peaks are in relation to the chemical structure of the cellulosic pure cotton fabric. In figure 6, *a* and *b*, comparing the FTIR spectra of dyed cotton fabric with that of undyed cotton fabric there was a new peak at 1600 $cm^{-1}$ corresponding to C=C stretching mode for the aromatic ring confirming the attachment of the aromatic dye molecules to the cellulose structure. Moreover, the characteristic cellulose band at 3334 $cm^{-1}$ is for O–H shifted to the lower region of 3333 $cm^{-1}$ which could be attributed to stronger hydrogen bonds between dye and cellulose than those between cellulose molecules. Similar results have also been reported in previous studies [20–22].

**Adsorption isotherm study**

The Langmuir adsorption isotherm has been successfully applied to many other real sorption processes. A basic assumption of the Langmuir theory is that sorption takes place at specific homogeneous sites within the adsorbent. It is then assumed that once a dye molecule occupies a site, no further adsorption can take place at that site. Theoretically, therefore, a saturation value is reached beyond which no further sorption can take place [18]. The Langmuir and Freundich adsorption parameters were determined in linear forms as follows [23, 24]:

$$\text{Langmuir isotherm:} \quad \frac{1}{q_e} = \frac{1}{Q} + \frac{1}{Q\,b\,C_e} \qquad (5)$$

$$\text{Freudlich isotherm:} \quad \ln q_e = \ln K_f + \left(\frac{1}{n}\right) \ln C_e \qquad (6)$$

where $Q$ is the maximum amount of the dye per unit weight of cotton fabric to form a complete monolayer coverage on the surface-bound at high equilibrium dye concentration $C_e$, $q_e$ – the amount of dye adsorbed per gram of cotton fabric at equilibrium, and $b$ – the Langmuir constant related to the affinity of binding sites. The value of $Q$ represents a practical limiting adsorption capacity when the surface is fully covered with dye molecules and assists in the comparison of adsorption performance (table 4) [25]. The linear plot of $1/q_e$ versus $1/C_e$ is obtained from this model as shown in figure 7.

The values of $R_L$ indicate the type of isotherm to be irreversible ($R_L$ = 0), favourable (0 < $R_L$ < 1), linear ($R_L$ = 1) or unfavourable ($R_L$ > 1):

$$R_L = \frac{1}{1 + K_L C_0} \qquad (7)$$

where $R_L$ can be 0 < $R_L$ < 1. The less than unity $R_L$ value supported a favourable adsorption [26–28], as seen in table 4.

The fit is good for the adsorption data of Scutellaria Orientalist flower extract dye onto cotton fabric at 60, 80, and 90°C (correlation coefficient, $R$ > 0.99). In the range of 60–90°C, an increase in the temperature does not affect the adsorption of Scutellaria

Table 4

THE CHARACTERISTIC PARAMETERS OF DYEING PROCESS OF SCUTELLARIA ORIENTALIST FLOWER EXTRACT DYE ON TO COTTON FABRIC

| Langmuir isotherm | | | | Freundlich isotherm | | | |
|---|---|---|---|---|---|---|---|
| **Temperature (°C)** | **b** | **Q(g/g)** | **$R^2$** | **$R_L$** | **$K_f$** | **n** | **$R^2$** |
| 60 | 1.12 | 0.932 | 0.998 | 0.485 | 0.486 | 2.0538 | 0.9795 |
| 80 | 1.11 | 0.802 | 0.999 | 0.472 | 0.478 | 2.0881 | 0.9887 |
| 90 | 1.06 | 0.797 | 0.998 | 0.476 | 0.440 | 2.2691 | 0.9989 |

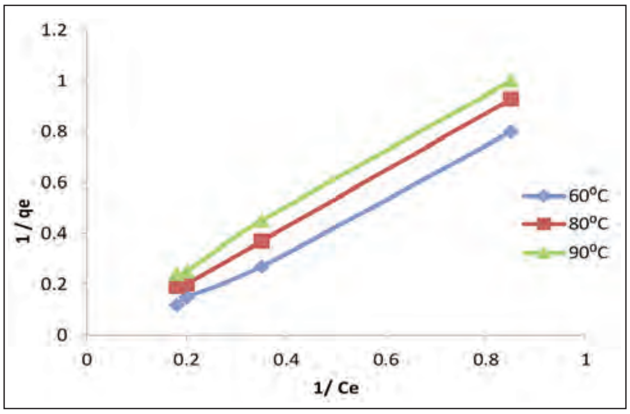



Fig. 7. Langmuir plots for the Scutellaria Orientalist flower extract dye adsorption on to cotton fabric for different temperature

Orientalist flower extract dye onto cotton fabric significantly. This can be explained by physical adsorption decreases with increasing temperature [24]. Also, indicates that the dyeing process is exothermic, and the $Q$ values decreased with increasing temperature. The $b$ values indicated that the cotton fabric has a maximum affinity for Scutellaria Orientalist flower extract dye almost the same at all temperatures, but slightly higher at 60°C. Similar results have also been reported in the previous study [24, 25, 29]. The values of $R_L$ (table 4) were observed to be in the range of 0–1, indicating that the adsorption of Scutellaria Orientalist flower extract dye on to cotton fabric was favourable for this study.

The plots of $\ln q_e$ versus $\ln C_e$ for the Scutellaria Orientalist flower extract dye adsorption onto cotton fabric for different temperatures according to the linear forms of the Freundlich isotherms are shown in figure 5. The values of the Freundlich constants were determined from the linear plot of $\ln q_e$ versus $\ln C_e$. The values are presented in table 2. The values of $n$ were found to be 2.05, 2.08, and 2.26 for 60, 80, and 90°C respectively, indicating that the adsorption was favourable. On the other hand, the values of $n$ between 2 and 10 show good adsorption [30]. The $K_f$

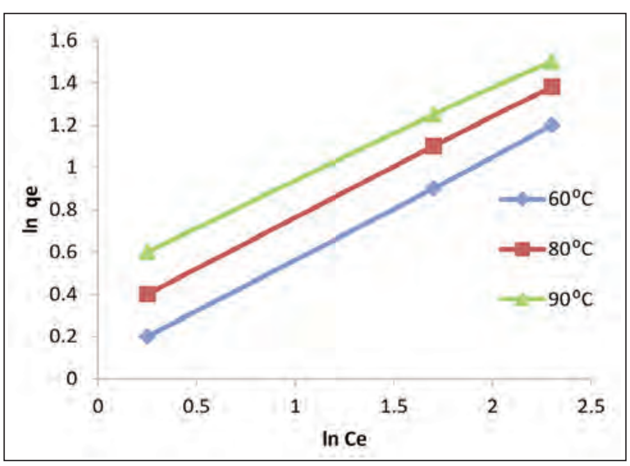



Fig. 8. Freundlich plots for the Scutellaria Orientalist flower extract dye adsorption on to cotton fabric for different temperature

values decreased with increasing temperature which again supported an exothermic process. From table 4, the Freundlich equation can be applied to fit the experimental data as well as the Langmuir equation because it gave a high correlation coefficient $R^2 > 0.99$. Similar adsorption isotherms results have been reported previously in work [24, 25, 31].

**Kinetics study**

The experimental data relating to absoprtion of Scutellaria Orientalist flower extract dye onto cotton fabric was investigated using the Lagergren pseudo-first and pseudo-second order (equations 8 and 9):

$$\log (q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \tag{8}$$

$$\frac{t}{q_t} = \frac{1}{k_2 q e^2} + \frac{t}{q_e} \tag{9}$$

where, $q_e$ is the amount of adsorption amount at equilibrium, $q_t$ – the amount of Scutellaria Orientalist flower extract dye adsorbed at various times, $t$ – time of adsorption duration and $k_1$ – the pseudo first-order adsorption rate constant. Equilibrium adsorption amount $q_e$ (cal) is determined by employing the linear plot of log $q_e - q_t$ versus the adsorption time ($t$).

Table 5

KINETIC PARAMETERS OF PSEUDO FIRST-ORDER AND PSEUDO SECOND-ORDER KINETIC MODELS FOR SCUTELLARIA ORIENTALIST FLOWER EXTRACT ADSORPTION ON COTTON FABRIC AT DIFFERENT TEMPERATURES

| Temperature | 60°C | 80°C | 90°C |
|---|---|---|---|
| **Pseudo-first order** | | | |
| $q_e$ (Exp.) | 0.0052 | 0.0080 | 0.0120 |
| $q_e$ (Cal) | 0.0099 | 0.0115 | 0.0119 |
| $k_1$ | $2.27\times10^{-2}$ | $2.64\times10^{-2}$ | $2.74\times10^{-2}$ |
| $R^2$ | 0,960 | 0.986 | 0.995 |
| **Pseudo-second order** | | | |
| $q_e$ (Cal) | 5.52 | 13.85 | 8.59 |
| $k_2$ | $7.8\times10^{-3}$ | $8.1\times10^{-3}$ | $8.4\times10^{-3}$ |
| $R^2$ | 0.910 | 0.946 | 0.965 |

The experimental kinetic data were adjusted according to the indicated models (figure 6, *a* and *b*) and the coefficients of correlation as well as the kinetic parameters of pseudo-first-order and pseudo-second-order kinetic models are given in table 3. The results of table 3 and figure 6, *a* and *b* showed that the pseudo-first-order model provided the best correlation with experimental results. This fact indicates that the adsorption of Scutellaria Orientalist flower extract dye on cotton fabric follows the pseudo-first-order kinetic model. Similar kinetic results have been recorded previously study [32–34].

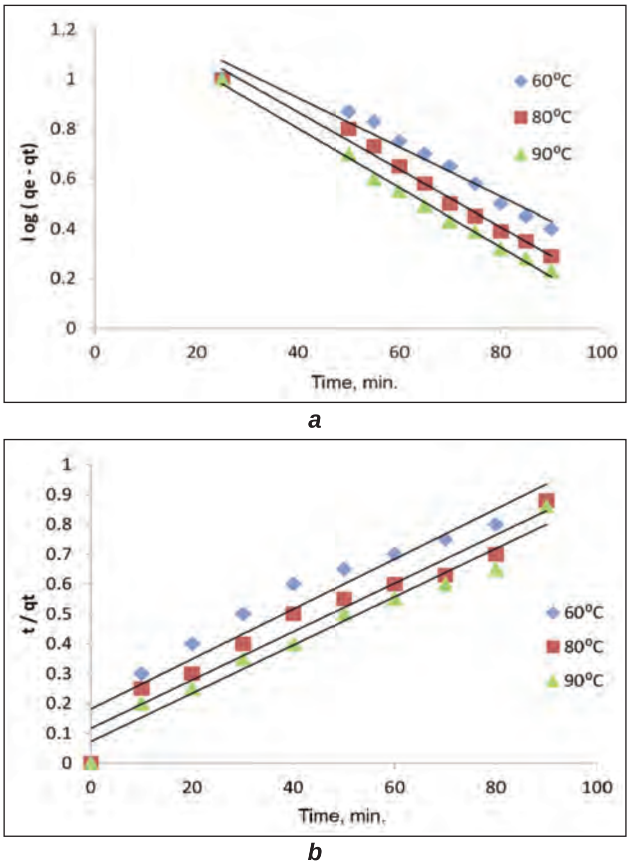



Fig. 9. The applicability of the: *a* – Pseudo first-order kinetic model; *b* – pseudo second-order kinetic model to Scutellaria Orientalist flower extract adsorption on cotton fabric

### Adsorption thermodynamic study

The various thermodynamic parameters standard free energy ($\Delta G$), standard enthalpy ($\Delta H$), and standard entropy ($\Delta S$) associated with the adsorption of Scutellaria Orientalist dye onto cotton fabric were calculated by using the following equations [27, 21]:

$$\Delta G = -RT \ln K_c \tag{10}$$

$$\ln K_c = \frac{-\Delta H}{RT} + \frac{\Delta S}{R} \tag{11}$$

$$K_c = \frac{C_{Ae}}{C_{Se}} \tag{12}$$

In the above equations, $R$ is the universal gas constant (8.314 J/mol K), $T$ – the temperature (K), $K_c$ – the equilibrium constant, and $C_{Ae}$ and $C_{Se}$ are the dye concentration adsorbed at equilibrium (mg/l) and the concentration of dye left in the dye bath at equilibrium (mg/L), respectively. The enthalpy ($\Delta H$) and entropy ($\Delta S$) are calculated from the slope and intercept of a plot of ln $K_c$ versus 1/T. The results are given in table 3. It is clear from table 3 that the value of $\Delta H$ is positive, indicating adsorption processes endothermic. The positive value of $\Delta S$ showed the affinity of cotton fabric to Scutellaria Orientalist flower extract dye and the increasing randomness at the solid-solution interface during the adsorption. The negative values of $\Delta G$ show that the Scutellaria Orientalist flower extract dye adsorption on cotton fabric was favourable and spontaneous with a high affinity of the adsorbate to the surface of the adsorbent. Similar thermodynamic results have been recorded on the cacao husk extract dye adsorption on cotton fabric, lac dyeing on silk, and coconut husk, and onto Raphia hookerie fruit epicarp [24, 32, 33].

## CONCLUSION

The adsorption behaviour of Scutellaria Orientalist flower extracts dye on cotton fabric was studied to understand the dyeing mechanism of natural dye. The study results demonstrate that a high dye uptake was achieved almost 90% of the Scutellaria Orientalist flower extracts were adsorbed into the cotton fabric. The adsorption equilibrium isotherm fitted for Langmuir and Frenundich but the adsorption equilibrium isotherm was best fitted to the Langmuir isotherm model. The positive value of ΔS showed the randomness of the solid-liquid interface during Scutellaria Orientalist flower extract dye adsorption onto cotton fabric. The negative values of $\Delta G$ indicated the spontaneous nature of adsorption, while the positive values of $\Delta H$ showed that the adsorption reaction was endothermic. The study results show that cotton fabric dyeing has good dyebath exhaustion by using the Scutellaria Orientalist flower extract dye conventional dyeing method. Also, the findings of the present study indicate that the Scutellaria Orientalist plant can be a good source of natural dye for eco-friendly textile industries.

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# The effect of ambient conditions on employees in textile and garment companies

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**ABSTRACT – REZUMAT**

**The effect of ambient conditions on employees in textile and garment companies**

*In this study, the effect of ambient conditions on employees was analyzed with the questionnaire applied to employees in selected textile and apparel companies and the results obtained were interpreted in terms of occupational health and safety. For the study, a total of 809 employees working in four companies including two textile companies and two garment companies were surveyed. 27.4% of the employees in the companies surveyed are women and 72.6% are men. In the survey conducted for the research, it was asked whether the environmental conditions in textile and apparel companies affect the employees negatively or not. According to the statistical analysis results made on the answers, it was concluded that high temperature, noise, moisture and bad ergonomy (positions that may cause discomfort in the musculoskeletal system) differ significantly, that is, they negatively affect the employees. The high temperature most negatively affected the employees in company D. Noise most negatively affected employees in company D. Moisture had the highest rate of affecting the employees in company A. The weak lighting rate is low for all companies. Bad ergonomy was seen at the highest rate in C and D companies, which are garment companies. Companies were informed about the negative conditions affecting employees and improvement studies were carried out.*

***Keywords:*** *ambient conditions, ergonomy, noise, occupational health, thermal comfort*

**Influența condițiilor ambientale asupra angajaților din companiile textile și de îmbrăcămminte**

*În acest studiu, a fost analizat efectul condițiilor ambientale asupra angajaților cu ajutorul chestionarului aplicat în firmele de textile și de îmbrăcăminte selectate, iar rezultatele obținute au fost interpretate în ceea ce privește sănătatea și securitatea în muncă. Pentru studiu, a fost chestionat un total de 809 de angajați care lucrează în patru companii, inclusiv două companii textile și două companii de îmbrăcăminte. 27,4% dintre angajații din companiile chestionate sunt femei și 72,6% sunt bărbați. Sondajul efectuat pentru studiu a abordat condițiile de mediu din companiile de textile și de îmbrăcăminte care afectează negativ angajații. Conform rezultatelor analizei statistice realizate pe răspunsuri, s-a ajuns la concluzia că temperatura ridicată, zgomotul, umiditatea și ergonomia necorespunzătoare (pozițiile care pot provoca disconfort la nivelul sistemului musculo-scheletal) diferă semnificativ, adică afectează negativ angajații. Temperatura ridicată a afectat în cea mai mare măsură angajații din compania D. Zgomotul a afectat cel mai mult angajații din compania D. Umiditatea a avut cea mai mare rată de afectare a angajaților din compania A. Rata slabă de iluminare a fost scăzută pentru toate companiile. Ergonomia necorespunzătoare a fost observată la cea mai mare rată în companiile C și D, care sunt companii de îmbrăcăminte. Companiile au fost informate despre condițiile negative care afectează angajații și au fost efectuate studii de îmbunătățire.*

***Cuvinte-cheie****: condiţii ambientale, ergonomie, zgomot, sănătate ocupaţională, confort termic*

## INTRODUCTION

The increase in productivity of the people working in the textile and ready-made clothing sector will result in the regulation of working conditions according to the workforce, thus providing a safer working environment and this will directly affect product quality. Affecting the health of the employee; physical factors such as temperature, noise, and vibration, chemical factors such as acid-alkaline, pesticide, paint, and dust, ergonomic factors and psycho-social factors can be summarized as workplace environment factors. With the Occupational Health and Safety Law No. 6331, important regulations have been made with the support of the law so that the employees can work in better conditions in the production sector. The purpose of Law No. 6331 on Occupational Health and Safety; is to regulate the duties, powers, responsibilities, rights and obligations of employers and employees to ensure occupational health and safety at workplaces and to improve existing health and safety conditions [1]. Within the scope of the law, six NACE codes have been introduced for workplace hazard classes, and within this framework, workplaces are classified as less dangerous, dangerous and very dangerous. For example, the manufacturing of textile products NACE code 13 is listed with other relevant textile areas under this code and the hazard group is given in table (13.10. Preparation and twisting of textile fibres (dangerous), 13.10.03 manufacture of natural cotton fibres (snowing, carding, etc.) (dangerous). 14 NACE code is the manufacture of clothing and under this code, for example, 14.12.08 occupational uniforms (including formal and special uniforms and school uniforms, excluding industrial work clothes) were included and this group is in the less dangerous group [2]. In this context, the textile and apparel industry is in the dangerous and less dangerous group in terms of occupational health and safety.

In the literature reviews, it was observed that the risk factors of muscle and skeleton and ergonomics were studied especially in garment factories [3–6]. In some studies, the role of hazard control measures in occupational health and safety was examined and risk analyzes were made [7–10]. There are also studies on noise and hearing loss in terms of occupational health, especially in weaving factories [11–12].

In this study, the effect of ambient conditions on employees was analyzed with the questionnaire applied to employees in selected textile and apparel companies and the results obtained were interpreted in terms of occupational health and safety. This field study was carried out to increase the awareness of the employees in two textile and two apparel enterprises that have been producing for many years and to ensure that these enterprises are improved in terms of occupational safety. Thus, the results obtained were shared with the business management, contributing to a positive step in terms of occupational health and safety.

## MATERIALS AND METHODS

### Study design

In this study, evaluations were done for statistical analysis of the results of the survey a total of 809 employees in four manufacturing companies in Malatya, Turkey. These companies are; A and B textile companies, and C and D garment companies. The number of people participating in the survey in Company A is 158, in Company B 169, in Company C 309 and Company D 173. The total number of employees participating in the survey is 809. Descriptive statistics on the employees participating in the survey: **Sex** (Female: 222 Persons; Male: 587 Persons); **Education** (Primary school: 164 Persons; Secondary school: 259 Persons; Highschool: 315 Persons; College: 71 Persons); **Position** (Managerial: 20 Persons; Preparation: 85 Persons; Production: 369 Persons; Finishing: 220 Persons; Others: 115); **Experience** (1 year: 202 Persons; 2–5 years: 203 Persons; 6–10 years: 210 Persons; 11–15 years: 116 Persons; 16 and above years: 78 Persons).

### Data collection

In this study, data were collected through a questionnaire. 100% of the employees answered the questionnaire. The first part of the questionnaire includes demographic aspects such as gender, age, education level of the employees, their department and their experience in the business. In the second part of the questionnaire, it was asked whether any factors were disturbing them in their work environment and negatively affecting their productivity while working. To understand what the negative factors were, they were asked if there were high temperatures, noise, moisture, weak lighting and bad ergonomy in the work environment.

### Data analysis

The results of the study were analyzed using IBM SPSS Statistics 22. Demographic data and numbers and percentages of study characteristics are given. Percentages of the relationship between businesses and environmental conditions are shown with Crosstab, and the Chi-Square test was applied to see if this relationship is significant.

## RESULTS

### Background characteristics of workers

For the study, a total of 809 employees who worked in four companies including two textile companies and two garment companies were surveyed.

According to statistical analysis, 27.4% of the employees in the companies are women and 72.6% are men. 20.3% of the employees are primary school graduates, 32% secondary school, 38.9% high school and 8.8% university graduates. 2.5% of the employees work in the administrative staff, 10.5% in the preparation department, 45.6% in production, 27.2% in the finishing operations and 14.2% in other departments (machine maintenance, electricity maintenance, cafeteria, etc.). 25% of the employees have been employed less than a year, 25.1% have 1–5 years of experience, 26% have 6–10 years of experience, 14.3% have 11–15 years of experience, and 9.6% are and have 16 years or more of experience. The youngest employees surveyed in businesses is 18 years old and the oldest is 53 years old. The average age of the respondents is 33.26.

### Evaluation of the high-temperature factor of the environment according to the companies

In the survey, it was asked to employees if the ambient temperature in the enterprise was at an uncomfortable level. 52.5% of the employees in business A, which is a textile business, said it was uncomfortable. Again, 50.3% of the employees in business B, which is a textile business, said it was at an uncomfortable level. While only 26.2% of the employees in facility C, which is a garment business, feel uncomfortable with the heat, 63% of employees in business D, which is also a garment business, feel uncomfortable with the heat. Looking at the survey results in general, 44.3% of the workers in the textile and apparel industry saw high temperatures as a disturbing factor affecting their productivity. Crosstab values related to the temperature of companies are given in table 1. As seen in table 2, because the Chi-Square value of the high temperature in the companies is lower than 0.05, the temperature factor differs significantly according to the companies.

Table 1

| HIGH TEMPERATURE OF THE ENVIRONMENT ACCORDING TO THE FACILITIES CROSSTAB | | | | | |
|---|---|---|---|---|---|
| **Studied companies** | | | **Temperature** | | **Total** |
| | | | **Present** | **Absent** | |
| Company | Company A | Count | 83 | 75 | 158 |
| | | % within company | 52.5% | 47.5% | 100.0% |
| | | % within temperature | 23.2% | 16.6% | 19.5% |
| | | % of total | 10.3% | 9.3% | 19.5% |
| | Company B | Count | 85 | 84 | 169 |
| | | % within company | 50.3% | 49.7% | 100.0% |
| | | % within temperature | 23.7% | 18.6% | 20.9% |
| | | % of total | 10.5% | 10.4% | 20.9% |
| | Company C | Count | 81 | 228 | 309 |
| | | % within company | 26.2% | 73.8% | 100.0% |
| | | % within temperature | 22.6% | 50.6% | 38.2% |
| | | % of total | 10.0% | 28.2% | 38.2% |
| | Company D | Count | 109 | 64 | 173 |
| | | % within company | 63.0% | 37.0% | 100.0% |
| | | % within temperature | 30.4% | 14.2% | 21.4% |
| | | % of total | 13.5% | 7.9% | 21.4% |
| Total | | Count | 358 | 451 | 809 |
| | | % within company | 44.3% | 55.7% | 100.0% |
| | | % within temperature | 100.0% | 100.0% | 100.0% |
| | | % of total | 44.3% | 55.7% | 100.0% |

Table 2

| HIGH TEMPERATURE OF THE ENVIRONMENT ACCORDING TO COMPANIES CHI-SQUARE TESTS | | | |
|---|---|---|---|
| **Indicator** | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| Pearson Chi-Square | 72.313[a] | 3 | 0.000 |
| Likelihood Ratio | 74.380 | 3 | 0.000 |
| Linear-by-Linear Association | 0.073 | 1 | 0.786 |
| N of Valid Cases | 809 | | |

Note: [a] 0 cells (0,0%) have an expected count less than 5; the minimum expected count is 69.92.

### Evaluation of the noise factor of the environment according to the companies

In the survey, it was asked to employees if the noise in the business was at an uncomfortable level. 42.4% of the employees in business A, which is a textile business, said it was uncomfortable. Again, 37.3% of the employees in business B, which is a textile business, said it was at an uncomfortable level. While 54% of employees in facility C, which is a garment company, are disturbed by noise, 72.3% of employees in company D, which is also a garment company, are disturbed by noise. Considering the survey results in general, 52.2% of the workers in the textile and apparel industry saw the noise as a disturbing factor in the environment and one that affected their efficiency. Crosstab values related to noise belonging to companies are given in table 3. In table 4, since the Chi-Square value of the noise in the companies is lower than 0.05, the noise factor significantly differs according to the companies.

### Evaluation of the moisture rate factor of the environment according to the companies

In the survey, it was asked to employees if moisture in the business was at an uncomfortable level. 41.8% of the employees in business A, which is a textile business, said it was uncomfortable. 26.6% of the employees in B, which is also a textile business, said that the moisture was at an uncomfortable level. While 5.8% of the employees in facility C, which is a garment company, feel uncomfortable with the moisture rate, 8.1% of employees in Company D, which is a garment company, are uncomfortable with the moisture rate. Considering the survey results in general, 17.7% of the workers in the textile and apparel industry saw moisture as a disturbing factor in the environment and affecting their productivity. Crosstab values related to the moisture of companies are given in table 5.

In table 6, since the Chi-Square value of the moisture in the companies is lower than 0.05, the moisture rate factor differs significantly according to the companies.

### Evaluation of the weak lighting factor of the environment according to companies

In the survey, it was asked to employees if the lighting in the business was uncomfortably bad. 1.9% of

Table 3

| CROSSTAB OF THE AMBIENT NOISE FACTOR ACCORDING TO THE COMPANIES | | | | | |
|---|---|---|---|---|---|
| **Studied companies** | | | **Noise** | | **Total** |
| | | | **Present** | **Absent** | |
| Company | Company A | Count | 67 | 91 | 158 |
| | | % within company | 42.4% | 57.6% | 100.0% |
| | | % within noise | 15.9% | 23.5% | 19.5% |
| | | % of total | 8.3% | 11.2% | 19.5% |
| | Company B | Count | 63 | 106 | 169 |
| | | % within company | 37.3% | 62.7% | 100.0% |
| | | % within noise | 14.9% | 27.4% | 20.9% |
| | | % of total | 7.8% | 13.1% | 20.9% |
| | Company C | Count | 167 | 142 | 309 |
| | | % within company | 54.0% | 46.0% | 100.0% |
| | | % within noise | 39.6% | 36.7% | 38.2% |
| | | % of total | 20,6% | 17.6% | 38.2% |
| | Company D | Count | 125 | 48 | 173 |
| | | % within company | 72.3% | 27.7% | 100.0% |
| | | % within noise | 29.6% | 12.4% | 21.4% |
| | | % of total | 15.5% | 5.9% | 21.4% |
| Total | | Count | 422 | 387 | 809 |
| | | % within company | 52.2% | 47.8% | 100.0% |
| | | % within noise | 100.0% | 100.0% | 100.0% |
| | | % of total | 52.2% | 47.8% | 100.0% |

employees at business A, a textile business, said they were uncomfortably weak. Again, 3.6% of employees at B, which is a textile business, said that the lighting was uncomfortably weak. While 4.2% of employees in facility C, which is a garment company, feel uncomfortable with the weakness of the lighting, 2.3% of employees in company D, which is also a garment company, feel uncomfortable with the weak lighting. Looking at the survey results in general, 3.2% of the workers in the textile and apparel industry saw weak lighting as a disturbing factor in the environment and affecting their efficiency. Crosstab values related to weak lighting belonging to companies are given in table 7. In table 8, it is seen that the weak lighting factor does not differ significantly according to the companies, since the Chi-Square value of weak lighting in the companies is higher than 0.05.

### Evaluation of bad ergonomy factor according to businesses

In the survey, it was asked to employees if ergonomy in the business was uncomfortably bad. 0.6% (only one person) of employees at firm A, a textile business, said it was uncomfortably bad. 0.6% of the employees in B, which is also a textile company, said that their working ergonomy was bad. While 4.5% of employees in business C, which is a garment business, feel uncomfortable with ergonamy, 4% of employees in business D, which is also a garment business, are uncomfortable with bad ergonamy.

Table 4

| Chi-SQUARE TESTS OF THE NOISE FACTOR OF THE ENVIRONMENT ACCORDING TO THE COMPANIES | | | |
|---|---|---|---|
| **Indicator** | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| Pearson Chi-Square | 49.459[a] | 3 | 0.000 |
| Likelihood Ratio | 50.736 | 3 | 0.000 |
| Linear-by-Linear Association | 38.613 | 1 | 0.000 |
| N of Valid Cases | 809 | | |

Note: [a] 0 cells (0,0%) have an expected count less than 5; the minimum expected count is 75.58.

Looking at the survey results in general, 2.8% of those working in the textile and apparel industry saw their working ergonomy as a disturbingly bad factor in the environment and affecting their productivity. Crosstab values related to bad ergonomy belonging to companies are given in table 9. In table 10, the bad ergonamy in the companies is significantly different from the bad ergonamy factor, as the Chi-Square value is lower than 0.05.

## DISCUSSION

The A and B enterprises, where the field studies were conducted, are the textile enterprises, and the C and D are apparel enterprises and they are the factories that have been producing for years. The purpose of this study is to improve the perspectives of the

Table 5

| CROSSTAB MOISTURE FACTOR OF THE ENVIRONMENT ACCORDING TO THE COMPANIES | | | | | |
|---|---|---|---|---|---|
| **Studied companies** | | | **Moisture** | | **Total** |
| | | | **Present** | **Absent** | |
| Company | Company A | Count | 66 | 92 | 158 |
| | | % within company | 41.8% | 58.2% | 100.0% |
| | | % within moisture | 46.2% | 13.8% | 19.5% |
| | | % of total | 8.2% | 11.4% | 19.5% |
| | Company B | Count | 45 | 124 | 169 |
| | | % within company | 26.6% | 73.4% | 100.0% |
| | | % within moisture | 31.5% | 18.6% | 20.9% |
| | | % of total | 5.6% | 15.3% | 20.9% |
| | Company C | Count | 18 | 291 | 309 |
| | | % within company | 5.8% | 94.2% | 100.0% |
| | | % within moisture | 12.6% | 43.7% | 38.2% |
| | | % of total | 2.2% | 36.0% | 38.2% |
| | Company D | Count | 14 | 159 | 173 |
| | | % within company | 8.1% | 91.9% | 100.0% |
| | | % within moisture | 9.8% | 23.9% | 21.4% |
| | | % of total | 1.7% | 19.7% | 21.4% |
| Total | | Count | 143 | 666 | 809 |
| | | % within company | 17.7% | 82.3% | 100.0% |
| | | % within moisture | 100.0% | 100.0% | 100.0% |
| | | % of total | 17.7% | 82.3% | 100.0% |

Table 6

| CHI-SQUARE TESTS FOR THE MOISTURE FACTOR OF THE ENVIRONMENT ACCORDING TO THE COMPANIES | | | |
|---|---|---|---|
| **Indicator** | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| Pearson Chi-Square | 113.090[a] | 3 | 0,000 |
| Likelihood Ratio | 109.587 | 3 | 0.000 |
| Linear-by-Linear Association | 93.519 | 1 | 0.000 |
| N of Valid Cases | 809 | | |

Note: [a] 0 cells (0,0%) have an expected count less than 5; the minimum expected count is 27.93.

employees and business management of these four enterprises in terms of the concept of occupational health and safety. Noise, temperature, humidity and lighting, which are physical risk factors, revealed the current situation of A, B, C and D businesses as environmental risks together with bad ergonomics. In the survey conducted for the study, it was asked whether the ambient conditions in the textile and apparel companies affect the employees negatively or not. According to the results of the statistical analysis made on the answers, it was analyzed that high temperature, noise, moisture and bad ergonomy differ significantly, that is, they affect the employees negatively, and weak lighting does not affect the employees as they do not differ significantly. It has been evaluated that the humidity value due to the working environment is high and inconvenient in A and B textile enterprises, the ergonomics is poor in C and D apparel enterprises due to repetitive movements and inappropriate postures, and the lighting is generally weak in all four enterprises.

According to the graphics created to compare the ambient conditions of the companies within themselves:

- The high temperature most negatively affected the employees in the D company (figure 1). The ambient temperature of the textile companies is higher than the ambient temperature of the garment companies. Despite this, the disturbance of the temperature at a higher rate in Company D, which is a garment company, indicates that the temperature is a problem that needs to be solved in D company.
- Noise most negatively affected employees in Company D (figure 2). As can be seen from the

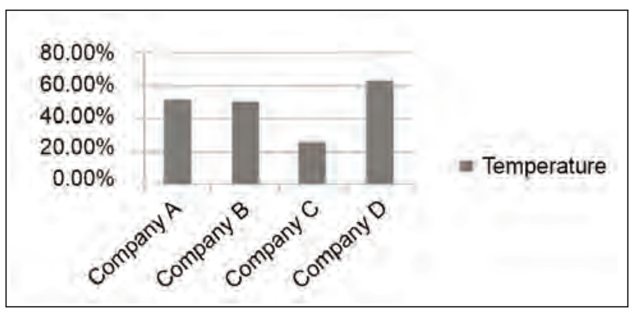


Fig. 1. Companies and temperature

Table 7

| CROSSTAB OF THE AMBIENT WEAK LIGHTING FACTOR ACCORDING TO THE COMPANIES | | | | | |
|---|---|---|---|---|---|
| **Studied companies** | | | **Weak lighting** | | **Total** |
| | | | **Present** | **Absent** | |
| Company | Company A | Count | 3 | 155 | 158 |
| | | % within company | 1.9% | 98.1% | 100.0% |
| | | % within weak lighting | 11.5% | 19.8% | 19.5% |
| | | % of total | 0.4% | 19.2% | 19.5% |
| | Company B | Count | 6 | 163 | 169 |
| | | % within company | 3.6% | 96.4% | 100.0% |
| | | % within weak lighting | 23.1% | 20.8% | 20.9% |
| | | % of total | 0.7% | 20.1% | 20.9% |
| | Company C | Count | 13 | 296 | 309 |
| | | % within company | 4.2% | 95.8% | 100.0% |
| | | % within weak lighting | 50.0% | 37.8% | 38.2% |
| | | % of total | 1.6% | 36.6% | 38.2% |
| | Company D | Count | 4 | 169 | 173 |
| | | % within company | 2.3% | 97.7% | 100.0% |
| | | % within weak lighting | 15.4% | 21.6% | 21.4% |
| | | % of total | 0.5% | 20.9% | 21.4% |
| Total | | Count | 26 | 783 | 809 |
| | | % within company | 3.2% | 96.8% | 100.0% |
| | | % within weak lighting | 100.0% | 100.0% | 100.0% |
| | | % of total | 3.2% | 96.8% | 100.0% |

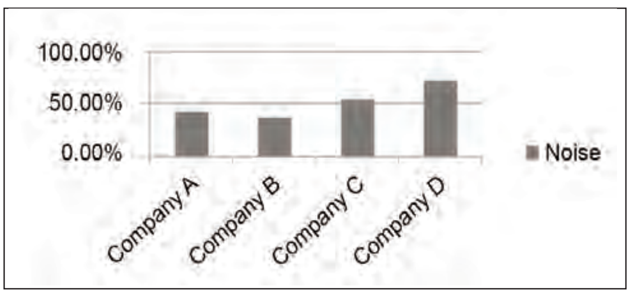


Fig. 2. Companies and noise

graph, the noise mostly affects the workers in the apparel companies negatively. The source of this noise is hundreds of sewing machines working at the same time.

- Moisture had the highest rate of affecting the employees in the A company (figure 3). Yarn, dyeing and finishing departments are the parts of the companies with the highest moisture. Employees of company A work intensively in these departments. Compared to company B, the rate of being disturbed by moisture is very high in company A. For this reason, improvement studies should be carried out regarding moisture in company A.

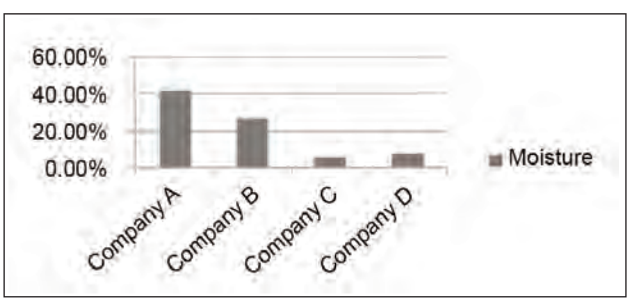


Fig. 3. Companies and moisture

Table 8

| CHI-SQUARE TESTS OF THE WEAK LIGHTING FACTOR OF THE ENVIRONMENT ACCORDING TO THE COMPANIES | | | |
|---|---|---|---|
| **Indicator** | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| Pearson Chi-Square | 2.372[a] | 3 | 0.499 |
| Likelihood Ratio | 2.481 | 3 | 0.479 |
| Linear-by-Linear Association | 0.155 | 1 | 0.694 |
| N of Valid Cases | 809 | | |

Note: [a] 0 cells (0,0%) have an expected count less than 5; the minimum expected count is 5.08.

- Weak lighting rate is low for all businesses (figure 4). As it did not differ significantly in statistical analysis, it was analyzed that it did not affect the employees negatively.
- Bad ergonomy was seen at the highest rate in C and D companies, which are garment businesses (figure 5). Ergonomy is very important for the employees of apparel businesses since most of the workers in apparel businesses work long hours.

Table 9

| CROSSTAB FACTOR OF BAD ERGONOMY OF THE ENVIRONMENT ACCORDING TO THE COMPANIES | | | | | |
|---|---|---|---|---|---|
| **Studied companies** | | | **Bad ergonomy** | | **Total** |
| | | | **Present** | **Absent** | |
| Company | Company A | Count | 1 | 157 | 158 |
| | | % within company | 0.6% | 99.4% | 100.0% |
| | | % within bad ergonomy | 4.3% | 20.0% | 19.5% |
| | | % of total | 0.1% | 19.4% | 19.5% |
| | Company B | Count | 1 | 168 | 169 |
| | | % within company | 0.6% | 99.4% | 100.0% |
| | | % within bad ergonomy | 4.3% | 21.4% | 20.9% |
| | | % of total | 0.1% | 20.8% | 20.9% |
| | Company C | Count | 14 | 295 | 309 |
| | | % within company | 4.5% | 95.5% | 100.0% |
| | | % within bad ergonomy | 60.9% | 37.5% | 38.2% |
| | | % of total | 1.7% | 36.5% | 38.2% |
| | Company D | Count | 7 | 166 | 173 |
| | | % within company | 4.0% | 96.0% | 100.0% |
| | | % within bad ergonomy | 30.4% | 21.1% | 21.4% |
| | | % of total | 0.9% | 20.5% | 21.4% |
| Total | | Count | 23 | 786 | 809 |
| | | % within company | 2.8% | 97.2% | 100.0% |
| | | % within bad ergonomy | 100.0% | 100.0% | 100.0% |
| | | % of total | 2.8% | 97.2% | 100.0% |

Table 10

| CHI-SQUARE TESTS OF THE BAD ERGONOMY FACTOR OF THE ENVIRONMENT ACCORDING TO THE COMPANIES | | | |
|---|---|---|---|
| **Indicator** | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| Pearson Chi-Square | 9.988[a] | 3 | 0.019 |
| Likelihood Ratio | 12.129 | 3 | 0.007 |
| Linear-by-Linear Association | 7.016 | 1 | 0.008 |
| N of Valid Cases | 809 | | |

Note: [a] 3 cells (37,5%) have an expected count of less than 5; the minimum expected count is 4.49.

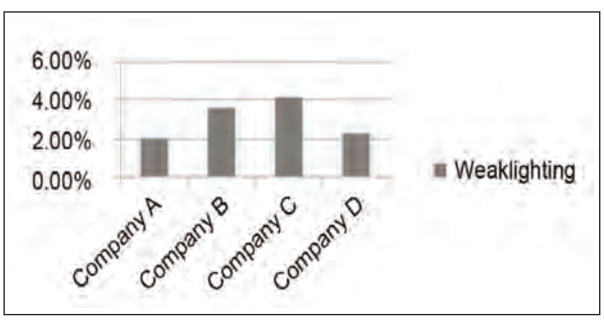


Fig. 4. Companies and weak lighting

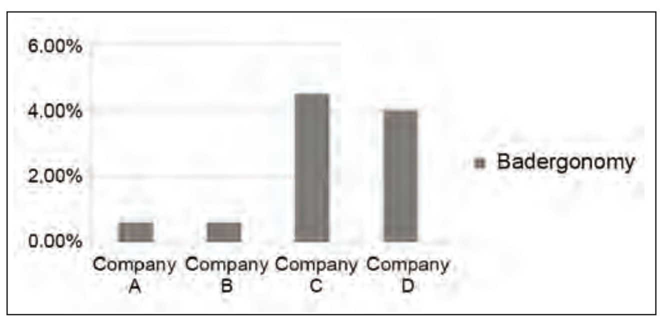


Fig. 5. Companies and bad ergonomy

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# The role evolution of textile industry in China's economy during 2002–2020: an input-output analysis

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**ABSTRACT – REZUMAT**

**The role evolution of textile industry in China's economy during 2002–2020: an input-output analysis**

*This paper uses the input-output (I-O) model to evaluate industry linkages and industry spread of China's textile industry (CTI) to investigate the role evolution of CTI in China's economy during 2002–2020. The research results show that: (1) the role of CTI in China's economy is on a declining trend and its share in the industrial sectors is shrinking; (2) CTI has long and high backward linkages with the upstream agriculture, chemistry and wholesale & retail and high forward linkages with the downstream garment, papermaking and culture, chemistry and health; these connections are becoming closer and closer; (3) the power of dispersion and the power of dispersion index of CTI has been greater than the sensitivity of dispersion and sensitivity of dispersion index for a long time; it indicates that CTI is still the sector that drives China's economic growth; (4) the final demand effect shows CTI has always been the most dependent on net exports, followed by consumption and investment and it's still an export-oriented industry. Finally, some relevant policy suggestions are put forward.*

***Keywords:*** *China's textile industry, role evolution, input-output model, industry linkage, industry spread*

**Evoluția rolului industriei textile în economia Chinei în perioada 2002–2020: o analiză input-output**

*Această lucrare utilizează modelul input-output (I-O) pentru a evalua legăturile și răspândirea industriei textile din China (CTI), pentru a investiga evoluția rolului CTI în economia Chinei în perioada 2002–2020. Rezultatele studiului arată că: (1) rolul CTI în economia Chinei are o tendință de scădere și ponderea sa în sectoarele industriale este în scădere; (2) CTI a avut de multă vreme legături strânse cu agricultura, industria chimică și comerțul cu ridicata și cu amănuntul pe pieţele din amonte și legături strânse cu industria de îmbrăcăminte, fabricarea hârtiei și cultura, industria chimică și sănătatea pe pieţele din aval; aceste legături devin din ce în ce mai strânse; (3) puterea de dispersie și puterea indicelui de dispersie al CTI au fost mai mari decât sensibilitatea de dispersie și sensibilitatea indicelui de dispersie pentru o lungă perioadă de timp; aceasta indică faptul că CTI este în continuare sectorul care stimulează creșterea economiei Chinei; (4) influența cererii finale arată că CTI a fost întotdeauna cea mai dependentă de exporturile nete, urmată de consum și investiții și este încă o industrie orientată spre export. În cele din urmă, sunt prezentate câteva sugestii relevante privind politicile de dezvoltare.*

***Cuvinte-cheie****: industria textilă din China, evoluția rolului, model input-output, legătura dintre industrii, răspândirea industriei*

## INTRODUCTION

The textile industry has been traditionally positioned as the pillar industry of China's national economy. It plays an important role in promoting economic growth, absorbing labour and expanding exports. In 2020, the prime operating revenue above the designated size of China's textile industry (CTI for short, hereafter) is approximately 2.35 trillion CNY. Textile enterprises directly employed about 2.86 million people and the exports amounted to approximately 280 billion USD. All the figures above show that CTI is the largest in the world. However, it should also be noted that although the gross output of CTI in 2020 increased nearly 4.35 times compared to 2001, its share in the industrial sectors fell from 5.76% in 2001 to 2.17% in 2020 and its ranking also dropped sharply from 5th to 16th. As a typical labour-intensive industry, the absorption of labour by CTI is also declining significantly. Until 2008, CTI has been the sector absorbing the largest labour in the industrial sectors, but its ranking has gradually dropped to the 9th by 2020. These evidences show that CTI is being overtaken by other industrial sectors and its position in the national economy is declining. So, what are the characteristics of the evolution of CTI's role in China's economy since the beginning of the 21st century? What's the impact of its role evolution on the national economic sectors? Answering these questions is essential to re-examine the role of CTI in China's economy and further promote the coordinated development of CTI and other sectors of the national economy.

In the early days of research on the role of an industry in the national economy, academics usually used indicators such as gross output, the number of employees etc. to conduct qualitative and descriptive analyses. With its continuous improvement, the input-output (I-O) method has been gradually applied to study the role played by industry in the national economy. The I-O method was established by economist Leontief in the 1930s [1] to quantitatively analyse the inter-industrial relationship of a specific country or region. Now it's widely used to solve a variety of practical economic problems, such as economic planning and forecasting. When analysing the role of an industry in the national economy, industry linkages and industry spread are commonly used as measures. Industry linkages refer to the technological correlation between an industry and its upstream and downstream industries with various inputs and outputs as the connecting link. Industry spread is when a change in an industry causes a change in the industries associated with it. By evaluating industry linkages and industry spread of a specific industry, it is beneficial to analyse its operation status and role in the national economy and further formulate related industrial policies to promote the coordinated development of national economic sectors.

Considerable research has analysed the roles of different industries in the economy at national and regional levels. At the national level, Kwak [2], Morrissey [3] and Wan [4] investigated the role changes of the marine industry in the economies of South Korea, Ireland and China respectively. Khanal [5] studies the impact of the tourism industry on Laos' economy. At the regional level, San [6], Rong [7] and Kelly [8] assessed the industry linkages and industry spread of the mining industry of Region II in Chile, the maritime industry in Taiwan, China and the aerospace industry in Florida, USA respectively. In addition, there were also studies using I-O tables from multiple countries to perform international comparisons for specific industries. Huang [9] analysed and compared the industry linkages and industry spread of China's steel industry with Germany, Britain, Japan and the United States to study the change of their positions in national economies. Gaygysyz [10] conducted comparative research on different roles played by the marine industry in the national economies of Estonia and Finland. However, in the research of the textile industry, the I-O method has not been fully used. Existing research in this area was scarce and had many shortcomings. You [11] used input coefficients to analyse the industry linkages of China's textile and garment industry over the period 2002–2012. But You's study was not only flawed by incomplete selection of indicators and insufficient data timeliness, but also failed to conduct a separate study on the textile industry. Chang [12], Wang [13] and Zhang [14] studied industry linkages of CTI in 2005, 2010 and 2002–2012 respectively. However, these researches also suffered from a low number of indicators and poor data timeliness.

To bridge the gap, this paper uses 2002, 2007, 2012 and 2017 China Input-output (I-O) tables and the 2020 China I-O prolong table as the data source. The 2020 China I-O prolong table was published in 2022 and is the latest data available. This paper evaluates industry linkages and industry spread of CTI using the input-output (I-O) model to investigate CTI's role-play in China's economy and its evolution. The research is outlined as follows. First, this paper calculates the input and output coefficients of CTI to examine: (1) how much CTI is influenced by other sectors; and (2) how much impact CTI has on other sectors. Then it calculates the power of dispersion, sensitivity of dispersion and final demand effect of CTI to evaluate the industry spread of CTI. Finally, based on the first two parts of the study, this paper discusses the potential for implications from the results and some policy recommendations for the optimization and upgrading of CTI to promote the coordinated development of CTI with other national economic sectors.

## METHODOLOGY AND DATA SOURCES

### Methodology

*Industry linkages*

Industry linkages can be divided into backward linkage and forward linkage according to the production process. Backward linkage is to analyse the impact of a specific industry on those industries that supply it with products or services as their intermediate consumption from an input perspective. It's usually measured by direct input coefficient ($a_{ij}$) and its economic meaning is the value of product $i$ consumed in the production of per unit product $j$. Based on the I-O table, it is calculated by dividing the transaction flows between sectors $i$ and $j$ ($x_{ij}$) by the total output of sector $j$ ($x_j$). The direct input coefficient reflects the technological correlation between sectors $i$ and $j$, measured by intermediate input. The larger the coefficient is, the tighter the correlation between these two sectors is. The calculation formula is as follows:

$$a_{ij} = \frac{x_{ij}}{x_j} \quad (i, j = 1, 2, ..., n) \tag{1}$$

Forward linkage is to analyse the impact of a specific industry on those industries that use the industry's products or services as intermediate inputs from an output perspective. It's commonly measured by the direct output coefficient ($c_{ij}$) and is calculated by dividing the transaction flows between sectors $i$ and $j$ ($x_{ij}$) by the gross output in sector $i$ ($x_i$). The larger the coefficient is, the more intermediate products in sector $i$ supplied to sector $j$ are. The calculation formula is as follows:

$$c_{ij} = \frac{x_{ij}}{x_i} \quad (i, j = 1, 2, ..., n) \tag{2}$$

*Industry spread*

Industry spread is commonly analysed by the power of dispersion (PD) and power of dispersion index (PDI), the sensitivity of dispersion (SD), the sensitivity of dispersion index (SDI) and the final demand effect. PD refers to the impact on all the industries' gross output of the national economy when the final demand of a specific industry changes. It is calculated by the sum of every column of the Leontief inverse matrix, which reflects the demand for the gross output of the national economy as the final demand of sector $j$ increases per unit. The greater the PD of sector $j$, the more intermediate input to sector $j$ is supplied from other sectors. PDI ($r_j$) is the ratio of PD of sector $i$ to the average of all the sectors. The calculation formula is as follows:

$$r_j = \frac{\sum_{i=1}^{n} \bar{b}_{ij}}{\frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{n} \bar{b}_{ij}} \quad (i, j = 1, 2, \ldots, n) \qquad (3)$$

SD refers to the impact on the gross output of sector $i$ when each sector's final demand in the national economy changes. It is calculated by the sum of every row of the Leontief inverse matrix, which means the increase in the production of sector $j$ as the final demand of each sector in the national economy increases per unit. The greater the SD, the more intermediate input to other sectors supplied from sector $j$. SDI ($s_j$) is the ratio of SD of sector $j$ to the average of all the sectors. The calculation formula is as follows:

$$s_j = \frac{\sum_{j=1}^{n} \bar{b}_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} \bar{b}_{ij}} \quad (i, j = 1, 2, \ldots, n) \qquad (4)$$

Final demand consists of consumption, investment and net exports (the difference between exports and imports) according to I-O theory. Final demand effect refers to the impact of final demand on the gross output of sector $i$. It is generally measured by production induction and dependence coefficient. Production induction represents the production of sector $i$ induced by consumption, investment and net exports. It can be obtained by multiplying each row of the Leontief inverse matrix with the final demand column:

$$X_i^M = \sum_{j=1}^{n} \bar{b}_{ij}\, Y_j^M \quad (i, j = 1, 2, \ldots, n;\ M = 1, 2, 3) \qquad (5)$$

$X_i^M$ refers to the output of sector $i$ induced by final demand $M$. $Y_j^M$ refers to the value of final demand $M$ of sector $j$. $M = 1, 2, 3$ represents consumption, investment and net exports respectively.

The dependence coefficient ($DC_i^M$) is the ratio of the output of sector $i$ induced by final demand $M$ to that of all the sectors and is calculated as follows:

$$C_i^M = \frac{X_i^M}{\sum_{j=1}^{n} X_i^M} \quad (i = 1, 2, \ldots, n;\ M = 1, 2, 3) \qquad (6)$$

**Data sources**

All the data used in this paper are obtained from 2002, 2007, 2012 and 2017 China (I-O) tables and the 2020 China I-O prolong table released by China's National Bureau of Statistics. The textile industry discussed in this paper refers to the textile industry defined by the national economy classification standard (GB/T 4754-2011), excluding the garment industry.

## THE EVOLUTION OF CTI'S ROLE IN CHINA'S ECONOMY

Overall, CTI's role in China's economy shows a declining trend in the period of 2001–2020. In terms of industrial scale (figure 1), the gross output of CTI first grew from 540.1 billion CNY in 2001 to 4084.4 billion CNY in 2016, then began to decrease as the foreign demand for China's textile products weakened. It dropped to 2347.4 billion CNY in 2020 and is still nearly 4.35 times that of 2001. However, its share and ranking in the industrial sectors have been declining. Its share falls from 5.76% to 2.17% and its ranking drops significantly from 5th to 16th. In terms of employment (figure 2), the total number of employees of CTI grew from 3.01 million in 2001 to a maximum of 6.52 million in 2008 after China entered into WTO. Then it begins to decrease after the outbreak of the 2008 international financial crisis and CTI gradually optimizes industrial structure by eliminating outdated production capacity and industrial transfer. Its total number of employees dropped to 2.86 million in 2020 with a decrease of about 56.12%. Its share in the industrial sectors decreased from 7.84% to 3.69% and its ranking dropped from 1st in 2001 to 9th in 2020. In sum, until 2008, the gross output of CTI has been ranked around 7th in the industrial sectors and the number of employees has always been the

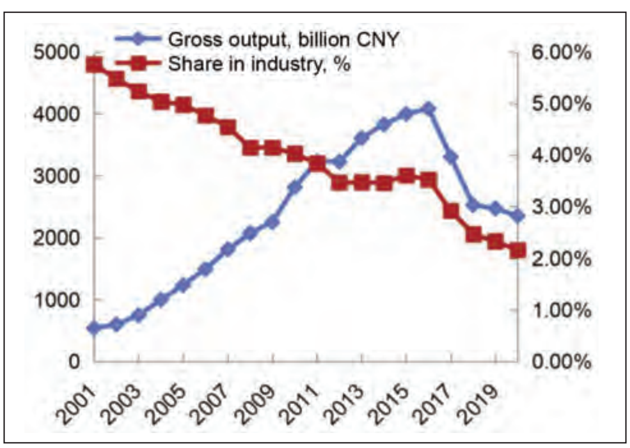


Fig. 1. CTI's gross output and its share in the industry

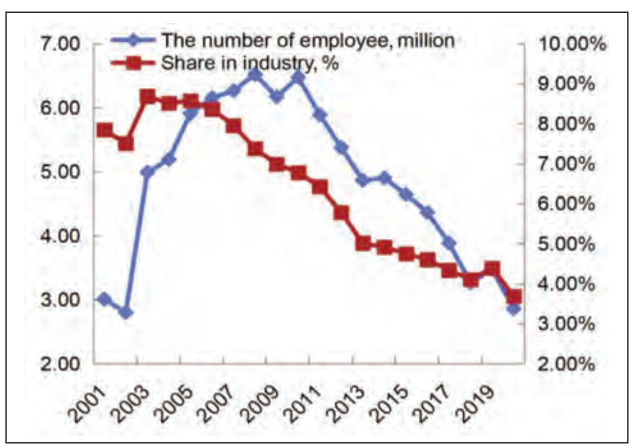


Fig. 2. CTI's employees and its share in the industry

largest. After that, both begin to decline gradually to 16th and 9th. It means that 2008 was the year when the role of CTI in the national economy changed significantly, which was largely related to the international financial crisis in 2008. Since then CTI has started industrial restructuring on a large scale, with the result that it has been continuously overtaken by other industrial sectors, both in terms of industrial scale and employment. As a result, the importance of CTI in the national economy is decreasing. And it is currently neither the sector that absorbs the most labour nor the main driver of national economic growth.

## INDUSTRY LINKAGES OF CHINA'S TEXTILE INDUSTRY

### Backward linkage

The top 5 sectors in the national economy that provide direct intermediate inputs for CTI are identified as shown in table 1. The sum of their direct input coefficients increased from 0.641 in 2002 to 0.746 in 2017, then decreased to 0.642 in 2020, indicating a fluctuant dependence of CTI on the top 5 sectors. In 2017 the top 5 were textile, agriculture, chemistry, post, information & software, which provided nearly 3/4 of the direct intermediate inputs for CTI's production. What's more, CTI has long maintained a higher backward linkage with itself, agriculture and chemistry during 2002–2020 and their direct input coefficients have always been in the top 3. The coefficient of CTI itself is always the largest, showing that the textile industry is the most dependent on its intermediate products. The reason is that the rapid development of manufactured textiles has increased the demand for intermediate products of CTI. For example, manufactured textiles consumed 33% of total fibre output in 2020, which exceeded household textiles (27%). The coefficients of agriculture and chemistry have always ranked 2nd and 3rd. This is because they provide the main raw materials such as natural fibre, chemical fibre and printing and dyeing agents for the production of CTI. It is worth noting that the coefficient of power, on the other hand, decreased from 0.022 (the 5th) in 2002 to 0.0001 (the 35th, not listed in table 1) in 2020. It implies that CTI has made significant improvements in energy saving and the restriction of power on CTI has been greatly weakened.

### Forward linkage

The sum of the direct output coefficients of the top 5 sectors gradually increased from 0.650 in 2002 to 0.690 in 2020 (table 2). It shows that the intermediate products of CTI are increasingly supplied to these sectors and the technological links between CTI and the top 5 are becoming stronger. Textile, garment, papermaking & culture and health are always among the top 5 sectors between 2012 and 2020. It means that textile products mainly flow into these downstream sectors and they have an increasing restriction on CTI's development. The coefficient of the garment had been rising from 0.210 in 2002 to 0.291 in 2020, which revealed that CTI was increasingly dependent on garments. The coefficient of papermaking & culture continuously increased from 0.013 (the 7th) in 2002 to 0.027 (the 3rd) in 2017, which showed that papermaking and culture were consuming more and more textile products. The increasing coefficient of health also indicates a growing demand for textiles. These are all beneficial to the development of CTI.

## INDUSTRY SPREAD OF CHINA'S TEXTILE INDUSTRY

### Power of dispersion and sensitivity of dispersion

The PD, PDI, SD and SDI of CTI all rose first and then fell throughout 2002–2020 (table 3). This means that both the pulling effect of CTI on China's economy and that of China's economy on CTI show an inverted U-shaped trend of growth followed by decline. In 2020, the PD and SD of CTI ranked 9th and 12th in the industrial sectors respectively, slightly higher than their share rankings. In contrast, except for 2012, the PD and PDI of CTI have been greater than the SD and SDI for a long time. It suggests that the pulling effect of CTI on China's economy is always stronger than that of China's economy on CTI. So it can be concluded that although the share and ranking of CTI in China's economy are gradually declining, it's still an important supporting industry that drives the growth of China's economy.

Table 1

DIRECT INPUT COEFFICIENT OF CTI DURING 2002–2020 (TOP 5 SECTORS)

| Sectors | 2002 | Sectors | 2007 | Sectors | 2012 | Sectors | 2017 | Sectors | 2020 |
|---|---|---|---|---|---|---|---|---|---|
| Textile | 0.339 | Textile | 0.383 | Textile | 0.410 | Textile | 0.374 | Textile | 0.354 |
| Agriculture | 0.133 | Agriculture | 0.144 | Agriculture | 0.176 | Agriculture | 0.185 | Agriculture | 0.121 |
| Chemistry | 0.105 | Chemistry | 0.120 | Chemistry | 0.099 | Chemistry | 0.111 | Chemistry | 0.088 |
| Wholesale & retail | 0.042 | Power | 0.023 | Information & Software | 0.037 | Post | 0.039 | Agricultural service | 0.045 |
| Power | 0.022 | Garment | 0.017 | Water | 0.019 | Information & Software | 0.036 | Wholesale & retail | 0.035 |
| Total | 0.641 | Total | 0.686 | Total | 0.742 | Total | 0.746 | Total | 0.642 |

Table 2

| DIRECT OUTPUT COEFFICIENT OF CTI DURING 2002–2020 (TOP 5 SECTORS) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sectors** | **2002** | **Sectors** | **2007** | **Sectors** | **2012** | **Sectors** | **2017** | **Sectors** | **2020** |
| Textile | 0.339 | Textile | 0.383 | Textile | 0.410 | Textile | 0.374 | Textile | 0.354 |
| Garment | 0.210 | Agriculture | 0.074 | Garment | 0.286 | Garment | 0.350 | Garment | 0.291 |
| Other social services | 0.042 | Chemistry | 0.049 | Chemistry | 0.040 | Papermaking & culture | 0.027 | Shoe | 0.017 |
| Public administration | 0.039 | Water | 0.024 | Papermaking & culture | 0.031 | Chemistry | 0.017 | Health | 0.015 |
| Other manufacturing | 0.019 | Garment | 0.023 | Health | 0.009 | Health | 0.015 | Culture | 0.013 |
| Total | 0.650 | Total | 0.554 | Total | 0.776 | Total | 0.784 | Total | 0.690 |

Table 3

| THE PD, PDI, SD AND SDI OF CTI DURING 2002–2020 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Indicator** | **2002** | | **2007** | | **2012** | | **2017** | | **2020** | |
| | **Value** | **Ranking** | **Value** | **Ranking** | **Value** | **Ranking** | **Value** | **Ranking** | **Value** | **Ranking** |
| PD | 3.024 | 10 | 3.563 | 10 | 3.491 | 14 | 3.363 | 9 | 3.320 | 9 |
| PDI | 1.198 | 10 | 1.214 | 10 | 1.182 | 14 | 1.235 | 9 | 1.187 | 9 |
| SD | 2.938 | 14 | 3.355 | 13 | 3.562 | 13 | 3.019 | 12 | 2.965 | 12 |
| SDI | 1.164 | 14 | 1.143 | 13 | 1.206 | 13 | 1.109 | 12 | 1.081 | 12 |

**Final demand effect**

The production induction of consumption, investment and net exports all showed a growing trend from 2002 to 2020 (table 4), suggesting that the pulling effect of final demand on CTI is increasing. The production induction and dependence coefficient of net exports have always been the largest, followed by consumption and investment. This is also in line with the current situation that CTI is still an export-oriented industry. Meanwhile, it should also be noted that the dependence coefficient of net exports shows a slight decline, implying that CTI is gradually becoming less dependent on exports. The dependence coefficient of consumption fluctuates around 0.38, which means that only 38% of CTI's output flows into consumption. So under the background of the global spread of COVID-19 and US-China trade friction, with exports showing a certain degree of contraction, actively expanding domestic consumption is of great significance for optimizing CTI's demand structure and developing the domestic market is also vital for the future development of textile enterprises. The dependence coefficient of investment has always been minimal, indicating that the textile industry is the least dependent on investment and investment plays a minor role in driving the development of CTI.

Table 4

| THE FINAL DEMAND EFFECT OF CTI DURING 2002–2020 | | | |
|---|---|---|---|
| **Year** | **Final demand** | **Production induction** | **Dependence coefficient** |
| 2002 | Consumption | 429 | 0.383 |
| | Investment | 78 | 0.069 |
| | Net exports | 614 | 0.548 |
| 2007 | Consumption | 445 | 0.360 |
| | Investment | 91 | 0.074 |
| | Net exports | 700 | 0.566 |
| 2012 | Consumption | 475 | 0.373 |
| | Investment | 65 | 0.051 |
| | Net exports | 732 | 0.576 |
| 2017 | Consumption | 494 | 0.375 |
| | Investment | 80 | 0.061 |
| | Net exports | 743 | 0.564 |
| 2020 | Consumption | 537 | 0.377 |
| | Investment | 94 | 0.066 |
| | Net exports | 794 | 0.557 |

Note: The unit of production induction is billion CNY.

## CONCLUSIONS & POLICY SUGGESTIONS

This paper uses the I-O model to evaluate industry linkages and industry spread of the textile industry to investigate its role evolution in China's economy from 2002–2020. The research results are as follows:

The role of CTI in China's economy is in a downward trend and its share in the industrial sectors is also shrinking. In terms of industry linkages, CTI has long maintained high backward linkages with the upstream agriculture, chemistry and wholesale & retail and high forward linkages with the downstream garment, papermaking and culture, chemistry and health. And these connections are becoming closer and closer. It reveals the proper operation of these sectors is increasingly important for the development of CTI. In terms of industry spread, the power of dispersion and power of dispersion index of CTI has been greater than the sensitivity of dispersion and sensitivity of dispersion index for a long time, which indicates that the pulling effect of CTI on China's economy is always stronger than that of China's economy on CTI. CTI still drives the growth of China's economy. The estimate of the final demand effect shows CTI has always been most dependent on net exports, followed by consumption and investment and it's still an export-oriented industry.

Therefore, it should be fully recognized that although the importance of CTI in China's economy is declining, it still drives China's economic growth. The findings also suggest we should always put more emphasis on the close cooperation between CTI and its upstream and downstream key sectors, such as agriculture, chemistry, garment, papermaking and culture and health. Further, it is also important to actively expand domestic consumption, reduce the dependence on exports and optimize the demand structure so that CTI will play a better role in promoting the coordinated development of China's economy.


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# ANOVA and Tukey's interpretation of the innovative FPSE method applied to museum textiles

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**ABSTRACT – REZUMAT**

**ANOVA and Tukey's interpretation of the innovative FPSE method applied to museum textiles**

*The need to protect textile museum collections against pests has led to the use of pesticides. Pesticides can persist over time, thus leading to problems such as possible injury to museum staff. To address this problem, attempts have been made to obtain an overview of pesticide detection without destroying collections.*
*In this paper, a nondestructive method for the extraction and detection of three pesticides was optimised. The selection of the main parameters of the method was carried out using statistical analysis of the obtained data by applying one-way ANOVA and the Tukey test.*
*FPSE optimisation is performed by evaluating the following parameters: polymer selection (individual or mixture of polymers), acid catalyst (trifluoroacetic acid, acetic acid and hydrochloride acid), amount of polymer (1 g, 2.5 g or 5 g), polymerisation time (30 minutes, 120 minutes and 240 minutes), ultrasonic bath temperature (40°C and 70°C), type of bath used to obtain the sol-gel (ultrasonic bath, water bath with stirring and mechanical stirrer) and influence of the last steps of the preparation of the sol-gel solution. After the extraction system was optimized, statistical analysis was conducted to assess the influence of pesticide extraction time on FPSE and desorption from FPSE in ethyl acetate.*

***Keywords:*** *statistical analysis, coating, extraction methods, nondestructive, chromatography, polymer*

**Interpretare ANOVA și Tukey pentru o metodă FPSE inovatoare aplicată textilelor din muzee**

*Necesitatea de a proteja colecțiile muzeale textile împotriva dăunătorilor a dus la utilizarea pesticidelor. Pesticidele pot persista în timp, ducând la apariția unor probleme ce pot pune în pericol sănătatea personalului muzeelor. Pentru a rezolva această problemă, s-au făcut încercări de a obține o imagine de ansamblu asupra prezenței pesticidelor fără distrugerea colecțiilor.*
*În această lucrare, a fost optimizată o metodă nedistructivă pentru extracția și detecția a trei pesticide. Selectarea parametrilor principali ai metodei a fost efectuată utilizând analiza statistică a datelor obținute prin aplicarea ANOVA unidirecțională și a testului Tukey.*
*Optimizarea FPSE s-a realizat prin evaluarea următorilor parametri: selecția polimerului (individual sau amestec de polimeri), catalizatorul acid (acid trifluoracetic, acid acetic și acid clorhidric), cantitatea de polimer (1 g, 2,5 g sau 5 g), timpul de polimerizare (30 minute, 120 minute și 240 minute), temperatura băii cu ultrasunete (40°C și 70°C), tipul de baie utilizată pentru obținerea soluţiei sol-gel (baie cu ultrasunete, baie de apă cu agitare și agitator mecanic) și influența ultimelor etape de preparare a soluției sol-gel. După optimizarea sistemului de extracție, a fost efectuată o analiză statistică pentru a evalua influența timpului de extracție a pesticidelor pe FPSE și a desorbției de pe FPSE în acetat de etil.*

***Cuvinte-cheie:*** *analiză statistică, peliculizare, metode de extracție, nedistructiv, cromatografie, polimer*

## INTRODUCTION

Textile fibres are an excellent food source for microbes and insects [1–4]. Various types of pesticides have been used in museum collections, leading to the need to develop methods of extraction, separation, and quantification methods with micro- or even nondestructive characteristics.
From a statistical point of view, the present paper evaluates the possibility of developing a new method of quantifying pesticides that may be present in textile museum collections by coupling a new extraction method (fabric phase sorptive extraction, FPSE) [5] with gas chromatography and mass spectrometry (GC/MS) without prejudicing these collections, which show signs of fragility and deterioration over time. Pesticides have many negative effects on humans and the environment, and it is important and still necessary to develop accurate, sensitive, and robust extraction and analysis methods to determine the amount of pesticides and to maintain compliance with applicable laws. In general, sampling techniques most often involve swabbing, wipe-based sampling of the surfaces of samples or removing part of an object [6], which is important because there is no application in the scientific literature of this extraction

method for museum object analysis. FPSE is a new type of microextraction developed by Kabir and Furton [7]. FPSE uses the sol-gel coating technology developed by Chong et al. [8] to create an inherently porous inorganic-organic hybrid absorbent material that is chemically bonded to the matrix of a flexible and permeable substrate, typically a textile. Table 1 shows some of the applications of the FPSE technique.

The statistical analysis [13] of the results obtained for each stage of the optimization process of the developed analytical system was carried out using Excel and one-way ANOVA [14], followed by a post hoc analysis to highlight the different groups as an average. For this, Tukey's HSD (honestly significant difference) [15] test, a test based on the comparison of two-by-two groups at a confidence interval of 95%, was selected for this analysis.

In the case of the one-way ANOVA method, the following two hypotheses were established:

- Null hypothesis – H0: the obtained values are independent, without a significant difference.
- Alternative hypothesis – H1: the obtained values are dependent, with significant differences.

The two proposed hypotheses are verified by determining the Pearson coefficient, "p", at a 95% confidence interval [16], with $p > 0.05$ indicating that the null hypothesis is accepted: from a statistical point of view, the difference is not significant, and $p < 0.05$ indicates that the null hypothesis is rejected; from a statistical point of view, the difference is significant.

To perform the Tukey test, the *q*_Tukey value was determined by comparing groups pairwise, and then the standardized critical *q* value was determined based on the number of groups and degrees of freedom.

- If *q*-Tukey > *q*-critical, there is a significant difference.
- If *q*-Tukey < *q*-critical: there is an insignificant difference.

The calculation formula for the *q* value is presented as follows:

$$q\text{-Tukey} = \frac{M_i - M_j}{\sqrt{\frac{Ms_{intra}}{n}}} \quad (1)$$

where $M_i$, $M_j$ – means of the two compared groups, $Ms_{intra}$ is the intragroup mean square and $n$ is the number of measurements in the group.

## MATERIALS AND METHODS

The materials and reagents used were 100% cotton fabric, polymer (polyethylene glycol (PEG), dimethylpolysiloxane (PDMS), polylactic acid (PLA) and ethyl cellulose (EC)), and trimethoxymethylsilane (MTMS). The solvent used was methylene chloride: acetone (50/50: V/V), trifluoroacetic acid 5% water (TFA), acetic acid 5% water (AA), and hydrochloric acid 5% water (HCl). For the pesticide solutions, all reagents used were Pestanal® grades: malathion, methoxychlor, and permethrin (consisting of cis and trans isomers) as pesticides of interest and ethyl acetate as the solvent for the pesticide solution.

First, the sol-gel solution was prepared with 2.5 g of polymer, 2.5 ml of MTMS, 5 ml of solvent and 1 ml of 5% TFA. After the sol-gel solution was obtained, the textile support was cut into 5 cm × 5 cm pieces, which were immersed in the solution and allowed to polymerize. Thus, the Polymer-FPSE was obtained.

Fabric phase sorptive extraction of pesticides is achieved by introducing one square of 1 cm × 1 cm Polymer-FPSE into 1 ml of 100 ppm pesticide mix solution and keeping it for 30 minutes at room temperature. Next, the Polymer-FPSE was removed, left for 1 min at room temperature and then placed in 2 ml of ethyl acetate for pesticide extraction. After the extraction time, the solution was injected into the chromatographic system coupled with a mass spectrometer detector.

FPSE optimisation was performed by evaluating parameters such as polymer selection (individual or mixture of polymers), acid catalyst (trifluoroacetic acid, acetic acid and hydrochloride acid), amount of polymer (1 g, 2.5 g or 5 g), polymerisation time (30 minutes, 120 minutes and 240 minutes), ultrasonic bath temperature (40°C and 70°C), and type of bath used to obtain the sol-gel (ultrasonic bath, water bath with stirring and mechanical stirrer).

The last step in the preparation of the sol-gel solution was stirring the reaction vessel for 15 minutes at room temperature at a speed of 450 rpm using a mechanical stirrer, after which the obtained mixture

Table 1

APPLICATION OF THE FPSE TECHNIQUE (ADAPTED FROM ZILFIDOU ET AL.) [9]

| System | Support | Polymer | Sample | Reference |
|---|---|---|---|---|
| FPSE-HPLC-UV | Cellulose | PEG | Tapp water<br>Substituted phenols | [5] |
| FPSE-HS-GC-MS | Fibreglass | PDMDPS | Ambient air<br>Sex pheromone | [10] |
| FDSE-FI-FAAS | Polyester | PDMDPS | River water<br>Heavy metals | [11] |
| SE/GC–MS | Celluloses | CW/PTHF/PDMS | Vegetable<br>Organophosphorus pesticides | [12] |

was centrifuged for 5 minutes at a speed of 5000 rpm at 20°C. The influence of the last steps for sol-gel preparation is verified to obtain a shorter preparation method. To optimize FPSE, the influence of pesticide extraction time on FPSE and desorption from FPSE in ethyl acetate was also assessed.
A schematic representation of the process is presented in figure 1.

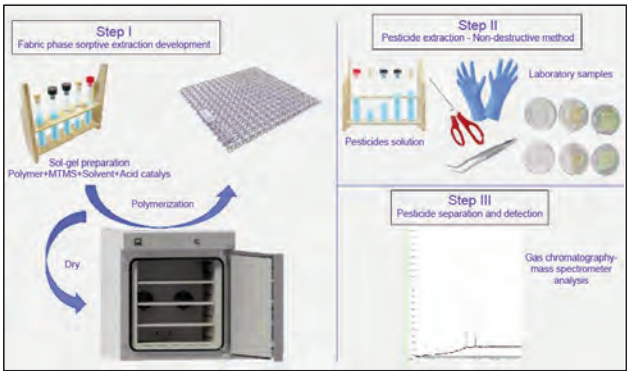


Fig. 1. Fabric phase sorptive extraction development

## RESULTS AND DISCUSSION

To facilitate the presentation of the results, in the case of the application of one-way ANOVA, the results will be interpreted in the form of “$p<0.05$” or “$p>0.05$”. In the case of the Tukey test, if there is a significant difference, the result will be noted with “S”, and if there is an insignificant difference, the result will be noted with “I”. To complete the statistical analysis, five measurements for each sample were performed.

### Polymer selection

The chromatographic peak area values of the polymers used in the study obtained after measurements are given in table 2 and the ANOVA results are given in table 3.
In all cases, $p < 0.05$ indicated a significant difference between groups.

Table 3

| ANOVA RESULTS FOR THE INFLUENCE OF POLYMER | |
|---|---|
| **Pesticides** | **P value between groups** |
| Malathion | p<0.05 |
| Methoxychlor | p<0.05 |
| cis-Permethrin | p<0.05 |
| trans-Permethrin | p<0.05 |

To evaluate which group was different, Tukey’s test was performed. Due to the substantial number of pairs (91 pairs) in table 4, only the results obtained for the pairs with PEG and PDMS, the polymers that presented the largest area (25 pairs), are presented.
The obtained results indicate significant differences for all the polymer variants used. Considering these differences, two individual polymers, PEG and PDMS, will be utilized, and the results obtained for these 2 variants will be evaluated. The notation of the extraction method in which PEG is used is PEG-FPSE, and that in which PDMS is used is PDMS-FPSE.

### Acid catalyst influence

The chromatographic peak area values of the acid catalysts used in the study obtained after measurements are given in table 5 and the ANOVA results are given in table 6.
Except for trans-permethrin, where the null hypothesis is accepted, meaning that the obtained values are independent, without a significant difference, for the remaining analytes of interest, the null hypothesis is rejected, indicating a significant difference. In the case of PEG-FPSE, the analysis of the sample with hydrochloric acid could not be performed, as the textile support was degraded. Thus, the interpretation will be performed using the results obtained after the application of one-way ANOVA. In this case, the comparison was made for PEG-AA vs. PEG-TFA. Tukey's

Table 2

| CHROMATOGRAPHIC PEAK AREA OBTAINED FOR POLYMER SELECTION | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Area** | **PEG** | **PDMS** | **PLA** | **EC** | **PEG/PDMS** | **PEG/PLA** | **PEG/EC** |
| Inj 1 | 1661 | 888 | 1609 | 1073 | 839 | 1277 | 1661 |
| Inj 2 | 1666 | 889 | 1630 | 1079 | 840 | 1276 | 1666 |
| Inj 3 | 1668 | 880 | 1618 | 1097 | 839 | 1289 | 1668 |
| Inj 4 | 1668 | 888 | 1579 | 1088 | 836 | 1252 | 1668 |
| Inj 5 | 1665 | 870 | 1578 | 1080 | 834 | 1243 | 1665 |
| **Area** | **PDMS/PLA** | **PDMS/EC** | **PLA/EC** | **PEG/PDMS/PLA** | **PEG/PDMS/EC** | **PDMS/PLA/EC** | **PEG/PDMS/PLA/EC** |
| Inj 1 | 527 | 1384 | 1266 | 798 | 1213 | 827 | 887 |
| Inj 2 | 523 | 1409 | 1273 | 799 | 1212 | 837 | 898 |
| Inj 3 | 527 | 1386 | 1303 | 796 | 1217 | 854 | 922 |
| Inj 4 | 546 | 1408 | 1318 | 806 | 1231 | 811 | 913 |
| Inj 5 | 539 | 1380 | 1288 | 798 | 1189 | 817 | 892 |

Note: Inj – injection number.

Table 4

| TUKEY TEST RESULTS FOR THE INFLUENCE OF POLYMERS | | | | |
|---|---|---|---|---|
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** | **trans-Permethrin** |
| PEG vs. PDMS | S | S | S | S |
| PEG vs. PLA | S | S | S | S |
| PEG vs. EC | S | S | S | S |
| PEG vs. PEG/PDMS | S | S | S | S |
| PEG vs. PEG/PLA | S | S | S | S |
| PEG vs. PEG/EC | S | S | S | S |
| PEG vs. PDMS/PLA | S | S | S | S |
| PEG vs. PDMS/EC | S | S | S | S |
| PEG vs. PLA/EC | S | S | S | S |
| PEG vs. PEG/PDMS/PLA | S | S | S | S |
| PEG vs. PEG/PDMS/EC | S | S | S | S |
| PEG vs. PDMS/PLA/EC | S | S | S | S |
| PEG vs. PEG/PDM/PLA/EC | S | S | S | S |
| PDMS vs. PLA | S | S | S | S |
| PDMS vs. EC | S | S | S | S |
| PDMS vs. PEG/PDMS | S | S | S | S |
| PDMS vs. PEG/PLA | S | S | S | S |
| PDMS vs. PEG/EC | S | S | S | S |
| PDMS vs. PDMS/PLA | S | S | S | S |
| PDMS vs. PDMS/EC | S | S | S | S |
| PDMS vs. PLA/EC | S | S | S | S |
| PDMS vs. PEG/PDMS/PLA | S | S | S | S |
| PDMS vs. PEG/PDMS/EC | S | S | S | S |
| PDMS vs. PDMS/PLA/EC | S | S | S | S |
| PDMS vs. PEG/PDM/PLA/EC | S | S | S | S |

Table 5

| CHROMATOGRAPHIC PEAK AREA OBTAINED FOR THE ACID CATALYST INFLUENCE | | | | | | |
|---|---|---|---|---|---|---|
| **Area** | **PEG-1 g** | **PEG-2.5 g** | **PEG-5 g** | **PDMS-1 g** | **PDMS-2.5 g** | **PDMS-5 g** |
| Inj 1 | 691 | 1499 | 916 | 625 | 1661 | 556 |
| Inj 2 | 652 | 1498 | 935 | 618 | 1666 | 539 |
| Inj 3 | 692 | 1494 | 898 | 601 | 1668 | 557 |
| Inj 4 | 651 | 1495 | 935 | 639 | 1668 | 571 |
| Inj 5 | 670 | 1488 | 926 | 637 | 1665 | 547 |

Note: Inj – injection number.

Table 6

| ANOVA RESULTS FOR THE ACID CATALYST INFLUENCE | | | | | |
|---|---|---|---|---|---|
| **Area** | **PEG-AA** | **PEG-TFA** | **PDMS-AA** | **PDMS-HCl** | **PDMS-TFA** |
| Inj 1 | 1009 | 1499 | 1171 | 913 | 1661 |
| Inj 2 | 1019 | 1498 | 1172 | 911 | 1666 |
| Inj 3 | 1039 | 1494 | 1182 | 941 | 1668 |
| Inj 4 | 1033 | 1495 | 1171 | 908 | 1668 |
| Inj 5 | 1047 | 1488 | 1183 | 933 | 1665 |

Note: Inj – injection number.

test was applied to the PDMS-FPSE samples for all analytes of interest.

As shown in table 7 and table 8, the only insignificant difference appears in the case of trans-permethrin: for both PDMS-FPSE and PEG-FPSE, both TFA and AA were present. For the remaining compounds, the differences are significant, and the type of acid used influences the results. Taking into account these results, ***trifluoracetic acid*** was further used.

Table 7

| TUKEY TEST RESULTS FOR THE ACID CATALYST INFLUENCE | | |
|---|---|---|
| **Pesticides** | **P value between groups** | |
| | **PEG – FPSE** | **PDMS – FPSE** |
| Malathion | p<0.05 | p<0.05 |
| Methoxychlor | p<0.05 | p<0.05 |
| cis-Permethrin | p<0.05 | p<0.05 |
| trans-Permethrin | p>0.05 | p<0.05 |

Table 8

| TUKEY TEST RESULTS FOR PDMS-FPSE | | | | |
|---|---|---|---|---|
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** | **trans-Permethrin** |
| PDMS-AA vs. PDMS-HCl | S | S | S | S |
| PDMS-AA vs. PDMS-TFA | S | S | S | I |
| PDMS-HCl vs. PDMS-TFA | S | S | S | S |

**Polymer quantity influence**

The chromatographic peak area values of the polymer quantity used in the study obtained after measurements are given in table 9 and the ANOVA results are given in table 10.

In all cases, $p<0.05$ resulting in a significant difference between groups (table 11).

Table 9

| CHROMATOGRAPHIC PEAK AREA OBTAINED FOR THE POLYMER QUANTITY INFLUENCE | | | | | | |
|---|---|---|---|---|---|---|
| **Area** | **PEG-1 g** | **PEG-2.5 g** | **PEG-5 g** | **PDMS-1 g** | **PDMS-2.5 g** | **PDMS-5 g** |
| Inj 1 | 691 | 1499 | 916 | 625 | 1661 | 556 |
| Inj 2 | 652 | 1498 | 935 | 618 | 1666 | 539 |
| Inj 3 | 692 | 1494 | 898 | 601 | 1668 | 557 |
| Inj 4 | 651 | 1495 | 935 | 639 | 1668 | 571 |
| Inj 5 | 670 | 1488 | 926 | 637 | 1665 | 547 |

Note: Inj – injection number.

Table 10

| ANOVA RESULTS FOR THE POLYMER QUANTITY INFLUENCE | | |
|---|---|---|
| **Pesticides** | **P value between groups** | |
| | **PEG – FPSE** | **PDMS – FPSE** |
| Malathion | p<0.05 | p<0.05 |
| Methoxychlor | p<0.05 | p<0.05 |
| cis-Permethrin | p<0.05 | p<0.05 |
| trans-Permethrin | p<0.05 | p<0.05 |

Table 11

| TUKEY TEST RESULTS FOR THE POLYMER QUANTITY INFLUENCE | | | | |
|---|---|---|---|---|
| **PEG-FPSE** | | | | |
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** | **trans-Permethrin** |
| PEG-1g vs PEG-2.5g | S | S | S | S |
| PEG-1g vs PEG-5g | S | S | S | S |
| PEG-2.5g vs PEG-5g | S | S | S | S |
| **PDMS-FPSE** | | | | |
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** | **trans-Permethrin** |
| PDMS-1g vs. PDMS-2.5g | S | S | S | S |
| PDMS-1g vs. PDMS-5g | S | S | S | I |
| PDMS-2.5g vs. PDMS-5g | S | S | S | S |

Except for PDMS-1g vs PDMS-5g for trans-permethrin, where the difference is insignificant, for the rest of the compounds, the amount of polymer used significantly influences the results, so the version with ***2.5 g polymer*** will be used for the following steps.

**Influence of polymerisation time**

The chromatographic peak area values of the polymerization time used in the study obtained after measurements are given in table 12 and the ANOVA results are given in table 13.

In all cases, $p<0.05$ indicated a significant difference between groups (table 14).

The only insignificant difference occurs in the case of PEG-120 minutes vs. PEG-240 minutes for methoxychlor because either of the two variants can be used for this compound. For the other compounds, the polymerization time led to significantly different results. For the subsequent experiments, the polymerization time was ***30 minutes***.

**Bath temperature influence**

The chromatographic peak area values of the bath temperature used in the study obtained after measurements are given in table 15 and the ANOVA results are given in table 16.

Given that the one-way ANOVA-test is initially applied for the evaluation of two groups (40°C and 70°C), it is no longer necessary to perform the Tukey test, and the statistical evaluation can be carried out based on the coefficient $p$.

Thus, in the case of cis-permethrin, the null hypothesis, H0, is accepted for both PEG-FPSE and PDMS-FPSE, and the obtained values are independent, without a significant difference. For the remaining compounds, the alternative hypothesis, H1, is accepted, and the obtained values are dependent, which shows significant differences. Next, for the PEG-FPSE and PDMS-FPSE variants, a ***temperature of 70ºC*** was used.

Table 12

CHROMATOGRAPHIC PEAK AREA OBTAINED FOR THE POLYMERIZATION TIME INFLUENCE

| Area | PEG - 30 minutes | PEG - 120 minutes | PEG - 240 minutes | PDMS - 30 minutes | PDMS - 120 minutes | PDMS - 240 minutes |
|---|---|---|---|---|---|---|
| Inj 1 | 2269 | 1499 | 1688 | 2578 | 1661 | 2136 |
| Inj 2 | 2253 | 1498 | 1671 | 2582 | 1666 | 2135 |
| Inj 3 | 2259 | 1494 | 1670 | 2561 | 1668 | 2136 |
| Inj 4 | 2231 | 1495 | 1671 | 2572 | 1668 | 2122 |
| Inj 5 | 2248 | 1488 | 1668 | 2544 | 1665 | 2116 |

Note: Inj – injection number.

Table 13

ANOVA RESULTS FOR THE POLYMERIZATION TIME INFLUENCE

| Pesticides | P value between groups | |
|---|---|---|
| | PEG – FPSE | PDMS – FPSE |
| Malathion | p<0.05 | p<0.05 |
| Methoxychlor | p<0.05 | p<0.05 |
| cis-Permethrin | p<0.05 | p<0.05 |
| trans-Permethrin | p<0.05 | p<0.05 |

Table 14

TUKEY TEST RESULTS FOR THE POLYMERIZATION TIME INFLUENCE

| TUKEY TEST RESULTS FOR PEG-FPSE | | | | |
|---|---|---|---|---|
| Pair | Malathion | Methoxychlor | cis-Permethrin | trans-Permethrin |
| PEG-30 minutes vs. PEG-120 minutes | S | S | S | S |
| PEG-30 minutes vs. PEG-240 minutes | S | S | S | S |
| PEG-120 minutes vs. PEG-240 minutes | S | I | S | S |
| **TUKEY TEST RESULTS FOR PDMS-FPSE** | | | | |
| Pair | Malathion | Methoxychlor | cis-Permethrin | trans-Permethrin |
| PDMS-30 minutes vs. PDMS-120 minutes | S | S | S | S |
| PDMS-30 minutes vs. PDMS-240 minutes | S | S | S | S |
| PDMS-120 minutes vs. PDMS-240 minutes | S | S | S | S |

Table 15

| CHROMATOGRAPHIC PEAK AREA OBTAINED FOR THE BATH TEMPERATURE INFLUENCE | | | | |
|---|---|---|---|---|
| **Area** | **PEG-40°C** | **PEG-70°C** | **PDMS-40°C** | **PDMS-70°C** |
| Inj 1 | 2643 | 2269 | 2352 | 2578 |
| Inj 2 | 2595 | 2253 | 2310 | 2582 |
| Inj 3 | 2660 | 2259 | 2296 | 2561 |
| Inj 4 | 2645 | 2231 | 2261 | 2572 |
| Inj 5 | 2633 | 2248 | 2356 | 2544 |

Note: Inj – injection number.

Table 16

| ANOVA RESULTS FOR THE BATH TEMPERATURE INFLUENCE | | |
|---|---|---|
| **Pesticides** | **P value between groups** | |
| | **PEG – FPSE** | **PDMS – FPSE** |
| Malathion | p<0.05 | p<0.05 |
| Methoxychlor | p<0.05 | p<0.05 |
| cis-Permethrin | p>0.05 | p>0.05 |
| trans-Permethrin | p<0.05 | p<0.05 |

**Bath type influence**

The chromatographic peak area values of the bath type used in the study obtained after measurements are given in table 17 and the ANOVA results are given in table 18.

In all cases, $p < 0.05$ indicated a significant difference between groups (table 19).

The type of bath used to make the sol-gel solution led to significant differences for all compounds, regardless of the type of polymers used (PEG or PDMS), except the compound cis-Permethrin. For this compound, there is an insignificant difference between PDMS-UB and PDMS-MS. Thus, for this analyte, either of the two options can be utilized. Considering the obtained results, an ***ultrasound bath*** was utilized.

**The final steps of sol-gel preparation influence**

The chromatographic peak area values of the last steps for sol-gel preparation used in the study obtained after measurements are given in table 20 and the ANOVA results are given in table 21.

In this case, the statistical analysis of the results will be carried out via one-way ANOVA:

– the null hypothesis, H0 (the obtained values are independent, without a significant difference), is accepted in the case of PEG-FPSE for trans-permethrin and in the case of PDMS-FPSE for malathion and cis-Permethrin.

– the alternative hypothesis, H1 (the obtained values are dependent, with significant differences) is accepted in the case of PEG-FPSE for malathion, methoxy-

Table 17

| CHROMATOGRAPHIC PEAK AREA OBTAINED FOR THE BATH TYPE INFLUENCE | | | | | | |
|---|---|---|---|---|---|---|
| **Area** | **PEG-UB** | **PEG-WB** | **PEG-MS** | **PDMS-UB** | **PDMS-WB** | **PDMS-MS** |
| Inj 1 | 2643 | 718 | 911 | 2578 | 622 | 2372 |
| Inj 2 | 2595 | 738 | 909 | 2582 | 619 | 2488 |
| Inj 3 | 2660 | 719 | 902 | 2561 | 610 | 2448 |
| Inj 4 | 2645 | 708 | 917 | 2572 | 614 | 2404 |
| Inj 5 | 2633 | 708 | 908 | 2544 | 643 | 2384 |

Note: Inj – injection number.

Table 18

| ANOVA RESULTS FOR THE BATH TYPE INFLUENCE | | |
|---|---|---|
| **Pesticides** | **P value between groups** | |
| | **PEG – FPSE** | **PDMS – FPSE** |
| Malathion | p<0.05 | p<0.05 |
| Methoxychlor | p<0.05 | p<0.05 |
| cis-Permethrin | p<0.05 | p<0.05 |
| trans-Permethrin | p<0.05 | p<0.05 |

Table 19

| TUKEY TEST RESULTS FOR THE BATH TYPE INFLUENCE | | | | |
|---|---|---|---|---|
| **TUKEY TEST RESULTS FOR PEG-FPSE** | | | | |
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** | **trans-Permethrin** |
| PEG-UB vs. PEG-WB | S | S | S | S |
| PEG-UB vs. PEG-MS | S | S | S | S |
| PEG-WB vs. PEG-MS | S | S | S | S |
| **TUKEY TEST RESULTS FOR PDMS-FPSE** | | | | |
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** | **trans-Permethrin** |
| PDMS-UB vs. PDMS-WB | S | S | S | S |
| PDMS-UB vs. PDMS-MS | S | S | I | S |
| PDMS-WB vs. PDMS-MS | S | S | S | S |

Table 20

| CHROMATOGRAPHIC PEAK AREA OBTAINED FOR THE SOL-GEL PREPARATION LAST STEPS INFLUENCE | | | | |
|---|---|---|---|---|
| **Area** | **PEG-long** | **PEG-short** | **PDMS-long** | **PDMS-short** |
| Inj 1 | 2643 | 2684 | 2578 | 2516 |
| Inj 2 | 2595 | 2757 | 2582 | 2666 |
| Inj 3 | 2660 | 2732 | 2561 | 2589 |
| Inj 4 | 2645 | 2708 | 2572 | 2550 |
| Inj 5 | 2633 | 2705 | 2544 | 2718 |

Note: Inj – injection number.

Table 21

| ANOVA RESULTS FOR THE SOL-GEL PREPARATION LAST STEPS INFLUENCE | | |
|---|---|---|
| **Pesticides** | **P value between groups** | |
| | **PEG – FPSE** | **PDMS – FPSE** |
| Malathion | p<0.05 | p>0.05 |
| Methoxychlor | p<0.05 | p<0.05 |
| cis-Permethrin | p<0.05 | p>0.05 |
| trans-Permethrin | p>0.05 | p<0.05 |

chlor and cis-permethrin, and in the case of PDMS-FPSE for methoxychlor and trans-permethrin. Considering these results, a ***short version*** of the method will be used, eliminating the last operations from the preparation of the sol-gel solution.

### Influence of pesticide extraction time

The chromatographic peak area values of the extraction-desorption time used in the study obtained after measurements are given in table 22 and the ANOVA results are given in table 23.

Table 22

| CHROMATOGRAPHIC PEAK AREA OBTAINED FOR EXTRACTION-DESORPTION TIME OF PESTICIDE INFLUENCE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | **PEG 30-30** | **PEG 30-60** | **PEG 30-120** | **PEG 60-30** | **PEG 60-60** | **PEG 60-120** | **PEG 120-30** | **PEG 120-60** | **PEG 120-120** |
| Inj 1 | 1074 | 658 | 693 | 724 | 898 | 1697 | 1107 | 883 | 950 |
| Inj 2 | 1072 | 678 | 701 | 753 | 910 | 1677 | 1132 | 912 | 990 |
| Inj 3 | 1100 | 672 | 707 | 759 | 905 | 1687 | 1126 | 899 | 982 |
| Inj 4 | 1092 | 667 | 693 | 739 | 898 | 1690 | 1112 | 890 | 975 |
| Inj 5 | 1095 | 643 | 699 | 731 | 894 | 1681 | 1102 | 883 | 966 |
| **Area** | **PDMS 30-30** | **PDMS 30-60** | **PDMS 30-120** | **PDMS 60-30** | **PDMS 60-60** | **PDMS 60-120** | **PDMS 120-30** | **PDMS 120-60** | **PDMS 120-120** |
| Inj 1 | 507 | 562 | 616 | 600 | 756 | 717 | 744 | 621 | 831 |
| Inj 2 | 530 | 568 | 638 | 621 | 769 | 752 | 795 | 671 | 891 |
| Inj 3 | 522 | 568 | 628 | 619 | 766 | 734 | 774 | 654 | 859 |
| Inj 4 | 512 | 544 | 609 | 606 | 761 | 723 | 764 | 643 | 841 |
| Inj 5 | 530 | 552 | 618 | 605 | 756 | 713 | 753 | 629 | 842 |

Note: Inj – injection number.

Table 23

| ANOVA RESULTS FOR THE EXTRACTION-DESORPTION TIME OF PESTICIDE INFLUENCE | | |
|---|---|---|
| **Pesticides** | **P value between groups** | |
| | **PEG – FPSE** | **PDMS – FPSE** |
| Malathion | p<0.05 | p<0.05 |
| Methoxychlor | p<0.05 | p<0.05 |
| cis-Permethrin | p<0.05 | p<0.05 |
| trans-Permethrin | p>0.05 | p<0.05 |

Except for PEG-FPSE, for trans-permethrin, $p < 0.05$ resulted in a significant difference between groups.
To facilitate the varying extraction times, the pairwise structure will be of the *x–y* type, where "x" represents the pesticide extraction time on the extraction system (PEG-FPSE or PDMS-FPSE) and "y" represents the pesticide extraction time on the system of extraction into the extraction solvent (ethyl acetate).
For example, 30–30 means that the FPSE is placed for 30 minutes on the lab sample and for another 30 minutes in the extraction solvent (table 24).

Table 24

| TUKEY TEST RESULTS FOR PEG-FPSE | | | |
|---|---|---|---|
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** |
| 30-30 vs. 30-60 | S | S | S |
| 30-30 vs. 30-120 | S | S | S |
| 30-30 vs. 60-30 | S | S | S |
| 30-30 vs. 60-60 | S | S | S |
| 30-30 vs. 60-120 | S | S | S |
| 30-30 vs. 120-30 | S | S | S |
| 30-30 vs. 120-60 | S | S | S |
| 30-30 vs. 120-120 | S | S | S |
| 30-60 vs. 30-120 | S | I | I |
| 30-60 vs. 60-30 | S | S | S |
| 30-60 vs. 60-60 | S | S | S |
| 30-60 vs. 60-120 | S | S | S |
| 30-60 vs. 120-30 | S | S | S |
| 30-60 vs. 120-60 | S | S | S |
| 30-60 vs. 120-120 | S | S | S |
| 30-120 vs. 60-30 | S | S | S |
| 30-120 vs. 60-60 | S | S | S |
| 30-120 vs. 60-120 | S | S | S |
| 30-120 vs. 120-30 | S | S | S |
| 30-120 vs. 120-60 | S | S | S |
| 30-120 vs. 120-120 | S | S | S |
| 60-30 vs. 60-60 | S | S | S |
| 60-30 vs. 60-120 | S | S | S |
| 60-30 vs. 120-30 | S | S | S |
| 60-30 vs. 120-60 | S | S | S |
| 60-30 vs. 120-120 | S | S | S |
| 60-60 vs. 60-120 | S | S | S |
| 60-60 vs. 120-30 | S | S | S |
| 60-60 vs. 120-60 | I | I | I |
| 60-60 vs. 120-120 | S | I | I |
| 60-120 vs. 120-30 | S | S | S |
| 60-120 vs. 120-60 | S | S | S |
| 60-120 vs. 120-120 | S | S | S |
| 120-30 vs. 120-60 | S | S | S |
| 120-30 vs. 120-120 | S | S | S |
| 120-60 vs. 120-120 | S | S | S |

Table 25

| TUKEY TEST RESULTS FOR PDMS-FPSE | | | | |
|---|---|---|---|---|
| **Pair** | **Malathion** | **Methoxychlor** | **cis-Permethrin** | **trans-Permethrin** |
| 30-30 vs. 30-60 | S | S | S | I |
| 30-30 vs. 30-120 | S | S | S | S |
| 30-30 vs. 60-30 | S | S | S | S |
| 30-30 vs. 60-60 | S | S | S | S |
| 30-30 vs. 60-120 | S | S | S | S |
| 30-30 vs. 120-30 | S | I | S | I |
| 30-30 vs. 120-60 | S | S | S | S |
| 30-30 vs. 120-120 | S | S | I | I |
| 30-60 vs. 30-120 | S | S | S | I |
| 30-60 vs. 60-30 | S | S | S | S |
| 30-60 vs. 60-60 | S | S | S | S |
| 30-60 vs. 60-120 | S | S | S | S |
| 30-60 vs. 120-30 | S | S | I | I |
| 30-60 vs. 120-60 | S | S | S | S |
| 30-60 vs. 120-120 | S | S | S | I |
| 30-120 vs. 60-30 | I | S | S | I |
| 30-120 vs. 60-60 | S | S | S | S |
| 30-120 vs. 60-120 | S | I | I | I |
| 30-120 vs. 120-30 | S | S | S | I |
| 30-120 vs. 120-60 | I | I | I | I |
| 30-120 vs. 120-120 | S | S | S | S |
| 60-30 vs. 60-60 | S | I | I | I |
| 60-30 vs. 60-120 | S | S | S | I |
| 60-30 vs. 120-30 | S | S | S | S |
| 60-30 vs. 120-60 | S | S | S | I |
| 60-30 vs. 120-120 | S | S | S | S |
| 60-60 vs. 60-120 | S | S | S | I |
| 60-60 vs. 120-30 | I | S | S | S |
| 60-60 vs. 120-60 | S | S | S | S |
| 60-60 vs. 120-120 | S | S | S | S |
| 60-120 vs. 120-30 | S | S | S | S |
| 60-120 vs. 120-60 | S | I | I | I |
| 60-120 vs. 120-120 | S | S | S | S |
| 120-30 vs. 120-60 | S | S | S | I |
| 120-30 vs. 120-120 | S | S | S | I |
| 120-60 vs. 120-120 | S | S | S | S |

As shown in table 25, most of the obtained results indicate significant differences, with *q*-Tukey > *q*-critic. For PEG-FPSE, the pesticide extraction time on FPSE was 60 minutes, and the pesticide desorption time from FPSE in ethyl acetate was 120 minutes.

For PDMS-FPSE, the pesticide extraction time on FPSE was 120 minutes, and the pesticide desorption time from FPSE in ethyl acetate was 120 minutes.

## CONCLUSIONS

In the present work, an innovative analytical system was developed and optimized based on nondestructive extraction and chromatographic analysis of the obtained samples. Fabric phase sorptive extraction was proposed for the determination of 3 pesticides (malathion, methoxychlor and permethrin: cis- and trans-isomers) that may be present in modern and contemporary textile objects. The evaluated parameters are listed as follows: polymer selection (individual or mixture of polymers), acid catalyst (trifluoroacetic acid, acetic acid and hydrochloride acid), amount of polymer (1 g, 2.5 g or 5 g), polymerisation time (30 minutes, 120 minutes and 240 minutes), ultrasonic bath temperature (40°C and 70°C), type of bath used to obtain the sol-gel (ultrasonic bath, water bath with stirring and mechanical stirrer) and the influence of the final steps of the preparation of the sol-gel solution. Moreover, the influence of pesticide extraction time on FPSE and desorption from FPSE in ethyl acetate was assessed.

The first step consisted of using one-way ANOVA, for which two hypotheses were issued: the null hypothesis (the obtained values are independent, without a significant difference) and the alternative hypothesis (the obtained values are dependent, with a significant difference). The two hypotheses were tested for a 95% confidence interval. When the alternative hypothesis was accepted and more than two groups of data were compared, Tukey's test was used to investigate which group showed different data, and depending on this result, the working parameter was selected.

By applying two statistical methods, the working parameters of the extraction system and the extraction of 3 pesticides of interest, namely, malathion, methoxychlor and permethrin (two cis- and trans-isomers), were selected.

This study provides new approaches for expanding scientific knowledge in the field of determining pesticides present in modern and contemporary textile objects and substantiates the performance of a new nondestructive method of extraction, separation, and detection of these compounds.


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# Exploring the factors influencing hesitation among textile industry weavers in adopting digital banking services in India

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**ABSTRACT – REZUMAT**

**Exploring the factors influencing hesitation among textile industry weavers in adopting digital banking services in India**

*These small textile weavers in this emerging country such as India have been hesitant to adopt digital banking methods. This is due to a lack of awareness and trust in digital payment systems, as well as a preference for traditional payment methods. Additionally, many small textile weavers lack the necessary infrastructure, such as smartphones and internet connectivity, to engage in digital banking. These challenges have created a barrier for small textile weavers to fully participate in India's growing digital economy. This study is an attempt not only to highlight the various realistic problems that are responsible for hesitation among textile weavers of India in the usage of digital banking but also to formulate a suitable model that could depict the significant variables that are responsible for the hesitation in the usage of digital banking among small textile weavers by using Step-wise regression method. The study relies on primary data collected by questionnaire from weavers in the top ten states in India based on residence and number of weavers, with 454 weavers participating from various states. The results of the study depict that there are 5 significant factors or predictors that are responsible for the hesitation among weavers of India in using e-banking namely a sense of insecurity due to cyber-crime, unaffordability of smartphones, lack of knowledge in operating smartphones, demonstration effect and network issues.*

***Keywords:*** *textile industry in India, weavers, digital banking, step-wise regression, demonstration effect*

**Examinarea factorilor care influențează atitudinea de ezitare în rândul specialiștilor din industria textilă în adoptarea serviciilor de banking digital în India**

*Acești mici specialiști din domeniul textil din această țară emergentă selectată, respectiv India, au ezitat să adopte metode bancare digitale. Acest lucru se datorează lipsei de conștientizare și încredere în sistemele de plată digitale, precum și preferinței pentru metodele tradiționale de plată. În plus, mulți țesători mici din industria textilă nu au infrastructura necesară, cum ar fi smartphone-urile și conexiunea la internet, pentru a se angaja în activități bancare digitale. Aceste provocări au creat o barieră pentru ca micii specialiști în țesătorie din industria textilă să participe pe deplin la economia digitală în creștere a Indiei. Acest studiu este o încercare nu numai de a evidenția diferitele probleme realiste care sunt responsabile de comportamentul de ezitare în rândul acestei categorii ocupaționale din India în utilizarea serviciilor bancare digitale, ci și de a formula un model adecvat care ar putea descrie variabilele semnificative care sunt responsabile pentru ezitarea în utilizarea serviciilor bancare digitale în rândul acestora prin utilizarea metodei de regresie de tip pas cu pas (step-wise). Studiul empiric se bazează pe datele primare colectate cu ajutorul chestionarului de la țesătorii din primele zece state din India, pe baza reședinței și a numărului de țesători, adică un număr de 454 de țesători participând din diferite state. Rezultatele studiului arată că există 5 factori sau predictori semnificativi care sunt responsabili pentru atitudinea de ezitare în rândul țesătorilor din India în utilizarea e-banking-ului și anume: sentimentul de insecuritate din cauza criminalității cibernetice, inaccesibilitatea telefoanelor inteligente, lipsa de cunoștințe în utilizarea telefoanelor mobile inteligente (smartphones), efectul demonstrativ și problemele de rețea.*

***Cuvinte cheie:*** *industria textilă din India, țesători, servicii bancare digitale, regresie de tip pas cu pas (step-wise), efect demonstrativ*

## INTRODUCTION

India has a rich history in the textile industry, with evidence of cotton cultivation and fabric production dating back to ancient times. The country is one of the world's leading producers of textiles and garments, and the sector contributes significantly to the Indian economy. In terms of textile and garment production, India ranks just behind China [1]. Moreover, this industry employs over 45 million people, making it one of the largest employers in the country. The sector contributes around 4% to India's GDP [2] and represents 14% of the total manufacturing output in the country. The textile and garment industry in India is divided into two main segments: the organised sector, which comprises large-scale manufacturing units, and the unorganised sector, which comprises small-scale producers and handloom weavers. The handloom sector, which is concentrated in rural areas, is an important source of employment and income for millions of people.

Textile weavers have played a crucial impact in the growth and development of the textile and garment industry in India. They are the backbone of the handloom sector, which is an important part of the Indian textile and garment industry. Textile weavers are skilled artisans who have been practising the craft of handloom weaving for centuries in India [3]. They are experts in weaving a variety of fabrics, including cotton, silk, and wool. The handloom sector in India employs over 4 million people, and the majority of them are weavers [4]. These weavers work in small-scale units, often from their homes, and produce a variety of handloom fabrics. Handloom fabrics are known for their unique designs and quality, and they have a significant demand both in domestic and international markets. The handloom sector in India contributes around 15% to the total cloth production in the country [5]. Textile weavers have preserved the traditional methods of handloom weaving in India, and they are an important link to the country's cultural heritage [6]. Their skills have been passed down from generation to generation, and they continue to create beautiful fabrics using age-old techniques. Their contributions to the textile industry in India are invaluable, and they are an essential part of the country's rich textile heritage.

However, small textile weavers in rural India face numerous challenges that impede their growth and development. Despite being skilled artisans, they struggle to make ends meet due to several factors beyond their control like lack of access to credit, limited market access, Competition from power loom and mill-made fabrics, lack of modern technology, low wages, and lack of training and education [7]. Similarly, even after the steps into the digital era by India where the digital banking section is considered the most successful attempt provoked by demonetization, these small weavers still hesitate to use digital banking, especially in rural India [8]. These small textile weavers in the country have been hesitant to adopt digital banking methods. This is due to a lack of awareness and trust in digital payment systems, as well as a preference for traditional payment methods. Additionally, many small textile weavers lack the necessary infrastructure, such as smartphones and internet connectivity, to engage in digital banking. These challenges have created a barrier for small textile weavers to fully participate in India's growing digital economy [9], highlighting the need for targeted education and support programs to help them overcome these obstacles.

## REVIEW OF LITERATURE

Several studies have examined the effects of online banking, and some of these objectives, locations, and sample sizes are described. The coefficients of the constructed model show that MSMEs benefit from the ease of accepting and making payments through digital banking. Managing company expenses, saving time, and preventing funds from being misappropriated are other benefits, but they are minor. Bankers aren't meeting the needs of these SMEs, so they aren't getting the most out of digital banking [10]. The results of an empirical study indicate that if the people of Uzbekistan had a better understanding of the advantages of online banking, its use would increase. Maintaining trust is crucial. As a result, we must resolve the prevailing security concerns. The role of the government in promoting the use of online banking is crucial [11]. A research team from the Manjula Department of Computer Science led by Vishnuvardhan et al. [12] analysed the threats to mobile device security that exist today. To transfer money from one mobile user account to another, SMS-based transaction schemes employ encrypted messages to communicate with the mobile network provider. Vishnuvardhan et al. [12] examined five hypothetical future standard categories of M-Banking services, identifying their known strengths and weaknesses. A bank is an authorised financial institution that takes customer deposits and lends money to small businesses, large corporations, and farms. For many sole proprietors, small farms, and independent contractors, cooperative banks remain their primary source of financing. All street banks are known as retail banks. However, “Its customers to enhance the limitation of space and time”, observes the authors.

Unquestionably, the widespread use of information and communication technologies has had an impact on the content and quality of banking operations. The Internet and other forms of electronic communication lie at the heart of this worldwide curve, acting as an absorber and a cooling force. Over the years, the advancement of information systems has brought about enormous changes in the Nigerian banking sector [13]. The MSMEs in Katihar are afraid that there is a possibility of fraud or hacking of bank accounts if they go for e-banking transactions. Few of the respondents feel that the transaction cost, limitation in the amount of accepting and making payments via e-wallets and lack of knowledge of using smart devices and digital banking are the restraints in using digital banking. It can be felt that more awareness and knowledge regarding digital banking should be provided by the bankers to the owners and managers. The Katihar District of Bihar has been surveyed using a questionnaire. 454 out of 600 people responded, for a 76% response rate. Cybercrime-related anxiety is followed by the requirement of high-tech gadgets to access online bank accounts. Many business owners avoid telling banks and governments about their financial dealings for fear of negative consequences [14]. In today's digital age, everyone has a mobile phone because it is such a ubiquitous piece of technology. Agents play a crucial role in the customer acquisition and liquidity management processes of mobile banking service providers. The Hamkor Bank, along with its international financial corporation and the Asian Development Bank, launched the Hamkor mobile platform in

May 2009, paving the way for the widespread use of mobile banking in Uzbekistan. Mobile banking needs to be used globally [15]. Electronic banking services have been slower to spread to underdeveloped nations than to those with more established economies. The results make it abundantly evident that more work needs to be done by the government in the areas of implementing financial-related regulations to protect bank customers' money, providing critical infrastructure, creating jobs for the youth, and encouraging the teaching of ICT in all institutions [16]. Complete digitalisation is a long-term goal. India is making progress, however slowly, in the correct way because the government is pushing it in the right direction. Among the less mysterious findings is the fact that a sizeable number of youngsters engage in digital transactions even though they may not be of legal age to do so. Based on this data, a set of recommendations for future development has been explored; these recommendations include things like digital biometric verification, the consolidation of several digital payment platforms, implicit redressal, shared wallets, etc. We propose a blockchain-based e-wallet service that incorporates simpler use, increased security, a decentralised network of transaction nodes, and a shared wallet, to bring in the adolescent population as regular digital users. Only the primary user can generate a dependent user's account in our blockchain-based shared wallet system, with complete control over the dependent user's spending limit. All participants can view the complete transaction history, and all transactions are reported to the primary user [17].

For financial institutions, mobile banking represents a less desirable alternative channel. It was anticipated that all respondent banks would have established a specific e-banking division, given that they have all been engaged in e-banking for at least the past six years. Sixty-seven per cent of the responding banks rely solely on internal business and technical staff for e-banking implementation and support, while thirty-three per cent work with external associates. This high percentage suggests, on the one hand, that banks have trained their employees and acquired the necessary technological know-how, and, on the other, that they may be hesitant to work with outside parties on systems of this nature [18]. According to research, patients with chronic pain disorders have more severe pain during periods of high relative humidity, high wind speed, and low atmospheric pressure. The relative humidity made the biggest impact. If the weather were to take a turn for the worst, the likelihood of a pain event would rise by a little over 20% compared to a normal day. Those with chronic pain may find this increased risk to be significant. Commercial banks in Malaysia can greatly benefit from implementing e-banking [19]. Commercial banks need to make a fundamental change to the way they do business by constantly introducing new ways of serving their customers, particularly in the areas of relationship building and two-way communication. In this new century, businesses must contend with a wide range of threats, including those posed by the environment, society, government, and the increasing influence of consumers.

**Research gap**

The existing literature was not enough to highlight the barriers or problems faced by the weavers of India in adopting e-banking. Moreover, there might be some hidden predictors in India that are responsible for the hesitant level which might not yet been explored by the existing related studies conducted on other developing countries like India. Hence, exploring the significant factors influencing hesitation among textile weavers in adopting digital banking services in India.

**Objectives of the study**

- To highlight the various realistic problems that are responsible for hesitation among small textile weavers of India in the usage of digital banking.
- To identify the significant reasons or problems that are affecting the hesitation in the usage of digital banking among small textile weavers
- To formulate a suitable model that could depict the significant variables that are responsible for the hesitation in the usage of digital banking among small textile weavers

## RESEARCH METHODOLOGY

This research makes use of empirical data. Primary data were used for analysis. A pilot survey of 20 weavers in the state of Odisha and 20 weavers in the state of West Bengal, has been conducted where some open-ended questions have been asked to explore various reasons that are creating hurdles for using weavers in using digital banking. It is also noted that most of the weavers, who are respondents of the study, are residing in rural areas of the states. After analysing the responses given by these 20 weavers in the state of Odisha and 20 weavers in the state of West Bengal, many reasons have been found that are responsible for the hesitation among weavers in using digital banking. These reasons are again inculcated while drafting the final questionnaire. The primary data were gathered with the aid of a bilingual questionnaire, written in both English and Hindi to ensure that all respondents could comprehend the questions. The questionnaire encompasses certain questions related to the personal profile of the weavers and, the opinion of these textile or handloom weavers regarding the various reasons that resist or discourage them from using digital banking on a Likert scale of 1 to 10. Additionally, a viewpoint on the degree of resistance among Indian weavers to using digital banking. An attempt has been made to collect data from 100 weavers from each of the top 10 states based on the number of weavers [20], by distributing a questionnaire in hard copies in some reachable states like Odisha, West Bengal and Jharkhand and by engaging some enumerators to collect data from remaining 7 states. The targeted sample size was 1000 i.e. 100 from each state. More respondents are being targeted to weed out those whose responses were either incomplete or whose data were deemed outliers for the study. Out of these 1000 targeted respondents, only 453 respondents have replied to the questionnaire which implies that the response rate was around 45%. The data was collected from December 2022 to April 2023. Step Wise Regression has been implemented to formulate a model that would represent the factors responsible for the hesitation among textile weavers of India in using digital banking.

### Need of the study

It is known that the textile industry is a crucial sector of the Indian economy, contributing significantly to the country's growth and development. However, despite the increasing digitization of banking services, many textile weavers in India continue to hesitate to adopt e-banking solutions. Understanding the reasons for this reluctance is essential to improve the accessibility and utilization of e-banking services among this segment of the population. Researching the factors responsible for hesitation among textile weavers in India to use e-banking can help policymakers and financial institutions identify the barriers to adoption and design effective interventions to promote the use of digital financial services. Some potential factors that may contribute to hesitation among textile weavers in India to use e-banking could include a lack of awareness and understanding of e-banking services, lack of access to digital devices or reliable internet connectivity, concerns about security and privacy, language barriers, and a preference for traditional banking methods. By identifying and addressing these factors, policymakers and financial institutions can create tailored solutions that address the unique needs of textile weavers in India and promote greater financial inclusion. Additionally, promoting the use of e-banking can enhance the efficiency of financial transactions, reduce the cost and time involved in traditional banking methods, and ultimately improve the financial well-being of textile weavers and their communities.

## ANALYSIS, RESULTS AND DISCUSSION

The pilot survey discloses many major reasons due to which the textile weavers hesitate to use E-banking. Those reasons are a Sense of Insecurity, not interested in disclosing transactions, unaffordability of smartphones, lack of knowledge in operating smartphones, demonstration effect, limited customer care support, transaction cost, network issues and language barrier. Again these reasons are considered as predictors and are regressed on the level of hesitation among textile weavers in using e-banking. This can be shown in the figure mentioned under the conceptual framework.

### Conceptual framework

The existence of a relationship between the predictors (independent variables) stated in the conceptual framework and the dependent variable i.e. level of hesitation among textile weavers in using e-banking is thoroughly explained in the hypotheses formulation section (figure 1).

### Hypotheses formulation

Textile weavers are hesitant to adopt e-banking for several reasons, many of which have a long-term impact. Following an analysis of the responses from the pilot survey, a subset of 20 weavers from the state of Odisha and a subset of 20 weavers from the

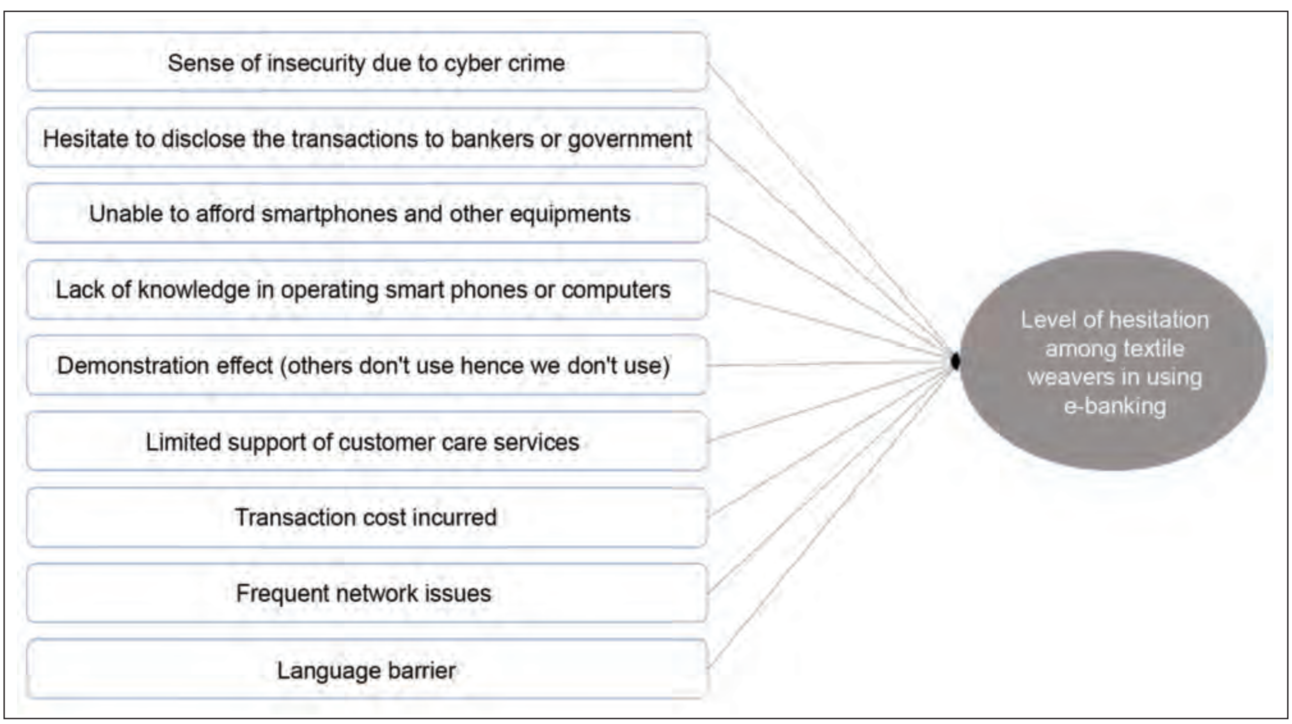


Fig. 1. Conceptual framework

state of West Bengal were chosen to provide input into the final model formulation.

*Sense of insecurity due to cyber-crime*

Even though e-banking has been widely adopted in developing countries like India, there is still a core of customers who are unwilling to make the switch to this pioneering form of financial service mainly due to a feeling of insecurity brought on by the rise of cyber-crime. As per the latest RBI report on trends and progress of banking in India [21] a total of 5406 frauds totalling 19,485 crore in various banking operations were reported, out of which 2321 incidents were in the case of e-banking.

$H_{1A}$: The level of Sense of Insecurity has a positive impact on the Level of hesitation among weavers in using E-banking.

*Hesitation to disclose the transaction to bankers or government*

Many people avoid digital banking as it may enable the bankers and government to know all the transactions of transferring and accepting funds.

$H_{1B}$: Not intent to disclose banking transactions has a positive impact on the Level of hesitation among weavers in using E-banking.

*Unable to afford smartphones and other equipment*

Consumer research suggests that the high price of an internet-enabled smartphone is a major disincentive for poor and middle-income customers in emerging nations to adopt mobile internet. About half of the people in India live in multidimensional poverty, and the cost of a smartphone, even at a low price, can take up to sixteen per cent of their income for those with the lowest incomes. We estimate that over 134 million people in India can't buy even the cheapest internet-enabled handset since it costs more than five per cent of their income [22].

$H_{1C}$: The unaffordability of Smartphones has a positive impact on the Level of hesitation among weavers in using E-banking.

*Lack of knowledge in operating smartphones or computers*

Users in rural areas typically lack even the most fundamental skills necessary to operate smartphones or ATMs and instead make do with more archaic forms of financial transactions like paper cheques and in-person withdrawals [23].

$H_{1D}$: Lack of knowledge in operating a smartphone has a positive impact on the Level of hesitation among weavers in using E-banking.

*Demonstration effect*

Demonstration effect means the activities of people are affected by observing the activities or decisions of others. The weavers do not intend to use digital banking services as none of the other weavers or others residing in rural areas are interested in using digital banking.

$H_{1E}$: Demonstration Effect on Level of Hesitation among weavers in using E-banking.

*Limited support of customer care services*

Since the level of satisfaction among users varies due to the technicality of the services, it is recommended that the support services provided during e-banking be simplified. Improved satisfaction can be achieved through smooth and favourable customer service and support [24]. Compliance with the Banking Codes and Standards Board of India (BCSBI) codes, which emphasize fair treatment of customers, is low across the board, with only 25% of the 51 banks receiving a “high” rating in 2017.

$H_{1F}$: Limited Support of Customer Care has a positive impact on the Level of hesitation among weavers in using E-banking.

*Transaction cost incurred*

There is also a possibility that many of the people of rural India feel that digital banking services incur some additional charges while transferring funds and sometimes lead to a deduction of a certain amount directly from the account generally at the end of the financial year.

$H_{1G}$: Transaction Cost Incurred has a positive impact on the Level of hesitation among weavers in using E-banking.

*Frequent network issues*

About half of the population in India has either limited or no access to the internet and other digital services. Unreliable electricity, low-cost connectivity and user equipment, a lack of industry incentives for cheap connectivity, difficult terrain, high infrastructure costs, weak backhaul, and questionable performance are just some of the obstacles to expanding internet access in India [25].

$H_{1H}$: Frequent Network Issues have a positive impact on the Level of hesitation among weavers in using E-banking.

*Language barrier*

The language barrier among rural people creates hesitation when using digital banking due to difficulties in understanding and navigating the technology. As digital banking platforms often use complex terminology and instructions in a language that may be unfamiliar to rural individuals, it becomes challenging for them to comprehend and feel confident in using these services. This lack of understanding can lead to hesitation, fear of making mistakes, and ultimately a reluctance to adopt digital banking solutions.

$H_{1I}$: Language Barrier has a positive impact on the Level of hesitation among weavers in using E-banking.

**Formulation of Step-Wise Regression Model**

The formulated hypotheses have to be tested by formulating a linear regression and considering all the factors discussed above as predictors. The results of the ANOVA and a linear regression model are mentioned in table 1 and table 2 respectively.

Table 1 represents the results of ANOVA of Model 1 where all the factors are considered as independent variables, for formulating the model. The value of the sum of squares of regression is the total variation in

Table 1

| RESULTS OF ANOVA[a] OF MODEL 1 | | | | | |
|---|---|---|---|---|---|
| **Model 1** | **Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
| Regression | 1137.762 | 9 | 126.418 | 55.226 | 0.000[b] |
| Residual | 1016.370 | 444 | 2.289 | | |
| Total | 2154.132 | 453 | | | |

Note: [a] Dependent Variable: How much do you hesitate to use digital banking?
[b] Predictors: (Constant), Network Issues in villages, Limited Support of Customer Care via Phone, Language Barrier, not wanting to disclose the transaction to bankers through online transactions, Sense of Insecurity due to cyber-crime, Demonstration Effect (Others don't use we hesitate to you), Knowledge about operating smartphones or computer, Unable to afford Smartphones and other equipments for E-banking, Transaction Cost Incurred.

the dependent variables that is explained by the regression model 1. The regression sum of squares is 1137.762 which is approx. 53% of the total sum of squares. It implies that the regression model explains about 53% of all the variability in the dataset used in this study. Moreover, the value of F statistics is significant as its p-value is less than 5% which shows a strong association between the independent and dependent variables taken in this study. The coefficients and the p values of each predictor in the model are shown in table 2.

Table 2 depicts the coefficients and the significance of each predictor of model 1. It can be said that all the beta values of the regression model are positive except for the level of not intending to disclose transactions to the government. These positive values of the predictors i.e., Sense of Insecurity is more due to cyber-crime, Knowledge about operating smartphones or computers, Transaction Cost Incurred, Unable to afford Smartphones and other equipment for E-banking, Demonstration Effect and Language Barrier represent positive impact or correlation with the level of hesitation among textile weavers in using e-banking. Moreover, the negative beta value of not intending to disclose transactions to the government represents an inverse correlation with the dependent variable and also indicates that it should be dropped while formulating the final regression model due to its non-significant p-value, 0.126 which is more than 0.05. Similarly, there are also 3 more predictors i.e., Transaction Cost Incurred, Language Barrier and Limited Support of Customer Care via Phone, which

Table 2

| COEFFICIENTS AND SIGNIFICANCE OF PREDICTORS OF MODEL 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model 1** | **Unstandardized coefficients** | | **Standardized coefficients** | **t** | **Sig.** | **Correlations** | | |
| | **B** | **Std. Error** | **Beta** | | | **Zero-order** | **Partial** | **Part** |
| (Constant) | 0.147 | 0.779 | | 0.188 | 0.851 | | | |
| Sense of Insecurity is more due to cybercrime | 0.118 | 0.034 | 0.135 | 3.422 | 0.001 | 0.378 | 0.160 | 0.112 |
| Do not want to disclose the transaction to bankers through online transactions | –0.083 | 0.054 | –0.051 | –1.532 | 0.126 | 0.055 | –0.072 | –0.050 |
| Knowledge about operating smartphones or computer | 0.091 | 0.042 | 0.088 | 2.155 | 0.032 | 0.403 | 0.102 | 0.070 |
| Transaction Cost Incurred | 0.018 | 0.043 | 0.021 | 0.418 | 0.676 | 0.369 | 0.020 | 0.014 |
| Unable to afford Smartphones and other equipment for E-banking | 0.112 | 0.049 | 0.113 | 2.300 | 0.022 | 0.438 | 0.108 | 0.075 |
| Demonstration Effect (Others don't use we hesitate to you) | 0.298 | 0.045 | 0.258 | 6.571 | 0.000 | 0.500 | 0.298 | 0.214 |
| Language Barrier | 0.024 | 0.050 | 0.023 | 0.476 | 0.635 | 0.338 | 0.023 | 0.016 |
| Limited Support of Customer Care via Phone | –0.203 | 0.147 | –0.046 | –1.376 | 0.169 | 0.005 | –0.065 | –0.045 |
| Network Issues in Villages | 0.642 | 0.049 | 0.449 | 13.195 | 0.000 | 0.558 | 0.531 | 0.430 |

Table 3

| STATUS OF HYPOTHESES AFTER FORMULATION OF MODEL 1 | | | |
|---|---|---|---|
| **Alternative hypotheses** | **Impact** | **P Value** | **Status of variable** |
| $H_{1A}$: The level of Sense of Insecurity has a positive impact on the Level of hesitation among weavers in using E-banking | Positive | Significant | Accepted |
| $H_{1B}$: Not intent to disclose banking transactions has a positive impact on the Level of hesitation among weavers in using E-banking | Negative | Non-Significant | Dropped |
| $H_{1C}$: The unaffordability of Smartphones has a positive impact on the Level of hesitation among weavers in using E-banking | Positive | Significant | Accepted |
| $H_{1D}$: Lack of knowledge in operating a smartphone has a positive impact on the Level of hesitation among weavers in using E-banking | Positive | Significant | Accepted |
| $H_{1E}$: Demonstration Effect on Level of Hesitation among Weavers in Using E-banking | Positive | Significant | Accepted |
| $H_{1F}$: Limited Support of Customer Care has a positive impact on the Level of hesitation among weavers in using E-banking | Positive | Non-Significant | Dropped |
| $H_{1G}$: Transaction Cost Incurred has a positive impact on the Level of hesitation among weavers in using E-banking | Positive | Non-Significant | Dropped |
| $H_{1H}$: Frequent Network Issues have a positive impact on the Level of hesitation among weavers in using E-banking | Positive | Significant | Accepted |
| $H_{1I}$: Language Barrier has a positive impact on the Level of hesitation among weavers in using E-banking | Positive | Non-Significant | Dropped |

although have positive beta values p values are non-significant due to values more than 0.05, hence these predictors should also be eliminated while framing the regression model and remaining predictors should remain in the final model. After formulation of this regression model, a clear status of accepting the alternative hypotheses and dropping the variable while formulating the final appropriate model can be seen in table 3.

Table 3 indicates that out of nine alternative hypotheses mentioned in the hypotheses formulation section, five alternative hypotheses are accepted and the remaining four are rejected. In other words, out of these 9 predictors, 5 predictors are selected for developing the next improved model as their impact is positive and significant on the dependent variable. The results of the improved model by taking only significant factors are mentioned in table 4 to table 7.

Table 4 represents the results of ANOVA of Model 2 where all the factors are considered as independent variables, for formulating the model. The value of the sum of squares of regression is the total variation in the dependent variables that is explained by the regression model 2. The regression sum of squares is 1126.357 which is approximately 54% of the total sum of squares, slightly improved as compared to model 1. It implies that the regression model explains about 54% of all the variability in the dataset used in this study. Moreover, the value of F statistics is significant as its p-value is less than 5% which shows a strong association between the independent and dependent variables taken in this study. Before finalizing any improved model the multicollinearity among independent variables needs to be examined, which is considered an obstacle for the regression model. Hence, before the computation of the coefficients and the p values of each selected predictor in the model, the correlation and covariance between predictors are shown in table 5.

Table 5 represents the correlation and covariance among each significant predictor chosen for the improved model. From the above table, it can be observed that most of the variables correlate 0.10 to 0.30 which is very low. Only the correlation between demonstration effect and unaffordability of smartphones, lack of knowledge in operating phones and

Table 4

| RESULTS OF ANOVA[a] OF MODEL 2 | | | | | |
|---|---|---|---|---|---|
| **Model 2** | **Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
| Regression | 1126.357 | 5 | 225.271 | 98.194 | 0.000[b] |
| Residual | 1027.775 | 448 | 2.294 | | |
| Total | 2154.132 | 453 | | | |

Note: [a] Dependent Variable: How much do you hesitate to use digital banking?
[b] Predictors: (Constant), Network Issues in villages, Sense of Insecurity is more due to cyber-crime, Demonstration Effect (Others don't use we hesitate to you), Knowledge about operating smartphones or computers, Unable to afford Smartphones and other equipment for E-banking.

Table 5

| CORRELATION AND COVARIANCE MATRIX | | | | | | |
|---|---|---|---|---|---|---|
| **Model 2** | | **Network Issues in Villages** | **Sense of Insecurity is more due to cybercrime** | **Demon-stration Effect** | **Knowledge about operating smartphones or computer** | **Unable to afford Smartphones and other equipment for E-banking** |
| Correlations | Network Issues in Villages | 1.000 | –0.020 | –0.157 | –0.114 | 0.013 |
| | Sense of Insecurity is more due to cybercrime | –0.020 | 1.000 | –0.055 | –0.211 | –0.275 |
| | Demonstration Effect | –0.157 | –0.055 | 1.000 | –0.101 | –0.339 |
| | Lack of Knowledge about operating smartphones or computer | –0.114 | –0.211 | –0.101 | 1.000 | –0.366 |
| | Unable to afford Smartphones and other equipment for E-banking | 0.013 | –0.275 | –0.339 | –0.366 | 1.000 |
| Covariances | Network Issues in Villages | 0.002 | $-3.264 \cdot 10^{-5}$ | 0.000 | 0.000 | $2.628 \cdot 10^{-5}$ |
| | Sense of Insecurity is more due to cybercrime | $-3.264 \cdot 10^{-5}$ | 0.001 | $-8.137 \cdot 10^{-5}$ | 0.000 | 0.000 |
| | Demonstration Effect | 0.000 | $-8.137 \cdot 10^{-5}$ | 0.002 | 0.000 | –0.001 |
| | Lack of Knowledge about operating smartphones or computer | 0.000 | 0.000 | 0.000 | 0.002 | –0.001 |
| | Unable to afford Smartphones and other equipment for E-banking | $2.628 \cdot 10^{-5}$ | 0.000 | –0.001 | –0.001 | 0.002 |

Note: [a] Dependent Variable: How much do you hesitate to use digital banking?

unaffordability of smartphones, correlate more than 0.30 but less than 0.40 although it is slightly higher but may not affect the model. The reason behind addressing multicollinearity is it can improve the stability, interpretability, and reliability of the regression model.

The covariance between two variables indicates the strength and direction of their linear relationship. The diagonal elements of the covariance matrix represent the variances of individual variables, while the off-diagonal elements represent the covariances between pairs of variables. All the variables or predictors show positive linear relationships except a few like network issues and sense of insecurity, demonstration effect and sense of insecurity, demonstration effect and unaffordability of smartphone, and unaffordability of phone and inability to operate it, which show negative linear relationship. A clear multicollinearity report could be assessed by running a multicollinearity test which gives the values of the Variance Inflation Factor (VIF) for each variable. The multicollinearity statistics along with the coefficients of selected variables are mentioned in table 6.

Table 6 reveals the collinearity statistics and coefficients of predictors along with the significance values. From the table above, it can be clearly stated that there is no existence of multicollinearity between the predictors as their VIF (Variance Inflation Factor)

Table 6

| COEFFICIENTS[a] AND COLLINEARITY STATISTICS OF MODEL 2 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Model 2** | **Unstandardized coefficients** | | **Standardized coefficients** | **t** | **Sig.** | **Collinearity statistics** | |
| | **B** | **Std. Error** | **Beta** | | | **Tolerance** | **VIF** |
| (Constant) | –1.012 | 0.269 | | –3.758 | 0.000 | | |
| Sense of Insecurity is more due to cybercrime | 0.130 | 0.033 | 0.149 | 3.929 | 0.000 | 0.736 | 1.359 |
| Knowledge about operating smartphones or computer | 0.088 | 0.042 | 0.085 | 2.102 | 0.036 | 0.644 | 1.552 |
| Unable to afford Smartphones and other equipment for E-banking | 0.120 | 0.043 | 0.121 | 2.769 | 0.006 | 0.555 | 1.802 |
| Demonstration Effect (Others don't use we hesitate to you) | 0.304 | 0.044 | 0.263 | 6.838 | 0.000 | 0.722 | 1.386 |
| Network Issues in Villages | 0.634 | 0.048 | 0.443 | 13.097 | 0.000 | 0.931 | 1.074 |

Note: [a] Dependent Variable: How much do you hesitate to use digital banking?

Table 7

| SUMMARY OF MODEL 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics | | | | |
| | | | | | R Square Change | F Change | df1 | df2 | Sig. F Change |
| 2 | 0.736[a] | 0.543 | 0.523 | 1.515 | 0.523 | 98.194 | 5 | 448 | 0.000 |

Note: [a] Predictors: (Constant), Network Issues in villages, Sense of Insecurity is more due to cyber-crime, Demonstration Effect (Others don't use we hesitate to you), Knowledge about operating smartphones or computers, Unable to afford Smartphones and other equipments for E-banking

is less than 2.5. VIF measures the degree of correlation between a predictor variable and the other predictor variables in a regression model. On the other hand, it can also be observed that all the beta values are positive which represents a direct relationship between the predictors and the dependent variable. Moreover, all the coefficients are statistically significant as the probability values are less than 0.05. The summary of the improved model i.e. of model 2 is mentioned in table 7.

Table 7 depicts the summary of model 2 which is the improved model. The value of R square is 0.543 which infers that that approximately 54.3% of the variance in the dependent variable can be explained by the predictors included in the regression model. In other words, the independent variables in the model collectively account for 54.3% of the variability observed in the dependent variable. The remaining 45.7% of the variance is attributed to factors not accounted for by the model or random variation. The formulated model can be written as follows:

$$\begin{gathered}\text{Level of Hesitation among Weavers}\\ \text{in using E-banking} = -1.012 + 0.130\ \text{Sense}\\ \text{of Insecurity due to Cyber Crime} +\\ + 0.120\ \text{Unaffordability of smart phones} +\\ + 0.088\ \text{Lack of knowledge in operating smart}\\ \text{phones} + 0.304\ \text{Demonstration Effect} +\\ + 0.634\ \text{Network Issues}\end{gathered} \tag{1}$$

By observing the coefficient of predictors of the above model, it can be inferred that network issues are creating a heavy impact on the level of hesitation among weavers in using e-banking, followed by demonstration effect and sense of insecurity.

## CONCLUSION

The above analysis and results depict that many hurdles are restricting or discouraging textile weavers from using digital banking services. Although there are many factors stated by the weavers that discourage the weavers from using digital banking there are certain factors whose coefficients are statistically significant as their p values are less than 0.05.

These factors are Network Issues in villages, the Sense of Insecurity is more due to cybercrime, the Demonstration Effect (Others don't use we hesitate to you), Knowledge about operating smartphones or computers and the unaffordability of Smartphones and other equipment. For each significant factor proper initiative should be taken not only by the government but also by the telecom companies so that the hesitant level among such weavers would be decreased or eliminated. Although government and telecom companies have already taken the initiative to aware people of India regarding recent frauds and scams in digital banking via messages, emails and calls to reduce the sense of insecurity in using e-banking some additional initiative has to be taken to aware and financial literate the people of rural India by conducting some evening classes and nukkad-natak (street shows). Many people in rural India are only able to fulfil their basic needs from their earnings, they don't have the optimum funds to afford smartphones and have knowledge in operating those. The government could have taken necessary steps by providing smartphones at lower rates or subsidized rates so not only the weavers but also the people of rural India could derive the benefits of digital banking. On the contrary, the government has categorized the phones under 18% GST during the COVID pandemic which again increases its costs. Network issues could be resolved when both government and telecom companies take joint initiatives to install more towers with multiple networks of different companies. The demonstration effect of not using phones will be resolved by the passage of time when some of the weavers start using e-banking. Although other factors were also there in the study they found non-significant hence no steps were required for those factors. However, the major limitation of this study is that most of the data was collected from those weavers who reside in rural areas of India where many of the facilities of banking are deprived. Hence, the significant factors and the model may not be representative of the hesitant level among those weavers residing in urban or near urban areas. Furthermore, only nine predictors are considered in this study, future researchers could also discover some more unexplored ones by running exploratory factor analyses, that are responsible for hesitation in using e-banking among not only weavers but also among other groups of workers or people. As India is taking all kinds of necessary steps to make it Digital-India, these barriers stated in this study should also be concentrated on to achieve this vision shortly.

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# INFORMATION FOR AUTHORS

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Generally, symbols and abbreviations shall be used according to ISO 31: Specifications for quantities, units and symbols. SI units must be used, or at least given comprehensive explanations or their equivalent.

Cited references shall be listed at the end of the paper in order of quotation and contain: **for a paper in a periodical** – the initials and surname of the author(s), title of journal and of the article, year and number of issue, number of volume and page numbers; **for a book** – the initial and surname of the author(s), full name of the book, publisher, issue, place and year of publishing, and the pages cited; **for patents** – the initial and surname of the author(s), the title, the country, patent number and year. It is preferable not to use sites as references.

[1] Hong, Y., Bruniaux, P., Zhang, J., Liu, K., Dong, M., Chen, Y., *Application of 3D-to-2D garment design for atypical morphology: a design case for physically disabled people with scoliosis*, In: Industria Textila, 2018, 69, 1, 59–64, http://doi.org/10.35530/IT.069.01.1377

Authors are requested to send an abstract of the paper, preferably no longer than 250 words and a list of 5–6 key words (preferably simple, not compound words, in alphabetical order).