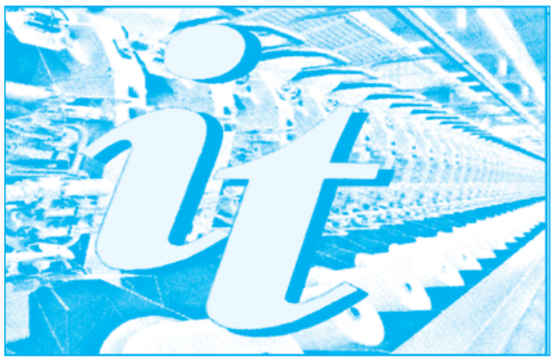

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Effects of chitosan on the metal absorption and UV protection properties of woven cotton fabric

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RATTANAPHOL MONGKHOLRATTANASIT

ABSTRACT – REZUMAT

Effects of chitosan on the metal absorption and UV protection properties of woven cotton fabric

In this research, cotton fabrics were treated with carboxylated chitosan, loaded by the pad-dry-cure method for investigating the absorption of heavy metals and the Ultraviolet (UV) protection properties of fabric samples. For this purpose, chitosan-treated cotton fabrics were soaked in $CuSO_4$ solution to investigate the rate of heavy metal absorption. The surface morphology of cotton fabrics was investigated using Scanning electron microscopy (SEM) analysis. Inductively coupled Plasma Spectroscopy (ICP) analysis was employed to examine the amount of heavy metals' absorption upon chitosan-treated cotton fabrics. Besides, reflection and transmission spectrophotometry analyses were used to examine the optical properties of cotton fabrics. The results show a noticeable increase in copper absorption by increasing the amount of chitosan. The maximum absorption of Cu belongs to the %6 chitosan-treated sample by 7357.6 PPM, equal to %7.35. The more concentration of chitosan in the fibre causes a higher rate of UV protection. Therefore, the chitosan-treated cotton fabrics examined in this work can be used for various water filtration purposes, notably to eliminate toxic metals. Also, It can be used as a wearable textile for protecting against harmful UV rays.

Keywords: *chitosan, metal absorption, UV protection, cotton, fabric*

Efectele chitosanului asupra absorbției metalelor și proprietăților de protecție UV ale țesăturii din bumbac

În această cercetare, țesăturile din bumbac au fost tratate cu chitosan carboxilat, aplicat prin metoda de fulardare-uscare-condensare pentru analiza absorbției metalelor grele și a proprietăților de protecție la ultraviolete (UV) ale mostrelor de țesături. În acest scop, țesăturile din bumbac tratate cu chitosan au fost înmuiate în soluție de $CuSO_4$ pentru a investiga viteza de absorbție a metalelor grele. Morfologia suprafeței țesăturilor din bumbac a fost investigată folosind analiza microscopiei electronice cu scanare (SEM). Analiza prin spectroscopie cu plasmă cuplată inductiv (ICP) a fost utilizată pentru a examina cantitatea de metalelor grele absorbite de către țesăturile din bumbac tratate cu chitosan. În plus, analizele de spectrofotometrie de reflexie și transmisie au fost utilizate pentru a examina proprietățile optice ale țesăturilor din bumbac. Rezultatele arată o creștere vizibilă a absorbției cuprului prin creșterea cantității de chitosan. Absorbția maximă de Cu aparține probei tratate cu chitosan 6% cu 7357,6 PPM, egal cu 7,35 %. Cu cât concentraţia de chitosan pe fibră este mai mare, cu atât rata de protecție UV este mai mare. Prin urmare, țesăturile din bumbac tratate cu chitosan examinate în această lucrare pot fi utilizate în diferite scopuri de filtrare a apei, în special pentru eliminarea metalelor toxice. De asemenea, pot fi utilizate ca textile purtabile pentru protejarea împotriva razelor UV dăunătoare.

Cuvinte-cheie*: chitosan, absorbție de metal, protecție UV, bumbac, țesătură*

INTRODUCTION

Throughout the vast and quick evolution of new science regarding the textile industry in the latter years, numerous global scientists have actively conducted investigations about practical textiles.

Practical textiles have been well-known as the most significant element of the textile industry. Nevertheless, a need for applicable high-tech textiles regarding UV protection, waste refinement, fireproofing, etc., could not be reached just by an ordinary single-step preparation [1, 2]. The growing requisition regard to the increasing demand for multipurpose fabrics needs powerful multidimensional scientific knowledge and process [3–5].

One of the most prevalent forms of textiles around the world is cellulose-made cotton fibres [6]. Sweat-absorbing, comfortableness, softness, and flexibility of cotton fibres made them one of the most common types of textiles worldwide. Besides, cotton textiles create a perfect habitat for microorganisms to be raised the cause of their ability to moisture preserving [7–10]. And one of the best natural biopolymers with numerous specific characteristics such as non-toxicity, antibacterial and cationic nature features is chitosan [11, 12].

Seeking an environmentally friendly method that replaces poisonous textile chemicals has been a permanent goal for the textile industry. In this regard, chitosan could be used as a superb alternative to

environmentally friendly textile chemicals. A recent paper has already reviewed the multiple applications of chitosan for dyeing and finishing textiles [13–15]. It also has been proven as a wonderful alternative for dyes and metal ions absorption [16].

Another perspective refers to the progressive awareness of consumers about an urgent need for sunlight protection which is connected with the prevalence of skin damage and its correlation with growing exposure to UV light. Intense and chronic drawbacks of ultraviolet radiation (UVR), such as speeding up skin deterioration and ageing, are apparent to everyone. Overexposure to UV radiation is the main cause of diverse eye, skin, and DNA problems. The main clusters of the UV radiation band include the UV-A band (320–400 nm), UV-B band (290–320 nm), and also UV-C band (200–290 nm). The ozone layer and existing oxygen in the atmosphere are responsible for the total absorption of the UV-C band, which has the highest energy among other regions. The rest of the total UV radiation which radiates to the ground consists of 94% UV-A and 6% UV-B. Despite UV-A which causes minor skin reactions and somehow immunological disorders, UV-B has been proven to be the main cause of skin cancer [17, 18]. Moreover, in recent years, studies have been conducted on the absorption of heavy metals using chitosan-treated cotton fabrics. For example, Ferrero F et al. prepared a chitosan-coated cotton gauze by UV-curing and tested it as an adsorbent to remove copper (II) and chromium (VI) ions from water solutions. The adsorption capacities increased with increasing metal ion concentration for both metal ions, while the temperature did not significantly affect the metal ions' adsorption process [19]. Rongjun Qu et al. investigated the adsorption of Au (III) from an aqueous solution using cotton fibre/chitosan composite adsorbents. The results show that chitosan-treated fibres can selectively adsorb Au (III) from binary ion systems in the presence of the coexistent ions Pb (II), Cu (II), Ni (II), Cd (II), Zn (II), Co (II), and Mn (II) [20].

Nauman, A et al. coupled chitosan and copper nanoparticles on the fabric surface. The fabricated chitosan/copper cotton cloth (Cu/Chi-CC) can be used as an easily removable substrate for the absorption of Congo red (CR) dye [21].

In this study, deposited chitosan upon cotton fabrics was employed for investigating its UV protection and heavy metals absorption properties. Pad dry cure method was employed for depositing chitosan on cotton fabrics. Chitosan-treated cotton fabrics were overwhelmed on $CuSO_4$ solution to investigate the absorption rate of heavy metals. Reflective and transmission spectroscopy, SEM and ICP analyses were performed to evaluate Cu absorption by chitosan-treated cotton fibres.

EXPERIMENTAL

Materials

In this study, chitosan modified polysaccharides with medium density and cotton fabrics was used to investigate the chitosan impact on the metals' absorbance by cotton fabrics. Also, the UV protection properties of treated cotton samples were studied. Employed chitosan was made by Fluka Co with a deacetylation degree of 70%, and the utilized cotton fabric was weaved by 18.8 Tex warp and weft yarns composed of 56.88 threads in each square inch. All the other agents such as acetic acid and copper sulphate ($CuSO_4$) were purchased with commercial grade.

Method

At first, specimens containing 1, 3 and 6 percentage of chitosan were made. This procedure was done by dissolving chitosan powder in deionized water containing 3% Acetic acid. Then chitosan was deposited on the cotton samples using the pad-dry-cure method. Cotton fabric was cut off into four equal pieces and was overwhelmed in solutions containing chitosan. Cotton specimens were padded with different concentrations of chitosan (e.g., 1, 3 and 6%) at 80% wet pick-up and dried at 90°C for 5 minutes. A stenter machine was used for curing samples at 120°C for 2 minutes. Afterwards, 1 wt% of $CusO_4$ solution was prepared, and specimens were immersed in the produced solution separately. For investigating the reflection factor of all treated samples and comparing them with untreated ones, reflection Spectroscopy (D.R.S., Xrite Sp64 Spectcophotometer, Varion Co., Italy) analysis was used over a range of 400–700 nm. Also, transmission spectroscopy analysis was used to investigate the protection capability of samples against UV radiation (NIR, Analytic Jena Spectrophotometer 250) over a range of 280–400 nm. Besides, for inspecting the surface morphology of all treated and untreated samples, Scanning electron microscopy (SEM-Model EM-3200, KYky China) was employed. Inductively coupled Plasma Spectroscopy (ICP-OES simultaneous Model VISTA-PRO-Varian Co.- Australia) was used to measure the rate of metal absorption. The amounts of absorbed copper on the surface of untreated and chitosan-treated cotton with different concentrations of chitosan were compared using ICP analysis. For studying the fastness properties, samples were washed. The samples were washed with nanionic detergent for 20 times and dried in an oven at 60°C for 5 min. The maintenance of Cu on washed samples was analysed and determined using the ICP method.

Moreover, this research investigated the mechanical properties of untreated, chitosan-treated cotton and chitosan-treated cotton/$CuSO_4$ loaded samples. The load and elongation at break value (tensile strength) were measured by a Dinamometer TIRA test 2300 (made in Germany). The size of samples used for measurement was 120 × 300 mm^2 and the standard of the measurement was CSN EN ISO 13934-1. The maximum cell of the system was 5000 N. The distance between the jaws and the extension rate was 200 mm and 100 $mm \cdot min^{-1}$, respectively.

RESULTS AND DISCUSSION

This study investigated the rate of metals absorption and UV protection properties of chitosan-treated cotton. As was explained in the experimental part, cotton samples were deposited with different concentrations of chitosan (e.g., 1, 3, and 6%). Chitosan-treated samples were loaded with 1% wt of copper sulphate solution. Reflection spectrophotometry analysis was employed to investigate the samples' optical properties. The reflection properties of both untreated and chitosan-treated cotton after immersion in copper sulphate solution are shown in figure 1. The reflection factor for 6% chitosan treated cotton after immersion in Cu solution is less than the others. Comparing the reflection percentage of samples, it was concluded that by increasing the amount of used chitosan, the reflection factor decreased (figure 1). The above statements are evidenced by checking the results of the 6% sample with the highest rate of chitosan and consequently is darker, which may be a result of copper & chitosan's presence on the fabric surface. The results show that, by increasing the percentage of chitosan on cotton samples, more amounts of copper sulphate can be adsorbed which corresponds with recent research [22].

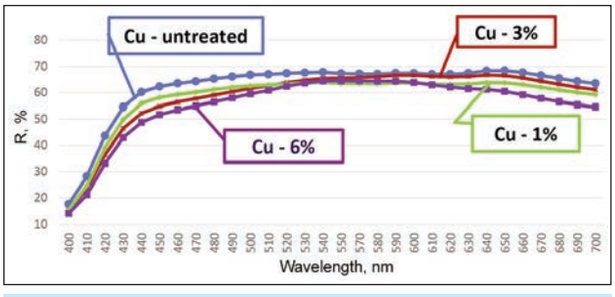

Fig. 1. Reflection factor for all chitosan-treated cotton fabrics with different percentages after $CuSO_4$ loading

Investigating the surface morphology of samples was done by SEM analysis (figures 2 and 3). Chitosan particles are apparent on the samples' surface as expected. The more amount of chitosan results in the higher particles' surface agglomeration and roughness. Consequently, the 6% chitosan-treated sample shows the most agglomeration and roughness. Another SEM analysis was done after overwhelming chitosan samples in the $CuSO_4$ solution (figures 4 and 5). As expected, the 6% chitosan-treated specimen absorbed more amounts of $CuSO_4$. These results confirm the achieved results by Perumal et al., which demonstrated that chitosan/gelatin hydrogel particles absorb a higher amount of Hg ion [23] that, coincides with the results of Shahraki et al. and Naeimi et al., which showed more rate of heavy metals ions absorption by utilizing chitosan [24, 25].
Structures that were observed on the samples' surface might be CuO nanoparticles. That is, chitosan-treated fabrics absorbed $CuSO_4$ and transformed it into CuO nanoparticles (chemical reaction 1).

$$CuSO_{4\,(aq)} + 2H_2O \rightarrow CuO + 2H_2SO_4 \qquad (1)$$

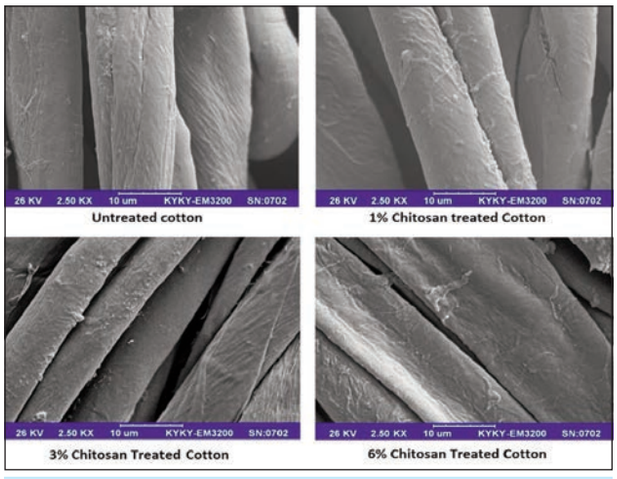

Fig. 2. SEM images of chitosan-treated cotton fibres, magnification of 2.5 kx

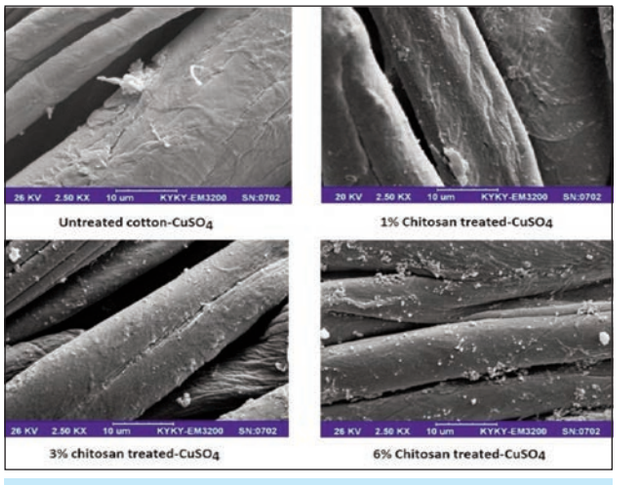

Fig. 3. SEM images of chitosan-treated cotton fibres, magnification of 10 kx

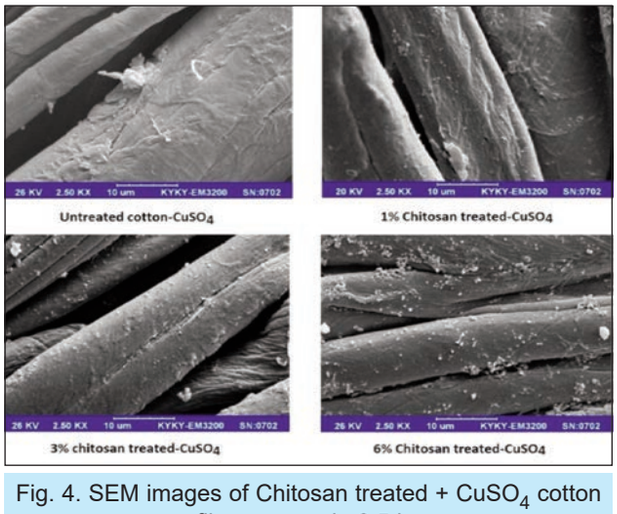

Fig. 4. SEM images of Chitosan treated + $CuSO_4$ cotton fibres, zoom in 2.5 kx

ICP analysis was employed for a precise investigation of the Cu amount on the fabrics' surface. The results show that chitosan-treated fabrics absorbed more Cu compared to raw fabrics. This rate of absorption had risen by increasing the amount of chitosan. The results show that the 6% chitosan-treated

Table 1

ICP ANALYSIS DATA OF CHITOSAN-TREATED/$CuSO_4$ LOADED COTTON FABRICS

Sample	EL.	Wavelength	Cal. conc. (ppm)	Cal. conc. (%)
Untreated/Cu-loaded cotton	Cu	324.754	6060.3	6.06
1% Chitosan treated/Cu-loaded cotton	Cu	324.754	6060.3	6.3
3% Chitosan treated/Cu-loaded cotton	Cu	324.754	6698.3	6.6
6% Chitosan treated/Cu-loaded	Cu	324.754	7357.6	7.3
Untreated/Cu-loaded cotton after 20 times of washing	Cu	324.754	4100.2	4.1
1% Chitosan treated/Cu-loaded cotton after 20 times washing	Cu	324.754	5070.5	5.07
3% Chitosan treated/Cu-loaded cotton after 20 times washing	Cu	324.754	6078.5	6.07
6% Chitosan treated/Cu-loaded cotton after 20 times washing	Cu	324.754	7124.7	7.12

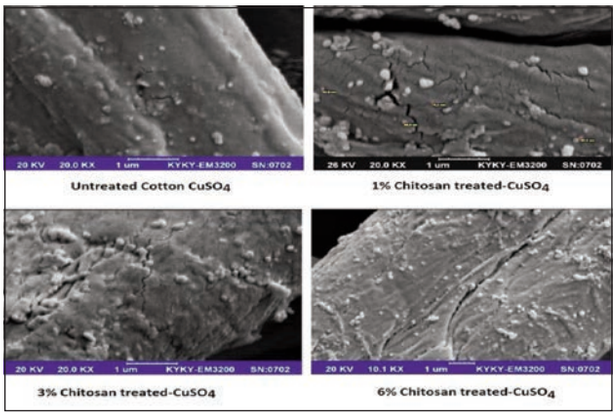

Fig. 5. SEM images of Chitosan treated+ $CuSO_4$ cotton fibres, higher magnification

sample absorbed 7,357.6 ppm, equivalent to 7.35% Cu (table 1). These results correspond to the outcomes of the SEM analysis. According to the structure of chitosan (figure 6), more particles appear on the surface by treating cotton samples with chitosan. Also, as seen in figures 3 and 4, the unevenness on the surface of cotton fibres increases with chitosan treatment. By increasing the concentration of chitosan, this roughness will be increased. So more amounts of copper can be absorbed by chitosan-treated cotton. Copper makes a bond with the surface of cotton, both chemically and physically. Some copper particles are imprisoned in rough surfaces, and some bond chemically with polar groups. The results related to fastness properties against washing, show that, after 20 times of washing, more amounts of copper remain on the chitosan-treated cotton as compared with untreated cotton. By increasing the concentration of chitosan, the fastness properties will be improved.

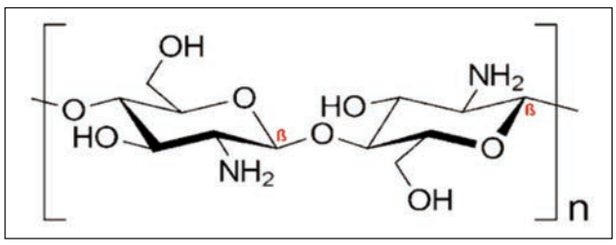

Fig. 6. Structure of chitosan

In this study, transmission spectroscopy was employed to examine protection against UV radiation (figure 7). As seen by increasing the amount of Chitosan, more Cu was absorbed by samples, and consequently, fewer UV rays passed through the fabrics. Finally, we can conclude that the chitosan-treated samples are more resistant to UV radiation. Besides, Rehan et al. and Shahidi et al. concluded in their research that, chitosan-treated cotton fabrics illustrated a higher protection level against UV light compared to untreated cotton fabrics [2, 24]. The investigations of Vilela. C et al. show remarkable UV absorption characteristics in both UV-A and UV-B regions by using an active component of chitosan which is similar to the obtained results in this research [26].

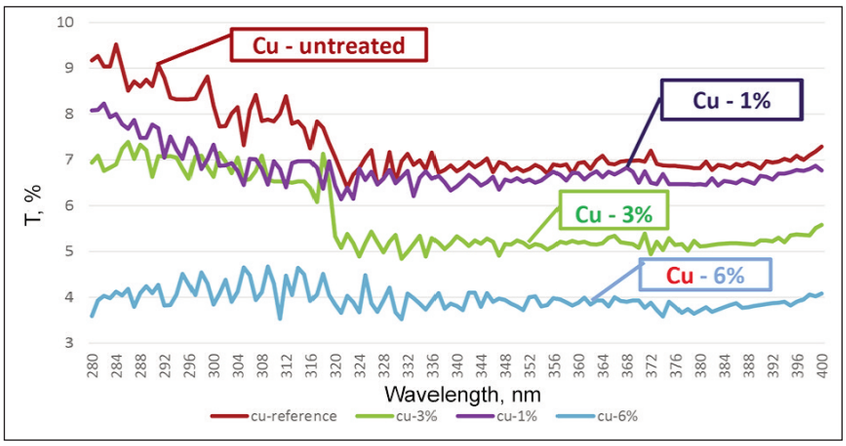

Fig. 7. Transmission factor for untreated and all chitosan-treated cotton fabrics after loading with $CuSO_4$

Table 2

MECHANICAL PROPERTIES OF UNTREATED AND TREATED SAMPLES IN WARP DIRECTION				
Sample	**Max elongation (mm)**	**Load F max (N)**	**Young's modulus *E* (MPa)**	**Time (s)**
Untreated cotton	23.27	2120.6	241.81	15.54
6% Chitosan treated	23.95	2123.7	241.41	15.55
6% Chitosan treated/Cu loaded	18.88	1839.95	235.1	12.66

Table 3

MECHANICAL PROPERTIES OF UNTREATED AND TREATED SAMPLES IN WEFT DIRECTION				
Sample	**Max elongation (mm)**	**Load F max (N)**	**Young's modulus *E* (MPa)**	**Time (s)**
Untreated cotton	14.69	1197.07	232.49	8.92
6% Chitosan treated	14.61	1196.35	231.46	8.93
6% Chitosan treated/Cu loaded	10.55	989.12	213.44	6.19

To investigate the effect of the chitosan treatment on the strength of the cotton fabrics, the maximum load and elongation at break (mechanical properties) were investigated. Both weft and warp directions were measured. The results are shown in tables 2 and 3. As it is seen, the mechanical properties of cotton samples after chitosan treatment will not change. However, coincident treatment with both chitosan and $CuSO_4$ solution causes reducing the mechanical properties. This reduction for 6% chitosan treated/loaded with $CuSO_4$ is more significant. However generally, this tensile strength reduction is not considerable.

CONCLUSIONS

In this research, the effect of chitosan on the metal absorption of cotton fabrics was carried out. Also, the effect of chitosan-treated/Cu-loaded cotton with different concentrations of chitosan on the UV protection properties of cotton was investigated.

The samples were prepared using different concentrations of chitosan and a certain percentage of $CuSO_4$. Reflective-Spectrometry analysis results presented that the 6% chitosan-treated sample has the most reduction in reflection. SEM analysis confirmed the presence of chitosan and copper on the cotton fabrics. By increasing the percentage of chitosan, more amounts of copper are adsorbed by cotton samples. The results of the ICP analysis confirm the outcomes of the SEM test. To examine the resistance of samples against UV radiation for wearable applications, NIR spectroscopy analysis was done. The results showed a significant decrease in UV passing by increasing the amount of chitosan and copper. It can be worth mentioning that this biopolymer has plenty of desirable properties such as low price, renewability, high absorption, and recoverability, which make it a good filter for absorbing contaminants such as heavy metal ions and wastewater from the textile industry. Also for use as cloth, it can be a good choice for protection of the body against UV and bacteria [12].

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Teamwork valorisation in Serbian textile organizations of different lengths and levels of operations

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ABSTRACT – REZUMAT

Teamwork valorisation in Serbian textile organizations of different lengths and levels of operations

The need of various textile organizations operating for different periods and at different levels for studying the values of teamwork as a significant performance of a successful operation expansion grows with the spreading of their business in the international environment and the strengthening of competition. The paper's subject matter is research on the attitudes of the owners and higher-level managers of different Serbian textile organizations whose focus is on the valorisation of the performance of teamwork in an organization. The research intends to assess the defined characteristics interacting with teamwork as a crucial concept of human resource management that has to be consistent and explicit, frequently also being the decisive organizational success factor. The paper starts from the premise that member selection is the most significant for the success of a team striving to rotate the leadership structure to make the members do key organizational tasks. All the more so because those making relevant decisions and the leadership style differ depending on the business operations level, the length of business operations and the special attributes of each organization. The results obtained in this research study show that the business operations level and the length of business operations significantly influence differences in organizational teamwork rates as observed through a collective influence of the defined variables. In the given study, comparative statistics methods, hypothetical-deductive methods, analytical-deductive and comparison methods, historical and statistical-descriptive methods are used.

***Keywords**: organization, team, teamwork, business operations level, length of business operations*

Valorificarea muncii în echipă în organizațiile textile din Serbia având operațiuni cu durate și niveluri diferite

Nevoia diverselor organizații textile care funcționează pe o perioadă diferită și la diferite niveluri de a studia valorile muncii în echipă ca performanță semnificativă a expansiunii operațiunii de succes crește odată cu răspândirea afacerilor lor în mediul internațional și întărirea concurenței. Obiectul lucrării este cercetarea atitudinilor proprietarilor și managerilor de nivel superior din diferite organizații textile sârbe, a căror accent este pe valorificarea performanței muncii în echipă într-o organizație. Cercetarea își propune să evalueze caracteristicile definite care interacționează cu munca în echipă, ca un concept crucial al managementului resurselor umane care trebuie să fie consecvent și explicit, deseori fiind și factorul decisiv de succes organizațional. Lucrarea pleacă de la premisa că selecția membrilor este cea mai importantă pentru succesul unei echipe care se străduiește să rotească structura de conducere, astfel încât membrii să execute sarcini organizaționale cheie. Acest lucru se întâmplă deoarece cei care iau decizii relevante și stilul de conducere diferă în funcție de nivelul operațiunilor afacerii, de durata operațiunilor afacerii și de atributele speciale ale fiecărei organizații individuale. Rezultatele obținute în acest studiu de cercetare arată că nivelul operațiunilor afacerii și durata operațiunilor afacerii au o influență semnificativă asupra diferențelor în vitezele de lucru în echipă organizaționale observate printr-o influență colectivă a variabilelor definite. În studiul dat, se folosesc metodele statisticii comparative, metodele ipotetico-deductive, metodele analitico-deductive și de comparație, metodele istorice și statistico-descriptive.

***Cuvinte-cheie**: organizaţie, echipă, lucru în echipă, nivelul operațiunilor afacerii, durata operațiunilor afacerii*

INTRODUCTION

Accelerated technical-technological development and energetic competition in the market impose the need for the continuous monitoring of the contemporary conception of labour and its adapting to newly created situations. In that sense, each organization's and simultaneously a textile organization's (i.e. such an organization's management's) task [1] is to give shape to the structure that will be able to adapt itself to the potential challenges coming from its closer and/or more distant environment at some point in time [2]. It is important that management should create an atmosphere in which every individual is needed and useful to the organization, which is the key motivator [3] for its employees to be loyal to it and be high performing. Numerous research studies have shown that organizations are far more productive and far more efficient in doing business and generate more quality results through teamwork [4, 5].

Although not new, the team concept of the paper represents the necessary element and the necessary precondition for the optimal conducting of organizational business processes independently of the business operations level and length. The teamwork genesis shows that the extensive and complex tasks that require different competencies and knowledge levels

or either consist of a series of operations that must be performed simultaneously or in parallel with each other impose the need for organizing it. Namely, when it was not clear how to solve the problem, then different opinions and knowledge are needed, which after the exchange of information and discussion lead to the highest quality result [6, 7]. The formation of work teams and other innovative and virtual [8, 9] teams has first of all been contributed to by concreate experiences of teamwork [10], where the pyramidal relationship has been replaced by an associative character in the communication and functioning processes [11].

In such a constellation, the organization's goals are set by its management, but it is a team [12] with clearly defined members who decide how to achieve the goals in reality. A team formed to solve diverse specific tasks in order to current organizational challenges [13] necessarily needs a reliable leader [14] who knows how to organize successful teamwork. The leader brings together individual persons on the team with different knowledge levels, competencies and characteristics, who all understand how to solve the key problems faced by the organization in crises. So, the leader [15] creates an advantage of teamwork [16] founded on the corporate culture [17] oriented towards action and challenge, good human resource management and a web of values supportive of successful communication [18]. At the same time, each teamwork combination is significant [19] for the development of the personnel potential and the most advanced modality of organizational functioning.

The transformation of an organization into a team organizational approach [20] dominantly implies forming temporary teams from the different functional organizational areas whose purpose is to solve concrete problems or find possibilities to achieve the evaluated goal. Teams are those who will make a difference between one particular organization and its competition [21] either in a good or in a bad direction. They need not work on a daily basis, but they must work as a team and effectively. That is where the leadership skill and ability [22] to form ad hoc teams [23] are crucial for the success of contemporary textile organizations. Successful teams are flexible and oriented towards the tasks that should be performed by bridging the gap between organizational potential and organizational performance.

Teamwork valorisation is performed based on the revelation of the influence of team culture, work environment [24, 25] and competencies [26], i.e. a set of knowledge, skills and behaviours, whereas business performance is connected with organizational goals and leadership style [27]. That stimulates teamwork that is based more on quality than on quantity and increases the responsibility on the part of both the employees and the owner(s)/manager(s) of the organization who do the best they can to maximally utilize the knowledge of their employees who are becoming team members [28]. Teamwork designed through careful thought improves the overall functioning of the organization, which ultimately reflects the purpose of its business policy and sustainable performance [29].

Irrespective of the problems that may come to light in teamwork and the cost price of teamwork, the results are far better, and decisions are more adequate. For the aforementioned reasons, teamwork is currently rated as the best modality of organizing work, and it is considered that the same will be a prevailing concept of action in the future.

RESEARCH METHODOLOGY

Numerous research studies carried out so far have, from various perspectives, confirmed the fact that organizations have increasingly more strongly been dedicated to the improvement of teamwork since they see it as the main means of acquiring a competitive advantage [30] and as a tool of an active initiative for a textile organization.

The subject matter of the research done in this study is teamwork valorisation and the valorisation of the other pre-profiled characteristics that are relevant for the expansion of the business done by national textile organizations of the different periods and levels of the business operations carried out in the selected market. While generating the methodological framework of the paper, a bibliographical-speculative algorithm is also used apart from the explorative mechanism, whereas multiple comparisons and statistical test methods are used in the results processing and interpretation.

The research study was performed in the form of an online questionnaire and through the direct collection of the primary data and pieces of information in the field. The sample [31] consisted of 136 organizations of different sizes. The research was done on a representative sample of 26 micro-organizations (19%), 38 small organizations (28%), 39 medium-sized organizations (29%), and 33 big organizations (24%), all having been selected from the database kept with the Business Registers Agency (BRA) of the Republic of Serbia. The sample included textile organizations of different sizes, simultaneously the organizations doing business in the international market accounting for the largest number of the organizations, i.e. 46%, followed by those doing business in the national market, accounting for 25%, then came those operating in the regional market, accounting for 17%, whereas those operating only in the local market were the least numerous, accounted for 12%. The decisive factor for the selection of the sampled organizations was the profitability of their business operations in the national frameworks of their profitable economic activities. A non-random sample was used for the needs of this research study. The questionnaire was essentially intended to collect information and valorise the teamwork of the national organizations in the context of the other selected performances in the function of their business operations efficiency. The survey was conducted anonymously

and pertained to the organizations that were operating both in the national and international markets. The questions were answered by the owners or higher-level top managers.

RESULTS AND DISCUSSION

The valorisation of teamwork and the products of teamwork performance is the factor essential for every organization's success. For that reason, the evaluation of the characteristics significant for the profitability of the business operations carried out by the textile organizations of the different lengths and levels of business operations as the projected strategic goal is defined by the analysis of the pre-grouped elements. The emphasis is on the evaluation of teamwork as an important characteristic for the expansion of their business operations in correlation with the level of their qualitative business operations about the comparable competition, the level at which the management in them is consistent and explicit, the probability that the organizations will achieve total business excellence at all the levels, the degree at which the idea of organizational business culture is achieved and the scope of the engagement of the consultants. The variables whose values depend on the independent variables were perceived through descriptive statistics to detect the configuration and compare the singled-out factors.

For that very reason, the managers of the Serbian textile organizations were asked as the respondents to characterize the teamwork also including the other performances within the framework of their business operations using marks from 1 to 5, the mark 1 being the lowest, and the mark 5 being the highest. The results as per the singled-out performances of the concrete indicator in the absolute and relative figures are given in table 1. The obtained outcomes refer to the conclusion that, apart from the elements mentioned in the matrix, teamwork stands out as a very important characteristic of the effective business operations carried out by the Serbian textile organizations, defined by the scope of acquiring and maintaining competitive advantage.

Most respondents participate in teamwork daily and have positive experiences, so they opine that teamwork can help establish human relations inside the organization and increase business performance.

In table 2, the performances are ranked based on the average marks (mean values) for each mentioned performance.

Based on the research results, it can be seen that the best-ranked characteristics in the textile organizations included in the sample are teamwork, their qualitative business operations about the comparable competition, the level at which the organizational management is consistent and clear, and chances for

Table 1

THE MARKS FOR TEAMWORK AND THE OTHER PERFORMANCES IN THE SERBIAN TEXTILE ORGANIZATIONS

Performances	Marks									
	1		2		3		4		5	
	Af	Rf	Af	Rf	Af	Rf	Af	Rf	Af	Rf
Teamwork in the organization	3	2.2	10	7.4	16	11.8	51	37.5	56	41.2
The level at which the organizational management is consistent and explicit	0	0	9	6.6	24	17.6	60	44.1	43	31.6
The organization's qualitative business operations about the comparable competition	0	0	2	1.5	22	16.2	57	41.9	55	40.4
The degree to which the idea of business culture is achieved in the organization	2	1.5	14	10.3	42	30.9	46	33.8	32	23.5
A chance for the organization to achieve high performances	2	1.5	6	4.4	22	16.2	58	42.6	48	35.3

Note: Af – absolute frequencies; Rf – relative frequencies (percentages); Mean values (MV).

Table 2

THE RANKED PERFORMANCES

Performances	Mean values	Performance rank
Teamwork in the organization	4.08	2
The level at which the organizational management is consistent and explicit	4.01	4
The organization's qualitative business operations about the comparable competition	4.21	1
A chance for the organization to achieve high performances	4.06	3
The degree to which the idea of business culture is achieved in the organization	3.68	15
The scope of the engagement of the consultants in the organization	3.13	23

the organization to achieve total business excellence at all the levels, which all received the average mark greater than 4. At the bottom of the table, the lower marks (below 3.70) position the level at which the idea of business culture in the organization is achieved and the level of engagement of the consultants in the organization. So, a large majority of the respondents declare that teamwork excellently influences the functioning of the organization. When a broader picture is perceived, it can be concluded that the raising of the level of business culture in individuals can influence teamwork more efficiently.

The two-factor analysis of the variance established the fact that the length of business operations and the level of business operations (local, national, regional and international) exert an influence on the differences in the characteristics of the business operations carried out by the Serbian textile organizations as a precondition for the creation of the organization of expected performances. The value 0.05 (the statistically significant difference being present for all the values Sig ≤ 0.05) was assigned to the difference significance level.

The obtained mean values of the marks for teamwork for each level and each length of business operations are given in table 3. The standard deviation (Std. Deviation) is a deviation from the mean value of the mark, and N stands for the number of respondents in the selected sample. It can be concluded that the organizations operating at the regional level, particularly those within them operating for 21 to 30 years, rated teamwork the best.

Apart from the tabular presentation, the mean values of the marks for teamwork in organizations of different lengths and levels of business operations are

Table 3

THE MEAN VALUE OF THE MARKS FOR TEAMWORK IN THE TEXTILE ORGANIZATIONS OF THE DIFFERENT LENGTHS AND LEVELS OF BUSINESS OPERATIONS

The business operations level	The length of the business operations of the organization	The mean value of the marks	Std. deviation	N
The local market	from 6 to 10 years	4.50	0.577	4
	from 11 to 20 years	5.00	0.000	3
	from 21 to 30 years	4.00	0.000	8
	over 40 years	4.00	0.000	2
	Total	4.29	0.470	17
The national market	up to 5 years	4.71	0.488	7
	from 6 to 10 years	5.00	0.000	2
	from 11 to 20 years	3.89	1.167	9
	from 21 to 30 years	2.90	1.370	10
	from 31 to 40 years	5.00	0.000	2
	over 40 years	3.50	1.732	4
	Total	3.85	1.329	34
The regional market	from 6 to 10 years	4.00	0.000	2
	from 11 to 20 years	4.25	0.886	8
	from 21 to 30 years	4.50	0.577	4
	over 40 years	4.33	1.000	9
	Total	4.30	0.822	23
The international market	from 6 to 10 years	4.53	0.516	15
	from 11 to 20 years	5.00	0.000	12
	from 21 to 30 years	3.76	0.944	21
	from 31 to 40 years	3.00	0.000	3
	over 40 years	3.27	1.009	11
	Total	4.06	0.973	62
Total	up to 5 years	4.71	0.488	7
	from 6 to 10 years	4.52	0.511	23
	from 11 to 20 years	4.50	0.880	32
	from 21 to 30 years	3.67	1.040	43
	from 31 to 40 years	3.80	1.095	5
	over 40 years	3.73	1.151	26
	Total	4.08	1.011	136

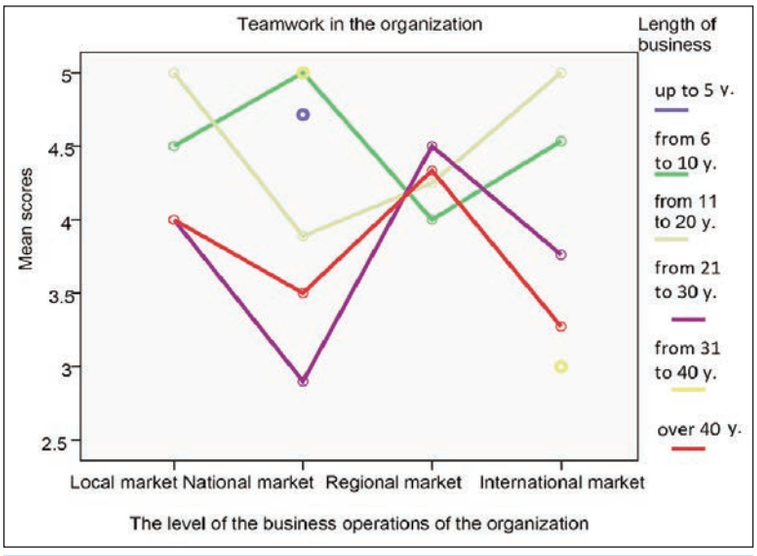

Fig. 1. The mean values of the marks for teamwork in the Serbian textile organizations

also technically presented using figure 1. It is noticeable that teamwork is rated the best by the organizations that do business in the local market in those operating from 11 to 20 years, by those operating in the national market from 31 to 40 years, and by those operating in the international market from 11 to 20 years.

The influence of the relations between the length of the business operations of the textile organization and the level of their business operations on teamwork is presented in table 4. In the column: The level of business operations/the length of business operations, Sig = 0.002, which is less than 0.05, so it can be assumed that there are considerable differences in the marks for teamwork in the organization. The influence of the relation between the level of business operations and the length of business operations is statistically significant.

After the analysis of the joint influence, separate influences were analysed. In column Sig, the value of the level of business operations reads Sig = 0.258 > 0.05, so a conclusion can be made that the level of business operations has no significant influence on the marks for teamwork in the organizations. In column Sig, the value of the length of business operations reads 0.003, which is less than 0.05, so a conclusion can be drawn that the length of business operations significantly influences the differences in the marks.

Based on this, it can be concluded that the level of business operations and the length of business operations play a significant role regarding the differences in the marks for teamwork in the organizations, perceived through the joint influence of the variables, whereas the individual influence is only significant for the length of business operations.

In a subsequent overview, the Tukey Test helped to establish which textile organizations particularly differ in the marks depending on the length of business operations. All the more so since it was noticed that the individual influence of the length of business operations differed.

Table 5 shows that a special difference is seen in the textile organizations that have been doing business for up to 5 years and from 21 to 30 years, from 6 to 10 years and from 21 to 30 years, from 6 to 10 years and over 40 years, from 11 to 20 years, and from 21 to 30 years, from 11 to 20 years, and over 40 years.

In parallel with the discovery of the key influences of the interaction of the variables in the subject-matter research study, the evaluation was conducted to learn between which Serbian textile organizations with different decision-makers there was a noticeable difference in teamwork which determines their outgoing performances independently of the level and period of their business operations. The results shown in table 6 reveal that the difference appears in the organizations in which decisions are made by the top management and the organizations in which decisions are made by the top management and the employees. The difference is also present in the organizations in which decisions are made by the top management and the employees and in those organizations in which the respondents expressed uncertainty concerning decision-makers.

Table 7 also shows the differences in the marks for teamwork in organizations in which there is a different leadership style. Based upon the outcomes, it can be noticed that teamwork differs in the organizations in which the leadership style is autocratic and participative, and in the organizations in which the leadership style is autocratic and democratic as well.

Table 4

THE INFLUENCE OF THE INTERACTION OF THE VARIABLES "THE LEVEL OF BUSINESS OPERATIONS" AND "THE LENGTH OF BUSINESS OPERATIONS" ON THE MARKS FOR TEAMWORK IN THE TEXTILE ORGANIZATIONS

The variables	Df	Mean Square	F	Sig.
The level of business operations	3	0.995	1.362	0.258
The length of business operations	5	2.816	3.856	0.003
The level of business operations/The length of business operations	10	2.187	2.995	0.002

Table 5

THE COMPARATIVE ANALYSIS OF THE TEXTILE ORGANIZATIONS OF THE DIFFERENT PERIODS OF BUSINESS OPERATIONS IN THE MARKS FOR TEAMWORK

(I) The length of the business operations of the organization	(J) The length of the business operations of the organization	The mean value of the difference (I–J)	Standard error	The significance of the error (Sig)	The 95% trust interval	
					The lower limit	The upper limit
up to 5 years	from 6 to 10 years	0.19	0.369	0.995	–0.88	1.26
	from 11 to 20 years	0.21	0.357	0.991	–0.82	1.25
	from 21 to 30 years	1.04(*)	0.348	0.039	0.03	2.05
	from 31 to 40 years	0.91	0.500	0.453	–0.54	2.36
	over 40 years	0.98	0.364	0.082	–0.07	2.04
from 6 to 10 years	up to 5 years	–0.19	0.369	0.995	–1.26	0.88
	from 11 to 20 years	0.02	0.234	1.000	–0.66	0.70
	from 21 to 30 years	0.85(*)	0.221	0.003	0.21	1.49
	from 31 to 40 years	0.72	0.422	0.527	–0.50	1.94
	over 40 years	0.79(*)	0.245	0.019	0.08	1.50
from 11 to 20 years	up to 5 years	–0.21	0.357	0.991	–1.25	0.82
	from 6 to 10 years	–0.02	0.234	1.000	–0.70	0.66
	from 21 to 30 years	0.83(*)	0.200	0.001	0.25	1.40
	from 31 to 40 years	0.70	0.411	0.532	–0.49	1.89
	over 40 years	0.77(*)	0.226	0.011	0.12	1.42
from 21 to 30 years	up to 5 years	–1.04(*)	0.348	0.039	–2.05	–0.03
	from 6 to 10 years	–0.85(*)	0.221	0.003	–1.49	–0.21
	from 11 to 20 years	–0.83(*)	0.200	0.001	–1.40	–0.25
	from 31 to 40 years	–0.13	0.404	1.000	–1.30	1.04
	over 40 years	–0.06	0.212	1.000	–0.67	0.56
from 31 to 40 years	up to 5 years	–0.91	0.500	0.453	–2.36	0.54
	from 6 to 10 years	–0.72	0.422	0.527	–1.94	0.50
	from 11 to 20 years	–0.70	0.411	0.532	–1.89	0.49
	from 21 to 30 years	0.13	0.404	1.000	–1.04	1.30
	over 40 years	0.07	0.417	1.000	–1.14	1.28
over 40 years	up to 5 years	–0.98	0.364	0.082	–2.04	0.07
	from 6 to 10 years	–0.79(*)	0.245	0.019	–1.50	–0.08
	from 11 to 20 years	–0.77(*)	0.226	0.011	–1.42	–0.12
	from 21 to 30 years	0.06	0.212	1.000	–0.56	0.67
	from 31 to 40 years	–0.07	0.417	1.000	–1.28	1.14

CONCLUSIONS

In the finalized research study, all the textile organizations included in the sample are privately owned. The largest number of them has been doing business in the period between 11 and 30 years, the number of the organizations according to the size being simultaneously proportional. A large percentage of the sampled organizations do business in the international market and in the largest percentage of the organizations, decisions are made by the owners and the top management. The participative management style is dominant in organizations, with the prevailing functional centralized organizational structure that repeatedly determines the differences in the marks for teamwork.

The answers given by the respondents coming from organizations of different business operations levels considerably differed from each other concerning the marks for some considered characteristics. So, the performance is “the qualitative business operations of the organization about equivalent rivals”, “teamwork in the organization”, “the probability that the organization will achieve total business excellence at all the levels of business operations” and “the level at which the organization’s management is consistent and explicit” rank with the average mark greater than 4. The organizational performances ranked somewhat lower with an average mark below 3.70 are “the level at which the idea of business culture in the organization is achieved” and “the scope of the engagement of the consultants”. The obtained results point

Table 6

THE DIFFERENCES IN THE MARKS FOR TEAMWORK IN THE TEXTILE ORGANIZATIONS IN WHICH THERE ARE DIFFERENT DECISION-MAKERS

Teamwork in the organization		The mean value of the difference (I–J)	Standard error	The significance of the error (Sig)	The 95% trust interval	
(I) In the organization, decisions are made by	(J) In the organization, decisions are made by				The lower limit	The upper limit
The owner	The top management	0.320	0.185	0.312	–0.16	0.80
	The top management and the employees	–0.402	0.248	0.372	–1.05	0.24
	I am not sure	1.169	0.579	0.186	–0.34	2.68
The top management	The owner	–0.320	0.185	0.312	–0.80	0.16
	The top management and the employees	–0.722(*)	0.252	0.025	–1.38	–0.07
	I am not sure	0.849	0.580	0.463	–0.66	2.36
The top management and the employees	The owner	0.402	0.248	0.372	–0.24	1.05
	The top management	0.722(*)	0.252	0.025	0.07	1.38
	I am not sure	1.571(*)	0.604	0.050	0.00	3.14
I am not sure	The owner	–1.169	0.579	0.186	–2.68	0.34
	The top management	–0.849	0.580	0.463	–2.36	0.66
	The top management and the employees	–1.571(*)	0.604	0.050	–3.14	0.00

Table 7

THE DIFFERENCES IN THE MARKS FOR TEAMWORK IN THE ORGANIZATIONS IN WHICH THERE IS A DIFFERENT MANAGEMENT STYLE

Teamwork in the organization		The mean value of the difference (I–J)	The standard error	The significance of the error (Sig)	The 95% trust interval	
(I) The management style in the organization is	(J) The management style in the organization is				The lower limit	The upper limit
Autocratic	Participative	–0.792(*)	0.219	0.002	–1.36	–0.22
	Democratic	–0.962(*)	0.234	0.000	–1.57	–0.35
	I am not sure	–0.321	0.383	0.835	–1.32	0.67
Participative	Autocratic	0.792(*)	0.219	0.002	0.22	1.36
	Democratic	–0.170	0.194	0.818	–0.67	0.34
	I am not sure	0.470	0.360	0.560	–0.47	1.41
Democratic	Autocratic	0.962(*)	0.234	0.000	0.35	1.57
	Participative	0.170	0.194	0.818	–0.34	0.67
	I am not sure	0.640	0.369	0.310	–0.32	1.60
I am not sure	Autocratic	0.321	0.383	0.835	–0.67	1.32
	Participative	–0.470	0.360	0.560	–1.41	0.47
	Democratic	–0.640	0.369	0.310	–1.60	0.32

to the conclusion that teamwork in the structure of the mentioned elements is profiled as an essential feature of the effective business of Serbian textile organizations, which has a decisive influence on the scope of acquisition and maintenance of their competitive advantage.

The results of the research study further show that the length of the business operations of an organization and the level of the business operations of an organization have an important joint influence on all the analysed characteristics that should ensure the business success of the organization. As far as individual influences are concerned, it is noticeable that

the length of business operations appreciably influences the differences in the qualitative business operations of the organization about the comparable competition and teamwork in the organization. The level of the business operations of the organization (the local market, the national market, the regional market, the international market) exerts a perceptible influence on the differences in the expectation that the organization will achieve total business excellence and on the level at which the organization's management is consistent and explicit. It is perceptible that teamwork in the national textile organizations doing business in the local market is rated the best in those from 11 to 20 years, in the national market in those from 31 to 40 years, and those operating in the international market from 11 to 20 years.

Depending on decision-makers in the organization and the disproportion in the management style, significant differences appear in the organizations concerning the level at which the idea of business culture in the organization is achieved and teamwork in the organization. Based upon the results, it is noticeable that teamwork differs in organizations in which there is an autocratic management style and participative management style, as well as in organizations in which the management style is autocratic and democratic.

Ultimately, the results of the study show that teamwork has a direct and significant influence on a textile organization's human capital and performance. The level and the length of business lay a significant role in the differences in teamwork ratings of teamwork in organizations, observed through the joint influence of the variables, while the individual influence is significant only for the length of business. The obtained results further point to the conclusion that organizations that operate at the regional level, and within them, those that operate from 21 to 30 years old, are the most valued teamwork. Teamwork is one of the foundations of interpersonal relations in the organization, valued through business culture as a business philosophy, and as such has a decisive influence on its work. Most of the respondents positively evaluated the team philosophy of business and are familiar with its importance in everyday business.

ACKNOWLEDGMENTS

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Recovery system-based textile actuators

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ABSTRACT – REZUMAT

Recovery system-based textile actuators

This paper presents a medical recovery system based on electrical stimuli transmitted through textile electrodes based on copper microparticles. The textile electrodes are connected to an electronic device capable of generating transcutaneous electrical nerve stimulation (TENS) using low-frequency (0–100 Hz) (diadynamic or interference) electrical currents. To evaluate the system, the current intensity, frequency and supply voltage were measured using different multimeters (Agilent Technologies U3606A and portable digital multimeter), and the signal was analysed. Depending on the intensity of the transcutaneous electrostimulation program, obtained by varying the electrical parameters, such as electrical voltage (U, mV), current intensity (I, mA) and frequency (f, Hz), it is possible that the patient feels pinches or vibration.

Keywords: *textile, electrodes, stimuli, actuators, TENS, electrostimulation*

Sistem de recuperare pe bază de actuatori textili

Această lucrare prezintă un sistem de recuperare medicală bazat pe stimuli electrici transmişi prin electrozi textili pe bază de microparticule de cupru. Electrozii textili sunt conectați la un dispozitiv electronic capabil să genereze stimulare electrică transcutanată nervoasă (TENS) utilizând curenți electrici de frecvență joasă (curenţi diadinamici şi interferenţiali având frecvenţa între 0 şi 100 Hz). Pentru evaluarea sistemului, intensitatea curentului, frecvența și tensiunea de alimentare au fost măsurate cu ajutorul unor multimetre (Agilent Technologies U3606A și multimetru digital portabil), iar semnalul a fost analizat. În funcție de intensitatea programului de electrostimulare transcutanată, obținută prin variaţia parametrilor electrici, precum tensiunea electrică (U, mV), intensitatea curentului (I, mA) și frecvența (f, Hz), este posibil ca pacientul să simtă ciupituri sau vibrații.

Cuvinte-cheie: *textile, electrozi, stimuli, actuatori, TENS, electrostimulare*

INTRODUCTION

The transcutaneous electrical nerve stimulation (TENS) technique allows electrical stimulation of nerves and muscles and is frequently used for recovery, pain control, sports and fitness. By applying low-frequency currents, electrotherapeutic effects such as analgesic, neuromuscular stimulation, vasodilator, biotrophic and regulation of the neurovegetative system (SNV) can be obtained.

The electrostimulation effect is obtained by modulating the current, varying parameters such as frequency, amplitude and duration, to reduce accommodation to the stimulus because accommodation to the stimulus can decrease the sensory perception of the stimulus. Thus, the current with an inhibitory effect has a frequency of 100 Hz, and the current with a frequency of 50 Hz acts dynamically, determining the support of muscle tone, the elimination of edema, the reduction of pain and the increase of muscle tone [1, 2].

Transcutaneous electrical nerve stimulation (TENS) systems are mainly used in medical recovery therapy for pain control [3–6], and some researchers recommend using TENS following thoracic surgery [7]. There are concerns about integrating wearable electrodes into textiles through conductive yarns [8], embroideries [9–11], pads with integrated TENS [12] electrodes [10] for the knee or smart gloves for pain relief in the hand and forearm in cases of carpal tunnel syndrome [13], diabetic neuropathy [14], nerve stimulation for persons with fibromyalgia [15] or rehabilitation in cases of wrist stiffness secondary to distal radioulnar fracture [16].

Some researchers have described the use of transcutaneous electrostimulation electrodes based on a conductive surface made by fabric immersion on commercial carbon-based dispersions (AquaCyl AQ0301 based on multiwalled carbon nanotubes (MWCNTs)) [17], electrodes embroidered with conductive wires (X-Silver and X-Static) for electrostimulation in the knee area [18, 19] or nanostructured electrodes based on Ti and Cu [20].

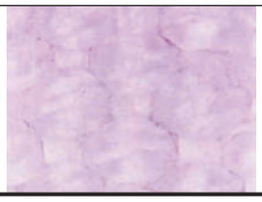
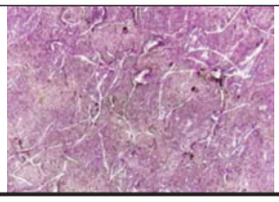
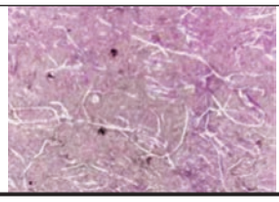
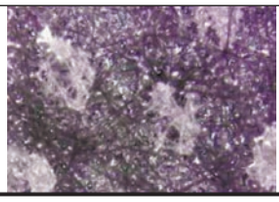
EXPERIMENTAL PART

Development of the prototypes used textile electrodes obtained by coating the fabrics with conductive pastes based on nickel, which was previously hydrophilized using RF plasma oxygen technology using an RF generator in MHz (Ni1) and kHz (Ni2).

Table 1 shows the images obtained by electron microscopy (magnitude 60x):

Table 1

ANALYSIS OF THE SURFACE TOPOGRAPHY OF TEXTILE ELECTRODES BY DIGITAL ELECTRON MICROSCOPY (SAMPLES P1, P2, P3, P4)

Magnitudine 60x			
P1	P2	P3	P4
			

– P1 (raw fabric);
– Electrode P2 based on conductive paste with Ni microparticles deposited on textile P1 (treated in RF plasma O_2 using an RF generator in MHz);
– Electrode P3 based on conductive paste with Ni microparticles deposited on fabric P1 (treated in RF plasma O_2 using an RF generator in kHz);
– Classic electrode (P4) based on electrode gel.

The textile electrodes P2–P3, having a surface resistance of 10^3–10^5 Ω, were used to develop prototypes M1–M2 by integrating electrodes P2 and P3 into knitted sleeves.

Textile electrodes connected to the transcutaneous electrostimulation (TENS) device (figure 1, *c* and d) using low-frequency (0–100 Hz) (diadynamic or interference) currents were used for testing. Using low-frequency currents can obtain electrotherapeutic effects such as analgesic, neuromuscular stimulation, vasodilator, biotrophic and neurovegetative system (SNV) regulation.

The electrostimulation effect is obtained by modulating the current, varying parameters such as frequency, amplitude and duration, to reduce accommodation to the stimulus because accommodation to the stimulus can decrease the sensory perception of the stimulus. Thus, the current with an inhibitory effect has a frequency of 100 Hz, and the current with a frequency of 50 Hz acts dynamically, determining the support of muscle tone, the elimination of edema, the reduction of pain and the increase of muscle tone.

Depending on the intensity of the transcutaneous electrostimulation program, which is obtained by

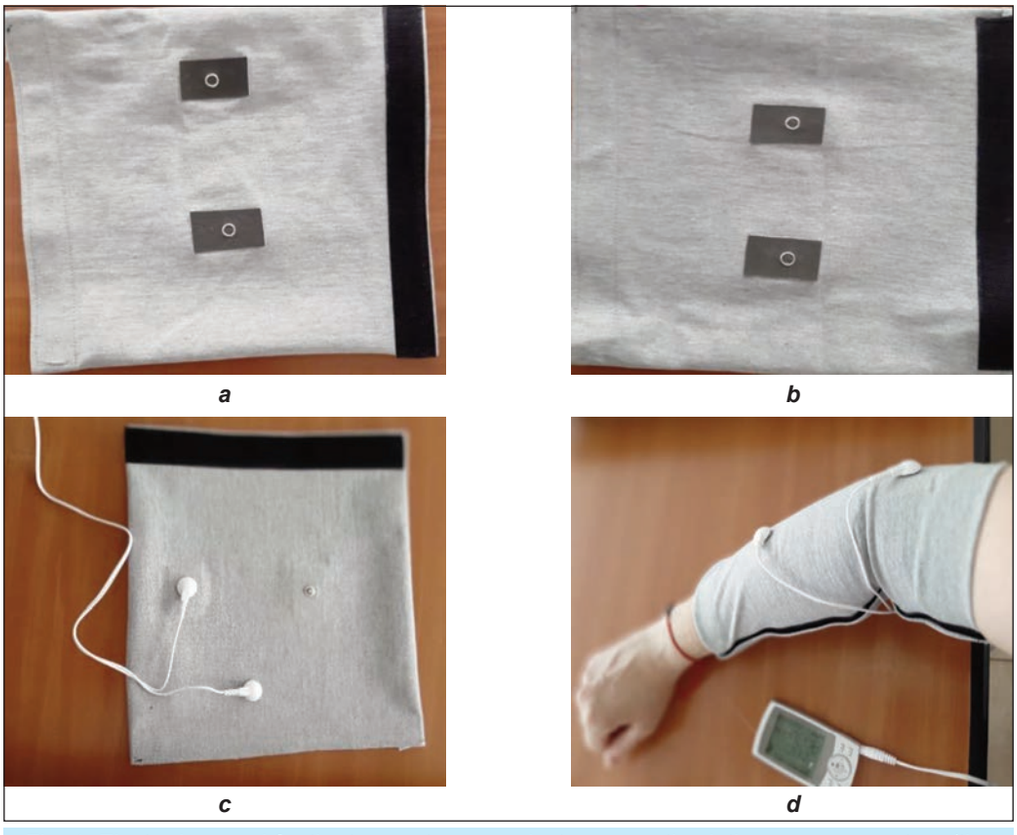


Fig. 1. Electrodes used for the transcutaneous electroneuro-stimulation recovery system (the surface view that comes into direct contact with the skin): *a* – M1 prototype based on Ni_1-based textile electrodes; *b* – M2 prototype based on Ni_2 textile electrodes; *c* – prototype M1 based on textile electrodes (front view); *d* – testing the M1 prototype

varying the electrical parameters, such as electrical voltage (U, mV), current intensity (I, mA) and frequency (f, Hz), it is possible that the patient feels a slight vibration.

The functionality of the prototypes is based on transcutaneous electrostimulation consisting of generating electrical impulses similar to those produced in the body, which are transmitted to nerves or muscle fibres through electrodes.

The study aims to investigate the data from transcutaneous electrostimulation devices (e.g., voltage, current intensity and frequency) produced during electrostimulation activity and passing the textile electrode barriers. The study's results consist of investigating the output data from the transcutaneous electrostimulation devices (voltage, current intensity and frequency) produced during the electrostimulation activity and passing the textile electrode barriers. To evaluate the prototypes, the current intensity, frequency and supply voltage were measured using multimeters (Agilent Technologies U3606A (figure 2) and PC-Link digital multimeter (figures 3, 4 and 5). Figures 3, 4 and 5 present the waveforms for current intensity, voltage and frequency transmitted through the TENS device using surface electrode textiles. The Oy axis represents the amplitude of the signal and time on the Ox axis.

Figure 6 shows the digital signals (245 samples of frequency in Hz, intensity in mA and voltage in mV) as multiple series.

Figure 7 shows the power spectral density for the spectra of the acquired digital signals (245 samples:

Fig. 2. Determination of the variation of the electric current in the conductive textile electrodes and of the frequency

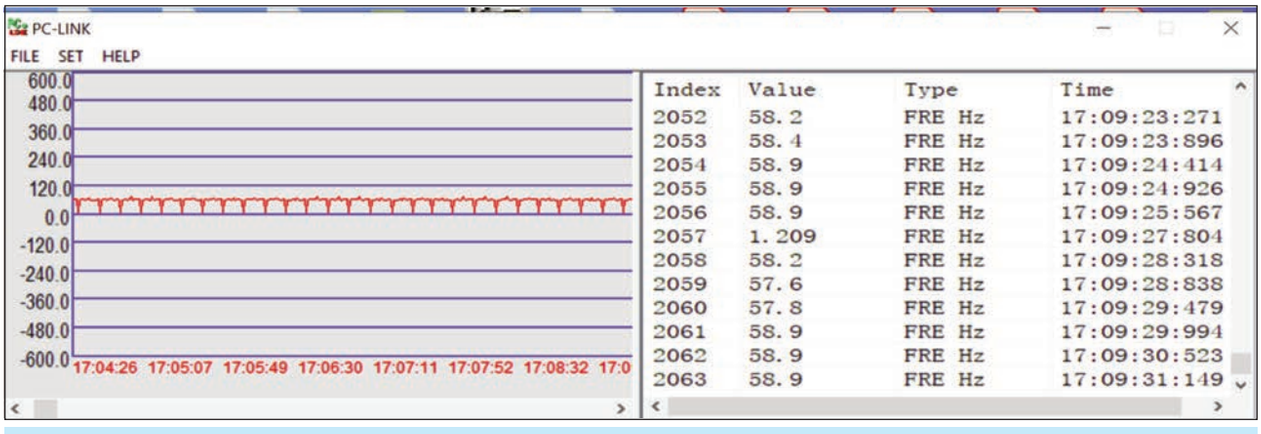


Fig. 3. Frequency measurement using PC-Link graphical view of the acquired digital signal for frequency (f, Hz)

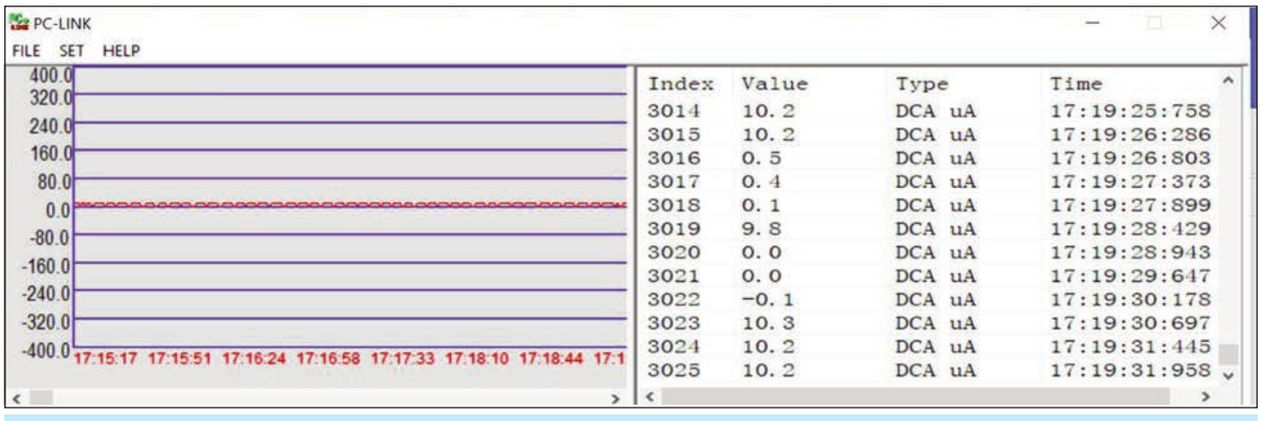


Fig. 4. Current intensity measurement using PC-Link graphical view software of the acquired digital signal for electric intensity (I, μA)

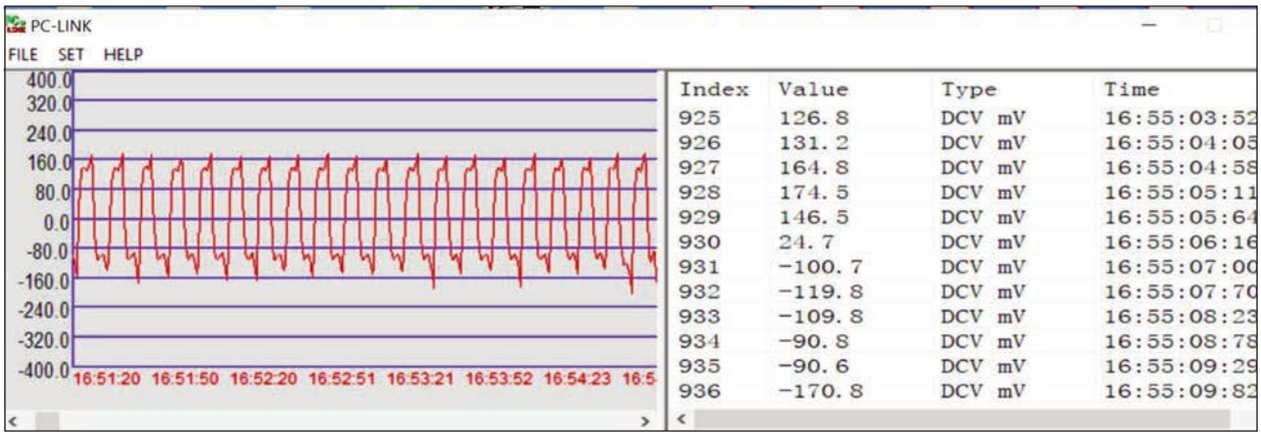


Fig. 5. Measurement of electrical voltage using software PC-Link graphical view of the acquired digital signal for electrical voltage (U, mV)

$f(t)$, $I(t)$, $U(t)$). The spectrum of a signal X(t) (for example, $f(t)$, $I(t)$ or $U(t)$) represents all the components in the frequency domain and is defined by the Fourier transform of that signal:

$$X(f) = \mathrm{F}\{x(t)\} = \int_{-\infty}^{+\infty} x(t) \cdot e^{-j2\pi ft}\, dt \qquad (1)$$

The power spectral density ($S_x(f)$ [W/Hz]) of the signal $X(t)$ represents the power distribution of the components in the frequency domain:

$$S_x(f) = \lim_{T\to\infty} \frac{\overline{|\mathrm{F}\{X_T(t)\}|^2}}{T} \qquad (2)$$

where $X_T(t)$ is the restriction of the random signal $X(t)$ to the interval $[T/2, T/2]$.

RESULTS AND DISCUSSION

In the test performed using the textile electrodes attached to the arm/forearm areas, the electrical stimuli transmitted by the conductive textile electrodes did not generate pain in contact with the skin. Electrical impulses transmitted to the tissue via textile electrodes affect neurotransmission in neural circuits, synapses, and muscle groups. The effect of electrostimulation is evident after repeating the procedures.

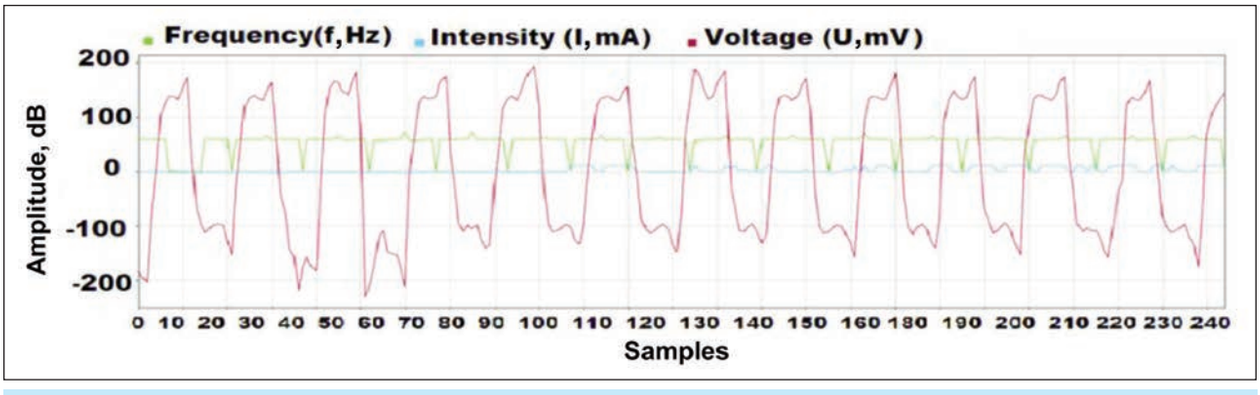


Fig. 6. Digital signals represented as multiple series

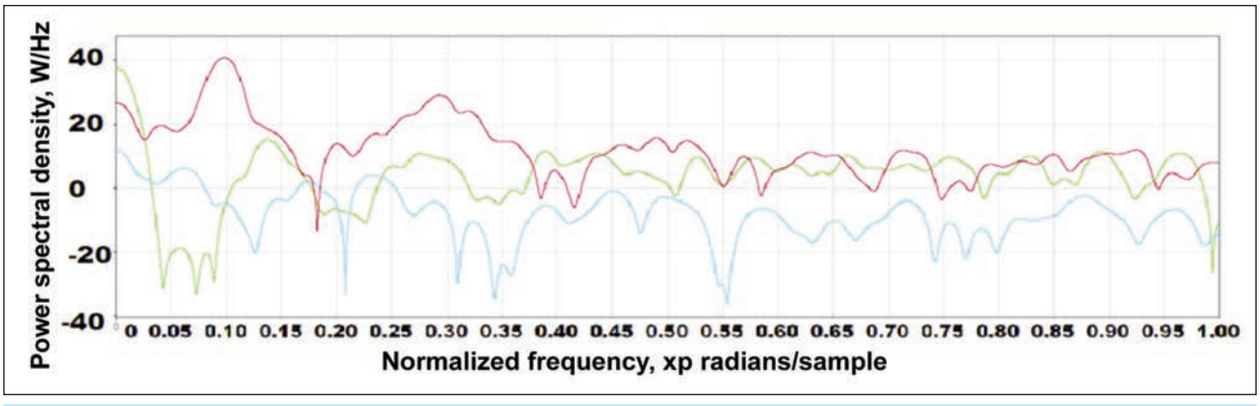


Fig. 7. Power spectral density $S_x(f)$, where $x \in \{f, I, U\}$) of the acquired digital signals f, I and U $x\pi$ radians/sample

Overall, it can be appreciated that electrodes made of textile materials remove the disadvantages known in the case of using gel, such as:

1. small amounts of gel may remain stuck to the skin;
2. drying the gel on the electrode makes its use practically impossible.

Testing the prototypes of a knitted sleeve with integrated textile electrodes and a TENS highlighted that transcutaneous electroneurostimulation can be generated using surface electrodes based on textile materials.

CONCLUSIONS

In conclusion, by analysing prototypes M1–M2, the following can be concluded:

- Textile materials covered with conductive pastes based on a polymer matrix and metal microparticles (Ni) can be used in systems based on actuators as electrodes to transmit low-frequency currents (0–100 Hz) for transcutaneous electrostimulation at the skin level;
- Comparatively analysing the classic (wet) electrodes based on conductive gel and the textile (dry) electrodes, it can be appreciated that the electrodes made of textile materials remove the disadvantages known in the case of using gel;
- Experimental models M1 and M2 (with a surface resistance of 10^3 Ω) allow better transmission of electric current and are recommended for use as surface electrodes for transcutaneous electrostimulation systems.

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Comparative analysis of natural fibres characteristics as composite reinforcement

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ABSTRACT – REZUMAT

Comparative analysis of natural fibres characteristics as composite reinforcement

Due to environmental concerns, natural fibre development is essential, and its utilization has recently attracted more attention. The use of jute, hemp, linen, sisal, and banana fibres in textile production is widespread around the world. Additionally, these fibres are widely accessible in many countries, including Pakistan, India, China, Turkey, and the United States. The objective of this study is to compare the physio-mechanical characteristics of the aforementioned natural fibres. All of these fibres were obtained locally. Scanning electron microscopy was used to examine the surface morphology of these natural fibres, and the results revealed that banana and sisal fibres are hollow in comparison to other fibres. A single fibre tensile testing apparatus was used to evaluate the mechanical characteristics. Banana and sisal fibres demonstrated the highest breaking strength and elongation, respectively. Fourier transform infrared spectroscopy was used to investigate the functional groups of these natural fibres. Differential scanning calorimetry and thermogravimetric analysis were used to investigate their thermal behaviour. Energy Dispersive X-Ray Analysis and Raman analysis were also carried out to ascertain the chemical composition.

Keywords: *natural fibres, mechanical properties, SEM, FTIR, TGA, DSC, EDX, Raman analysis*

Analiza comparativă a caracteristicilor fibrelor naturale ca armătură pentru compozite

Datorită preocupărilor legate de mediu, dezvoltarea fibrelor naturale este esențială, iar utilizarea lor a atras recent şi mai multă atenție. Utilizarea fibrelor de iută, cânepă, in, sisal și banane în producția de textile este larg răspândită în întreaga lume. În plus, aceste fibre sunt accesibile pe scară largă în multe țări, inclusiv Pakistan, India, China, Turcia și Statele Unite. Obiectivul acestui studiu este de a compara caracteristicile fizio-mecanice ale fibrelor naturale menționate mai sus. Toate aceste fibre au fost obținute local. Microscopia electronică cu scanare a fost folosită pentru a examina morfologia suprafeței acestor fibre naturale, iar rezultatele au arătat că fibrele de banană și sisal prezintă lumen, în comparație cu alte fibre. Pentru a evalua caracteristicile mecanice a fost utilizat un singur aparat de testare a rezistenţei la rupere a fibrelor. Valorile cele mai mari ale rezistenţei şi alungirii la rupere au fost înregistrate pentru fibrele de banană și, respectiv, de sisal. Spectroscopia în infraroșu cu transformare Fourier a fost utilizată pentru a investiga grupele funcționale ale acestor fibre naturale. Scanarea calorimetrică diferențială și analiza termogravimetrică au fost utilizate pentru a investiga comportamentul lor termic. Spectroscopia de raze X cu dispersie de energie și analiza Raman au fost, de asemenea, efectuate pentru a stabili compoziția chimică.

Cuvinte-cheie: *fibre naturale, proprietăți mecanice, SEM, FTIR, TGA, DSC, EDX, analiză Raman*

INTRODUCTION

Due to environmental concerns [1–4], the development of natural fibres is essential, and the usage of natural fibres has recently drawn more attention [5, 6]. The utilization of natural plant fibres as reinforcing elements has drawn more attention in recent years. Currently, India produces about 14.5 million tons of natural fibres annually, compared to a global production of 45.5 million tons. These fibres were strengthened using a variety of matrixes, including polyester, epoxy, vinyl ester, phenol-formaldehyde, and others. It was utilized as a substitute for synthetic fibres. Natural fibres can be categorized into a wide range of categories, including bast, leaf, seed, fruit, and wood fibre. Conventional applications of these fibres included rope, roofing, home furnishings, bandages, and a variety of other things. Composites with natural fibre reinforcement have good mechanical and thermal characteristics. Natural fibres have replaced synthetic polymers for composite materials used in the automotive, packaging, and aerospace industries. Natural fibres are becoming more popular as their use is expanded into engineering end uses like construction materials. High specific strength and modulus, availability, low cost, lightweight, recyclability, biodegradability, lack of health risks, and non-abrasive nature are the key benefits of these natural fibre-reinforced composites [7–9].

Glass fibre in composite materials might be replaced with natural fibres. Natural fibres are a desirable option because of their inherent benefits, which include low density, biodegradability, and mechanical

qualities that are comparable to those of glass fibre composites [10, 11]. Stalks, stems, seeds, roots, leaves, and fruit husks are just a few examples of the natural fibres that have been taken from various plant parts and employed as reinforcement in polymer-based composites to create industrial components. The natural fibres that are frequently used include jute, flax, kenaf, hemp, ramie (extracted from bast), sisal, pineapple, palf (extracted from leaf), cotton, kapok (extracted from seed), coir (extracted from fruit), bamboo, elephant grass (extracted from stalk), etc.
These fibres have also evolved into the primary determining elements in the choice, creation, and design of the components [12–14]. Natural fibres are employed in a variety of ways, including short, continuous, and randomly oriented. Due to their exceptional integrity and conformability for cutting-edge structural applications, woven fabric mats have recently attracted the most attention and are thought to be the most appealing [15, 16]. Compared to reinforcements that are short and randomly oriented, some studies have shown how the functional qualities of composites using woven fabric reinforcement from natural fibres are improved [17, 18].
Some researchers have looked into the combined effects of using various natural fibres as reinforcement to create composites made of hybridized natural fibres [19, 20]. Hybrid composites made from banana and kenaf have been studied for their impact on mechanical characteristics. It was claimed that as compared to composites made of separate fibres, the hybridization of kenaf and banana fibres increased the mechanical strength. In line with this, a different study claims that sisal and oil palm were hybridized to enhance the composites' mechanical properties [21].
Natural fibres have a high cellulose content, are inexpensive, easily renewable, and have the potential to be reinforced with polymers. Natural fibres are becoming more popular since they are affordable, light, strong, and biodegradable. They are also environmentally friendly due to ease of recyclability [22, 23]. Additionally, natural fibre composites are said to have environmental benefits such as decreased reliance on non-renewable energy and material sources, lower pollutant and greenhouse gas emissions, improved energy recovery, and end-of-life component biodegradability [24]. The natural fibre is thought to be an environmentally friendly material used as reinforcement for creating biocomposites, suitable for many industrial applications because of its high hydroxyl content of cellulose, which makes it susceptible to water absorption and affects the mechanical properties of materials [25, 26]. The fundamental function of cellulose, which makes up a bigger portion of natural plant fibres, is to absorb moisture. Some spirally coiled cellulose microfibres are joined by an amorphous lignin matrix. However, it contributes to defending against biological assaults and giving strength [27].
Using natural fibre in reinforced composites has numerous technological and environmental advantages. Numerous natural fibres, such as jute, straw, Flax, hemp, wood, sugarcane, bamboo, grass, kenaf, sisal, coir, rice husks, wheat, barley, oats, kapok, bagasse, cotton, mulberry, banana fibre, raphia, pineapple leaf fibre, and papyrus, have been investigated for use in plastics. The matrix materials used to reinforce the fibres are categorized as thermosets, thermoplastics and elastomers [28].
In addition, numerous natural fibres, including kenaf, hemp, flax, jute, sisal, banana, coir, and pineapple leaf fibres, are gaining increased prominence as environmentally friendly reinforcement for composite materials [29, 30]. The building and automobile industries utilize sisal more than any other fibre. This could be due to its remarkable mechanical properties, which are why it is utilized to produce concrete buildings and automotive car parts [31]. Similar to other plant-based natural fibres, hemp is a lignocellulosic reinforcing component used in composites. It is employed in a variety of structural applications, and the European Industrial Hemp Association (EIHA) organizes an annual hemp conference to share information on the most recent advancements in the use of hemp fibres in the food, food supplements, textile, automotive, and pharmaceutical industries. Studies on sisal plants in Kenya, China, and India have shown the mechanical properties of sisal fibres. Sisal fibre has a tensile strength of 347 MPa in Kenya and China and 400–700 MPa in India. Compared to untreated fibres, treated fibre-reinforced composites typically have a higher tensile strength [32, 33].
Natural fibre composites have the potential to take the place of expensive glass fibre in applications requiring little load-bearing capacity. Plant fibres provide several well-known benefits, including low cost and reduced tool wear during processing [34]. When it comes to transportation, such as cars, trains, and aircraft, natural fibres have proven to be more durable than synthetic fibre. For ceiling panelling and partition boards, other industries that use them are construction, building, packing, consumer goods, and military [35]. The automobile industry greatly benefits from the low density of natural fibres. According to a study, replacing 30% of glass fibres with 65% of hemp fibres results in a net energy savings of 50,000 MJ, or 3 tons less emissions [36, 37]. Many studies have been conducted on natural fibres, including topics like extraction, morphology, mechanical properties, etc. The comparison of five distinct natural fibres, including jute, hemp, linen, sisal, and banana fibres, is carried out in this research project.
The relevant composites were subjected to Scanning electron microscopy (SEM), tensile testing, Fourier-transform infrared spectroscopy (FTIR), Thermogravimetric Analysis (TGA), Differential scanning calorimetry (DSC), Energy Dispersive X-Ray (EDX), and Raman analysis to describe their thermal and physio-mechanical characteristics.

MATERIALS AND METHODS

Materials

Five distinct kinds of natural fibres, including jute, hemp, linen, sisal, and banana fibres, are provided by Elvin Textile Bursa, Turkey. All fibres are applied in their unprocessed, raw state.

Methodology

Morphological observations and fibre characterizations have been carried out at Bursa Technology Coordination and R&D Center (BUTEKOM).

Scanning Electron Microscopy (SEM)

Surface morphology of the fibres analysed by SEM (HITACHI TM3030 PLUS, Japan).

Tensile properties

According to ISO 5079, the mechanical characteristics, such as tensile strength (maximum breaking force), maximum elongation, and maximum elongation percentage, were assessed using a SHIMADZU AGS-X tensile tester.

Fourier Transform Infrared Spectroscopy (FTIR) analysis

To identify the functional groups of the fibres, FTIR analysis was done. Utilizing a Shimadzu IR-Tracer100 device in ATR mode and accordance with ASTM E1252, infrared spectroscopy (FTIR) analysis was carried out.

Thermogravimetric analysis (TGA)

TGA is applied to measure sample mass loss caused by temperature. It is employed to describe the thermal stability of the sample and the rate of decomposition. TGA of fibres was carried out using a SDTQ600 TA Thermogravimetric analyser in accordance with ISO 11358-1. The temperature range of the TGA was 20 °C to 600 °C with a heating rate of 20 °C/min under a nitrogen atmosphere and then heated from 600 °C to 900 °C under an oxygen atmosphere.

Differential scanning calorimetry (DSC) analysis

DSC is a popular thermal analysis used to identify temperature-related changes in the polymer, such as melting, crystallization, degradation, and glass transition. Q 2000 TA Instruments differential scanning calorimeter was used for DSC measurements in accordance with ASTM E1952 (ISO 11357-3). Under a nitrogen atmosphere, samples were heated from 40 °C to 280 °C at a rate of 10 °C/min.

Raman analysis

With a laser excitation wavelength of 785 nm, 1 mW laser intensity, and a 50X objective, Raman spectra were captured by a Renishaw inVia Reflex Raman microscope. Each sample was positioned on a piece of glass. Molecular vibrations can be determined using Raman spectroscopy. There is a significant capacity for water absorption due to the hydrophilic surface of the lignocellulosic structure. Water-related absorption bands do not significantly affect Raman spectroscopy as they do in FTIR.

RESULTS AND DISCUSSION

Scanning Electron Microscopy (SEM)

The longitudinal and cross-sectional views of the natural fibres are given below from figure 1 to figure 5. These can be compared with each other cross-sectionally and longitudinally. Hemp and linen resemble solid rods, while banana, sisal, and jute are straight, cylindrical fibres. In contrast to hemp and linen fibres, SEM micrographs demonstrated that banana, sisal, and jute fibres are hollow. Hemp, jute, and linen fibres all have some notches on their surfaces, according to SEM results. The smooth surface of linen fibre provides it with more softness than other natural fibres, and this makes it popular in clothing fabrics, particularly for women. Unlike other fibres, which have a smoother surface, banana fibres feature grooves on their surface. Banana fibres are a more practical solution for better moisture management and air permeability due to the surface grooves. However, banana fibres cannot be used as a substitute for linen fibre in clothing fabrics because of their rough surface.

Tensile strength and elongation

The capacity of a material to withstand the tensile load before failing is explained by its tensile characteristics. To ascertain the breaking strength or tensile strength, maximum elongation, and elongation % of natural fibre, the tensile test was carried out using the tensile tester. Finding the right application for the particular fibre is made much easier by these characteristics. The results of tensile tests are presented in table 1.

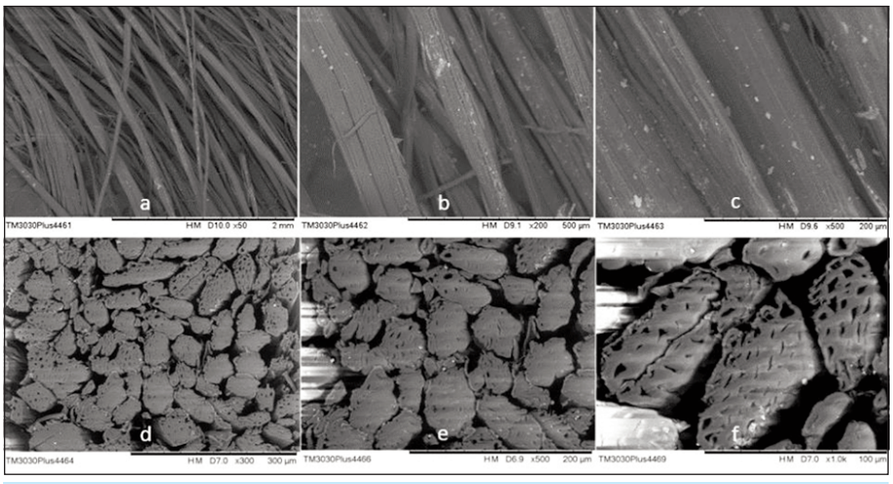

Fig. 1. SEM images for jute fibres: *a* – longitudinal view at x50; *b* – longitudinal view at x200; *c* – longitudinal view at x500; *d* – cross-sectional view at x300; *e* – cross-sectional view at x500; *f* – cross-sectional view at x1000

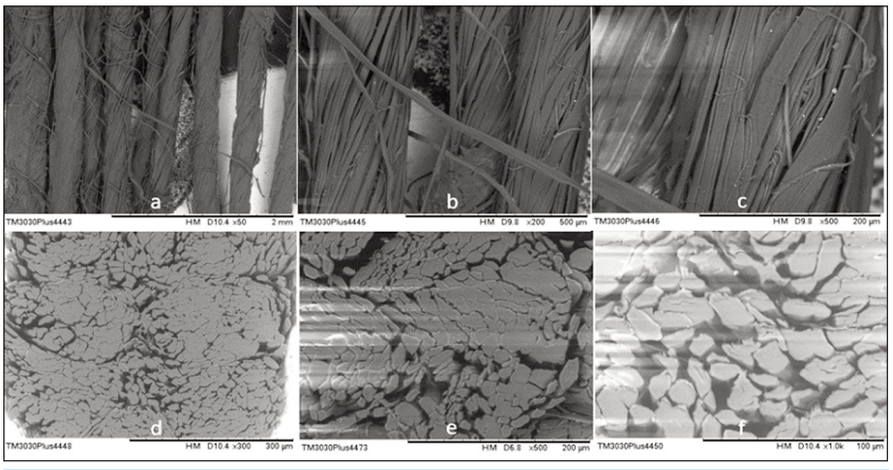

Fig. 2. SEM images for hemp fibres: *a* – longitudinal view at x50; *b* – longitudinal view at x200; *c* – longitudinal view at x500; *d* – cross-sectional view at x300; *e* – cross-sectional view at x500; *f* – cross-sectional view at x1000

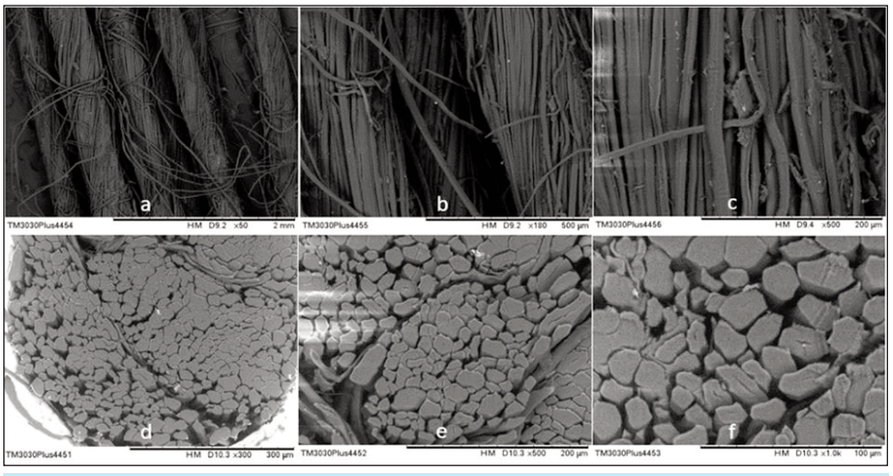

Fig. 3. SEM images for linen fibres: *a* – longitudinal view at x50; *b* – longitudinal view at x180; *c* – longitudinal view at x500; *d* – cross-sectional view at x300; *e* – cross-sectional view at x500; *f* – cross-sectional view at x1000

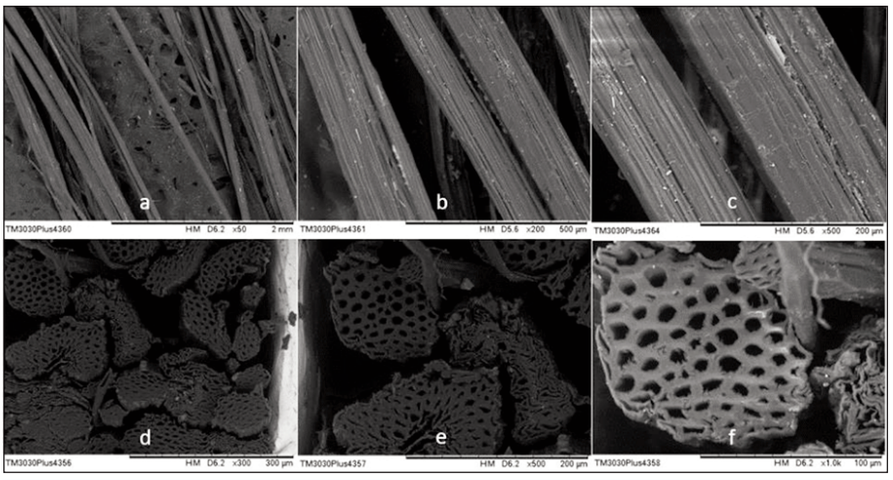

Fig. 4. SEM images for Sisal fibres: *a* – longitudinal view at x50; *b* – longitudinal view at x200; *c* – longitudinal view at x500; *d* – cross-sectional view at x300; *e* – cross-sectional view at x500; *f* – cross-sectional view at x1000

Figure 6 illustrates the tensile strength graphs. These graphs contain two separate regions: the first is an elastic zone, and the second is a plastic region. The area in which the curve deviates from its intended direction is addressed as the elastic region of the fibre. The permanent strain in the fibres can be seen when the curve descends and approaches the x-axis. This point displays the ultimate point of rupture of the fibre. Sisal fibre has the highest breaking strength, according to the graphs. Sisal fibre has a larger diameter or thickness than the other fibres, as demonstrated in the SEM examination, and as a result, it has a higher tensile strength.

Since hemp fibre has the smallest thickness and diameter among the fibres, it also has the worst tensile strength. Since hemp and linen fibres appear to have the same internal structure from a cross-sectional perspective and linen fibre has a slightly higher thickness than hemp fibre, it exhibits slightly better tensile strength.

FTIR measurements

Results from 20 scans with 8 cm^{-1} resolution between 600 cm^{-1} and 4000 cm^{-1} were acquired using FTIR. FTIR spectra of jute, hemp, linen, sisal, and banana fibres are presented in figure 7. The basic components of natural fibres are cellulose, hemicellulose, and lignin, which define their physical characteristics. Pectin and waxes are also present in some natural fibres, albeit in very small concentrations. Table 2 shows the chemical composition of jute, hemp, linen, sisal, and banana fibres. The vibrational bands of these elements are represented by the peaks in the FTIR spectra. The O-H stretching vibration is related to the broad peak at 3000–3600 cm^{-1}. The emergence of very strong and widespread absorption was a blatant sign that the fibre contained several hydroxyl groups. The asymmetric and symmetric C-H vibrations from the -CH_2

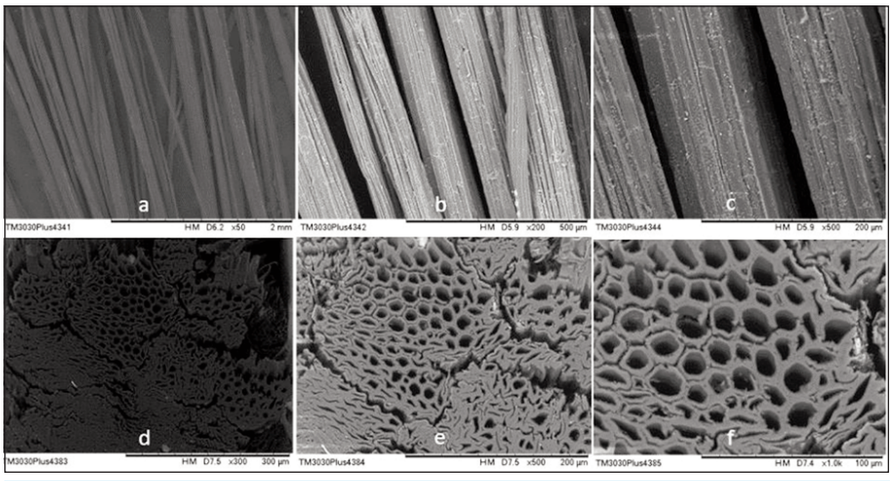

Fig. 5. SEM images for banana fibres: *a* – longitudinal view at x50; *b* – longitudinal view at x200; *c* – longitudinal view at x500; *d* – cross-sectional view at x300; *e* – cross-sectional view at x500; *f* – cross-sectional view at x1000

group of cellulose and hemicellulose, respectively, are represented by the peaks at about 2900 cm^{-1} and 2850 cm^{-1}. The carbonyl C=O bond of stretching vibration of carboxylic acid in lignin or ester group in hemicellulose causes the peak at 1639 cm^{-1} to appear [38]. -CH_2 symmetric bending in lignin, cellulose, and hemicellulose and -CH symmetric deformation of cellulose and hemicellulose are related to the peaks near 1427 cm^{-1} and 1369 cm^{-1}, respectively [39]. No new peaks were found in the FTIR spectra of the fibres. The heterogeneous structure of natural fibres is what causes the intensity variations in identical peaks that were found in different samples by FTIR and the presence of various peaks with low intensity.

Thermogravimetric analysis (TGA)

Figure 8 illustrates the fibres' TGA curves, which consist of four stages. The amount of mass that is retained as the temperature rises is shown in the graphs as the weight percentage (wt%). For jute, hemp, linen, sisal, and banana fibres, weight reduction in the first stage was 6.9%, 6%, 5.6%, 6.7%, and 6.4%, respectively. All natural fibres exhibit this tendency as a result of presented moisture. The FTIR study also demonstrates that the jute fibre absorbs the most water overall. The quantity of residual mass in the TGA curve abruptly drops between 148 and 416 °C. Depending on the

Table 1

TENSILE PROPERTIES OF NATURAL FIBRES

No.	Fibre	Max force (cN)	Max elongation (%)
1	Jute	114.88 ± 0.62	3.13 ± 0.37
2	Hemp	14.25 ± 0.47	10.71 ± 0.93
3	Linen	23.03 ± 0.30	16.06 ± 0.75
4	Sisal	818.08 ± 0.42	6.2 ± 0.29
5	Banana	371.44 ± 0.55	3.50 ± 0.37

Table 2

COMPARISON OF THE CHEMICAL STRUCTURE OF SOME NATURAL FIBRES

No.	Portion/ Fibre	Hemp	Sisal	Linen	Jute	Banana
1	Cellulose	70–75	78	81	61–75	60–65
2	Hemi-cellulose	16	10	14	13–20	6–9
3	Pectin	18	-	4	-	3–5
4	Lignin	4	8	3	5–13	5–10
5	Wax	-	2	-	-	-

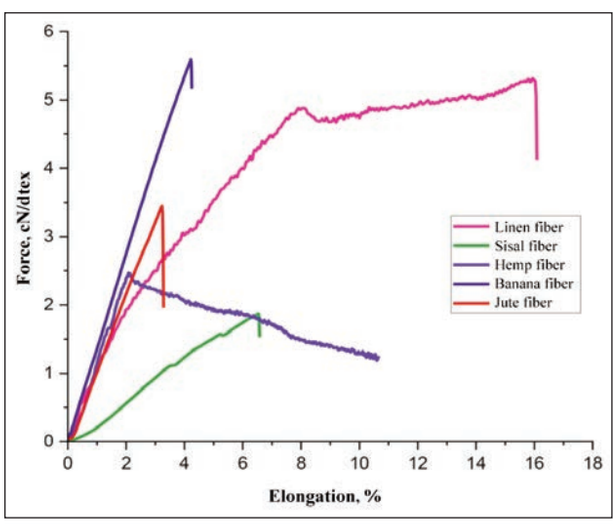

Fig. 6. Single fibre strength, the force-elongation curve of jute, hemp, linen, sisal, and banana fibres

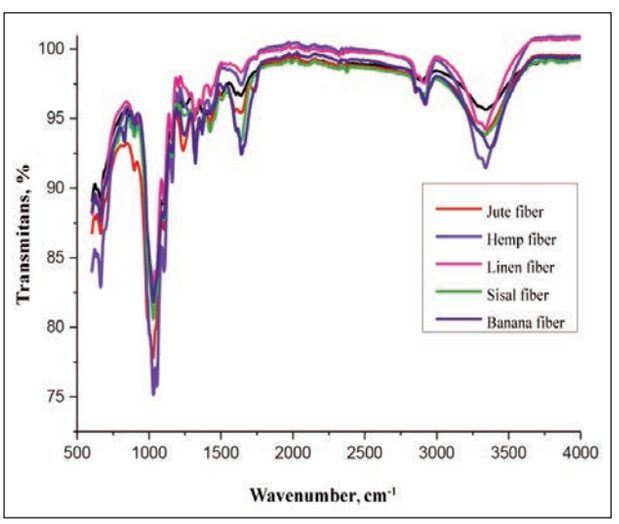

Fig. 7. FTIR spectra of jute, hemp, linen, sisal, and banana fibres in the range of 600 and 4000 cm^{-1}

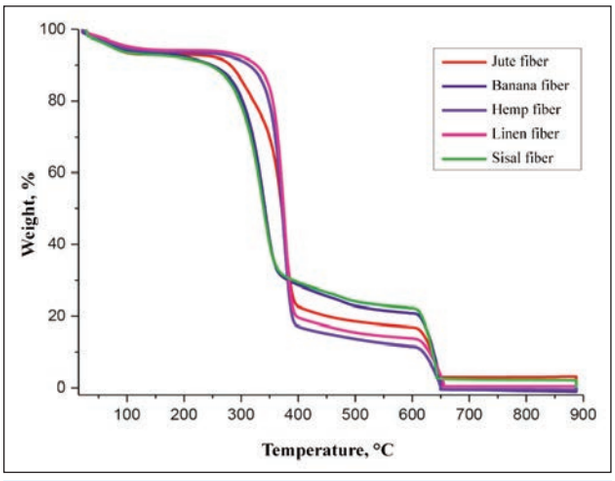

Fig. 8. TGA curves of jute, hemp, linen, sisal, and banana fibres

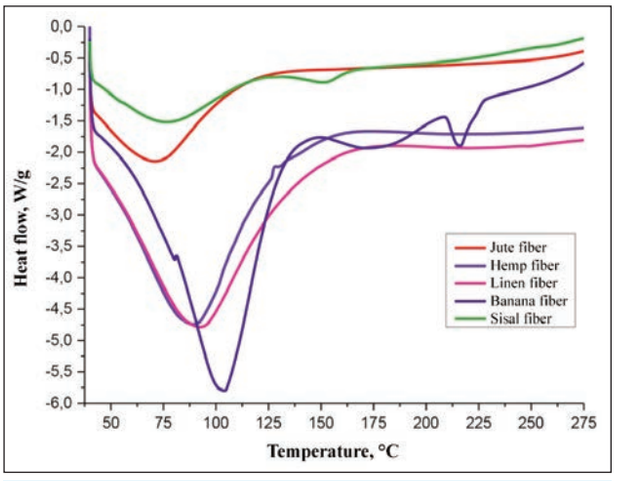

Fig. 9. DSC curves of jute, hemp, linen, sisal, and banana fibres

type of fibre, the second stage, which involves the majority of the weight loss, begins at 148 °C to 234 °C and ends at 395 °C to 416 °C. The temperature range where the rate of weight loss reaches its maximum value is thought to be when hemicellulose and cellulose start to break down [40]. The main weight loss, in this case, occurs between 148 °C and 416 °C. Compared to other fibres, linen fibre contains the most cellulose. The linen fibre has the highest value when the thermal decomposition temperatures are taken into account. Due to the breakdown of cellulose and lignin, a slight weight loss is seen in the third stage. Further raising the temperature does not affect the quantity of residual mass once the weight loss reaches about 75–80%. Their differing cellulose contents are the cause of this disparity. Coal oxidizes and breaks down into gaseous products with smaller molecular weights in the final step of the process.

Differential Scanning Calorimetry (DSC) analysis

The DSC method measures the enthalpy change brought on by variations in the sample's chemical and physical properties concerning temperature. According to the DSC curves shown in figure 9, the evaporation of water from the fibre structure results in a large endothermic peak that emerges between 30 °C and 135 °C. There is a large endothermic peak because water molecules have such a wide range of binding energies to the cellulose backbone.

According to TGA analysis, this peak corresponds to a weight reduction of 5.6% to 6.9%. The deepest peak, which indicates the existence of a highly moistened part of lignin, was seen in banana fibre.

Energy Dispersive X-Ray Analysis (EDX)

EDX is a technique that reveals an element's composition by analysing its different constituents. In figure 10, the ionization energy is displayed along the x-axis of the EDX spectrum, while the element counts are displayed along the y-axis. A larger presence in particular places indicates higher counts of that element. Carbon and oxygen were found in all of the natural fibres according to the EDX results in table 3, while additional elements were found in varying amounts in each fibre. The results revealed that all five natural fibres include calcium, iron, carbon, and oxygen.

Raman analysis

The Raman spectra of jute, hemp, linen, sisal, and banana fibres are displayed in figure 11. According to Eichhorn et al., the major peak at 1096 cm^{-1} is indicative of the C-O stretching mode of cellulose, but the peak at 380 cm^{-1} is only associated with crystalline cellulose I and is not present in amorphous cellulose [41]. Only the strongest bands in the spectrum

Table 3

EDX RESULTS

Elements	Jute		Hemp		Linen		Sisal		Banana	
	wt%	σ	wt%	σ	wt%	σ	wt%	σ	wt%	σ
C	54.8	0.2	52.4	0.2	49.6	0.2	54.2	0.8	46.8	1.3
O	43.7	0.2	47.1	0.2	49.9	0.2	44.4	0.8	46.2	1.3
Fe	0.6	0.1	0.2	0	0.4	0.1	0.8	0.2	-	-
Ca	0.3	0	0.1	0	0.2	0	0.4	0.1	-	-
Si	0.3	0	-	-	-	-	-	-	-	-
Al	0.2	0	-	-	-	-	-	-	-	-
K	0.1	0	-	-	-	-	0.3	0.1	6.1	0.4
S	0.1	0	-	-	-	-	-	-	-	-
Cl	-	-	0.1	0	-	-	-	-	-	-
Mg	-	-	-	-	-	-	-	-	0.9	0.2
Na	-	-	-	-	-	-	-	-	-	-

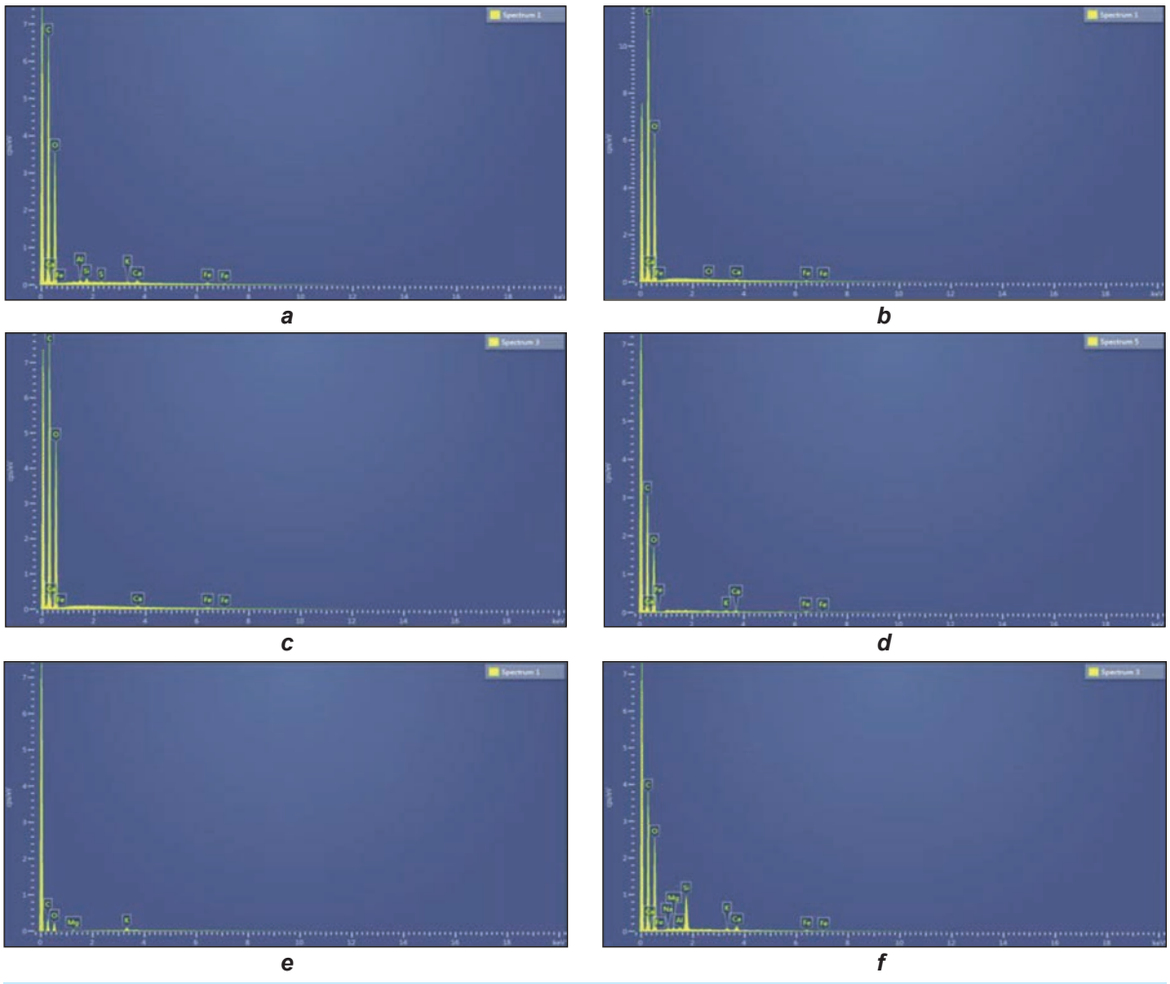

Fig. 10. EDX analysis: *a* – jute fibre; *b* – hemp fibre; *c* – linen fibre; *d* – sisal fibre; *e* – banana fibre

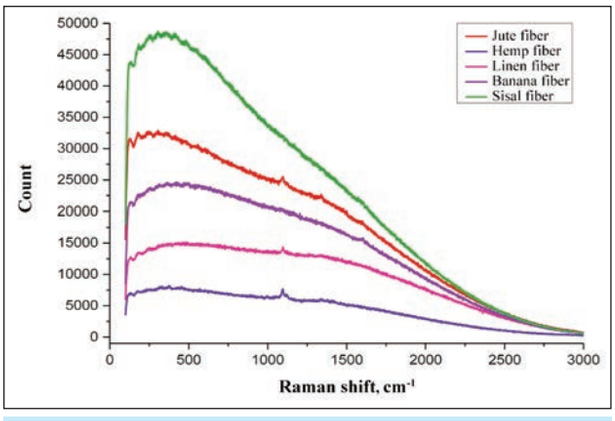

Fig. 11. Raman spectrum of jute, hemp, linen, sisal, and banana fibres

may be observed in Raman spectra because of the luminous background.

CONCLUSION

The objective of this study was to compare the physio-mechanical characteristics of the selected natural fibres. The natural fibres including jute, hemp, linen, sisal, and banana fibres were obtained from Elvin Textile Bursa. SEM, tensile testing, FTIR, Thermogravimetric analyzer, Differential calorimetry spectroscopy, Energy dispersive X-ray analysis, and Raman analysis were used to investigate the thermal and physio-mechanical properties of the fibres. The longitudinal and cross-sectional morphology of the natural fibres was revealed by the SEM. The SEM images demonstrated that whereas some fibres have filled cores, sisal and banana fibres had hollow internal structures. The highest breaking strength was demonstrated by sisal fibre (818.08 ± 0.42 cN), the lowest by hemp fibre (14.25 ± 0.47 cN), and the highest by linen fibre in terms of elongation before rupture. There are four stages in the TGA curves of fibres. The amount of mass that is retained as the temperature rises is indicated by the wt% in the graphs. In the case of jute, hemp, linen, sisal, and banana fibres, weight reduction in the first stage was 6.9%, 6%, 5.6%, 6.7%, and 6.4% respectively. All of the fibres are thermally stable below 148 °C, according to the graphs. The DSC curves, which showed the very least heat change after 150 °C, are likewise related to the TGA data. All of the natural fibres under consideration have carbon, oxygen, iron, and calcium present in their chemical structures, according to EDX and Raman analyses. According to the Raman spectra of jute, hemp, linen, sisal, and banana fibres [41], the main peak at 1096 cm^{-1} is indicative of the C-O stretching mode of cellulose, while the peak at

380 cm^{-1} is only associated with crystalline cellulose I and is not present in amorphous cellulose. Only the strongest bands in the Raman spectrum are visible due to the luminous background.

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A novel wool dye synthesised via recycling of side fraction of petrol: metal naphtenates (cyclohexane dicarboxylates)

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ABSTRACT – REZUMAT

A novel wool dye synthesised via recycling of side fraction of petrol: metal naphtenates (cyclohexane dicarboxylates)

The study aims to produce naphthenates (cyclohexane dicarboxylate) obtained from side fractions of petrol and used as dyestuff in the textile sector to abate waste-oriented pollution and to reutilize petroleum-based wastes. The investigations showed that obtaining blue dyestuff from copper, red dyestuff from cobalt and yellow dyestuff from nickel was possible. Moreover, it was determined that wool fabric could be dyed with good colour fastness with the dyestuffs mentioned. Therefore, this will help to reduce environmental pollution by addressing a novel and beneficial area of usage for naphthenates, produced via waste recycling.

Keywords: *petrol, naphthenate, dye, wool, recycling*

Un nou colorant pentru lână sintetizat prin reciclarea fracției secundare a benzinei: naftenați metalici (ciclohexan dicarboxilaţi)

Studiul își propune să producă naftenați (ciclohexan dicarboxilat) obținuți din fracții secundare ale benzinei și să fie utilizați sub formă de coloranţi în sectorul textil pentru a reduce poluarea orientată spre deșeuri și pentru a reutiliza deșeurile pe bază de petrol. Investigațiile au arătat că este posibilă obținerea de colorant albastru din cupru, colorant roșu din cobalt și colorant galben din nichel. Mai mult, s-a stabilit că materialul textil din lână poate fi vopsit pentru a avea o bună rezistență a culorii cu coloranții menționați. Prin urmare, acest lucru va ajuta la reducerea poluării mediului prin abordarea unui domeniu nou și benefic de utilizare a naftenaților, produși prin reciclarea deșeurilor.

Cuvinte-cheie*: benzină, naftenat, colorant, lână, reciclare*

INTRODUCTION

The Textile Industry is among the industries that cause the most environmental pollution. Dyeing methods used for the dyeing process in the textile sector and dyestuff variety are increasing with the changing and renewing technology. When the reasons for the increase in dyestuff variety are investigated, economy and environmental awareness may come first with the development of modern technology and industrialisation, there is an increase in the amount of waste that can pose a threat to living and environmental health. Increasing the cancer ratio each year is proof that wastes hurt human health. Recycling of wastes has gained great importance by utilising petroleum derivatives and abietic acid residuals known as wastes. This is significant for both reusability of wastes and preventing environmental pollution [1–3].

Many of the chemicals used in our daily lives are unsustainably derived from petroleum [4]. Petrol, one of the most precious subsurface raw materials in the world, provides benefits to humankind not only in technology but also in several other areas. Utilization areas of materials produced as a side fraction of petrol have been becoming increasingly crucial. Some side fractions do not have great value whereas others could be evaluated and sold after an additional process [5].

Dicarboxylic acids found in petroleum wastes are acid groups that contain two carboxyl groups and have the general formula $CnH2n(CO_2H)_2$. Their common feature is being acidic, those that dissolve in water give an acidic reaction. The relative position of the carboxyl group affects the physical and chemical properties of the molecule. Dicarboxylic acids show the familiar chemical behaviour of monocarboxylic acids. Dicarboxylic acids are solids and are more soluble in water than monocarboxylic acids with the same number of carbons. The lower members of the row dissolve in water and are less soluble in organic solvents, and the solubility decreases as the row progresses. In monocarboxylic acids, a polymeric structure is formed by combining the carboxyl groups at the two ends with hydrogen bonds in dicarboxylic acids, as in the formation of dimer molecules by the bonding of carboxyl groups with hydrogen bonds [6].

Naphthenates are derived from the side fractions of petrol, which are normally in the waste class. In recent years, recycling gained high importance to decrease waste-related pollution. In our previous study, we examined the application of silver naphthenates (silver monocarboxylate, silver dicarboxylate and silver

abietate) on cotton fabric surfaces, their antibacterial effects, and their washing resistance. Silver naphthenate was applied to cotton surfaces by impregnation method. Attitudes towards selected gram-negative and gram-positive bacteria were examined after 5, 10, 15 and 20 washes. [7]
This study, it was aimed to investigate the possibilities of using cyclohexane dicarboxylates, which are included in the metal naphthenates class and obtained as waste from the side fraction of petroleum, as a dyestuff in the textile industry. In our previous study, copper naphthenate dye was synthesized from the aforementioned waste and it was determined that this dye is suitable for dyeing wool [8]. As it is known, dyes for three main colours (yellow, red, and blue) are necessary to carry out trichromy dyeing in the textile field. For this reason; the current study, it was aimed to obtain dyes from metal complexes of cyclohexane dicarboxylates (copper, cobalt and nickel) giving yellow, red and blue colours. Therefore, a new application field, which will help to prevent environmental pollution, was introduced by developing a beneficial usage for waste, naphthenates, after recycling.

MATERIAL AND METHOD

Copper, cobalt and nickel cyclohexane dicarboxylate complexes were obtained from the reaction of naphthenic acid obtained from the side fraction of petrol and metal (Me) salts of copper, cobalt and nickel. The synthesis reaction of the metal cyclohexane di carboxylate compound is as follows:

$$2RCOOH + 2NaOH + MeCl_2 \rightarrow Me(RCOO)_2 + \\ + 2NaCl + 2H_2O$$

For actualization of the reaction, firstly cyclohexane dicarboxylic acid was dissolved in an organic solvent and acids sodium salts were constituted by adding caustic soda [6–7]. Then copper, cobalt and nickel cyclohexane di carboxylates were obtained by adding copper chloride, cobalt chloride and nickel chloride respectively [8].
A thermometer, condenser and dropping funnel were placed at the necks of a three-necked flask. Then, the solution of the cyclo hexane dicarboxylic acid (Sigma Aldrich) in 10% (v) diethyl ether, which was calculated stoichiometrically, was put into the flask. The solution of 10 % (v) NaOH was put into the dropping funnel. The temperature was raised to 40–45°C and the solution was stirred while dropping NaOH from the dropping funnel for 60 minutes. The pH of the medium was adjusted between 7 and 8. Then the heater was turned on, the dropping funnel was opened and the mixture was stirred by running an electromagnetic stirrer (Hot-Plate 300°C 15 cm circular M15 type) at room temperature for 1 hour, then the solution was kept for 24 hours. The solution obtained was put into the extraction flask and the liquid phase was separated from the organic phase. After the removal of solvent from the organic phase, a metal cyclohexane di carboxylates compound was obtained [9–13]
After the synthesis of cyclohexane di carboxylates dyes, optimum dissolution conditions for synthesized dyes were determined and their usability in wool dyeing was investigated.

Determination of the optimum dissolution conditions for synthesized dyes

To use a dye for the colouring of textile fibres, a solution or a dispersion of the dye should be prepared. Furthermore, in the case of the water solubility of the dye, to determine the maximum intensity of the dye that can be carried out, the upper limit of solubility (maximum solubility) needs to be known. Thus, to determine the optimum dissolution conditions for the synthesized dyes in this study, solutions:

- with 5 different dispersing agent concentrations (0.5; 1; 1.5; 2.0; 2.5 g/l)
- at 5 different pH values (1; 4; 7; 10; 13) and
- with 5 different dye concentrations (2; 4; 6; 8; 10 g/l)

were prepared. As it was observed in our washing fastness tests study that better solubility results could be obtained in the presence of ultrasonic energy, all dye solutions were prepared by being stirred for 30 minutes at 50–55ºC in an ultrasonic bath (Baysonic Ultrasound).
Firstly, solutions were prepared with 5 different dispersing agent concentrations (DENPOL HT (Denge Kimya)) at pH 7, with 6 g/l dye concentration. After the determination of optimum dispersing agent concentration, solutions were prepared at 5 different pH values, with 1 g/l dispersing agent concentration at 6 g/l dye concentration. After the determination of optimum pH, dye solutions were prepared at 5 different dye concentrations. Then absorbance values of all solutions were measured at maximum absorbance wavelength (nm) with Jenway type spectral photometer, also photographs of prepared solutions were taken. Furthermore, amounts of dissolved residue were determined with filtration.

Investigation of the usability of synthesized dyes in wool dyeing

To determine the usability of synthesized metal cyclohexane di carboxylate compounds in wool dyeing, the dyeing profile given in figure 1 was carried out at pH 7. The liquor ratio was 1:20 and equalizing and dispersing agent concentrations were 1 and 0.5 g/l, respectively. Dyeing liquors were prepared in an ultrasonic bath, and then dyeing procedures were performed on Thermal HT Dyeing Machine [14].
Since fastness is very important and must be at a sufficient level in textile dyeing, washing fastness tests of dyed samples were performed on James H. Heal 815 20 LGyrowash according to ISO 150 C06 standard. Water fastnesses of the samples were performed according to ISO 105 E01 standard. Acidic and basic perspiration fastnesses of the samples were performed on Prowhite Perspiration Fastness Device according to ISO 105 E04 standard. Dry and

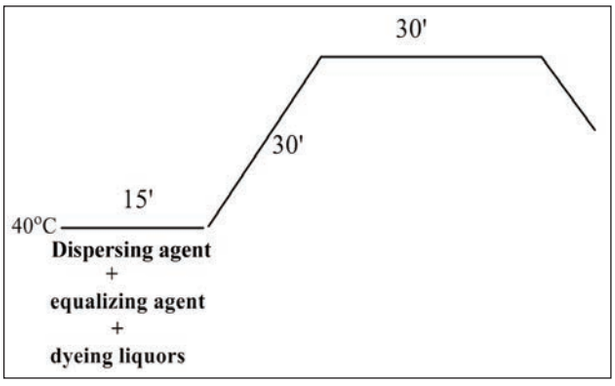

Fig. 1. The dyeing profile

wet rubbing fastnesses of the samples were performed on Prowhite Manual Crockmeter Device according to ISO 105X12 standard, and light fastnesses of the samples were performed according to 105-B02:2001 ISO 150 C06 standard.

A lack of harmful effects of the dye on human health is important as well as fastness properties. Therefore, to determine the allergic effect of dye, allergy tests were performed on dyed samples with high-performance liquid chromatography & mass spectroscopy according to IHTM AL.2.090&AL.2.178 DIN 54231 standard. Furthermore, to determine the carcinogenic effect of dye, carcinogenic tests were performed on dyed samples with high-performance liquid chromatography devices according to IHTM AL.2.091 DIN 54231 standard in Intertek Testing Laboratory.

RESULTS AND DISCUSSION

Determination of the optimum dissolution conditions for synthesized dyes

Effect of dispersing agent concentration

As determined in our previous study, the dye was not soluble directly in aqueous medium, but dissolved in organic solvents (such as benzyl alcohol). By taking

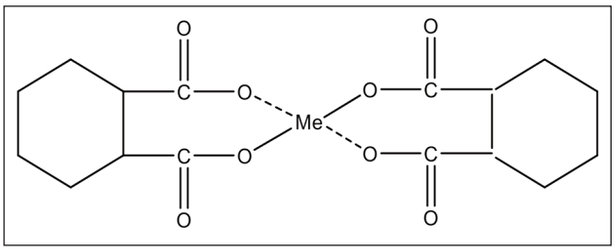

Fig. 2. Molecular structure of metal cyclohexane di carboxylate dye

into consideration the molecular structure of the dye that is given in figure 2, it was expected for the compound to have limited solubility in water, because it does not contain groups such as sulpho ($-SO_3^-$) which provides solubility [8].

Production in an organic solvent medium would cause problems in the textile dyeing process in terms of ecological criteria. Therefore, using possibility of the aforementioned dye dispersed in an aqueous medium was investigated. For that purpose, solutions of synthesized dye were prepared with 5 different dispersing agent concentrations (0.5; 1; 1.5; 2; 2.5 g/l) in the presence of ultrasound at 6 g/l concentration and pH 7. Images of filtration sheets of dye solutions prepared in the presence of ultrasound with these 5 different concentrations are given in figure 3. To determine the optimum concentration for dispersing agent, a filtration process was performed to determine whether undissolved dye remained. The solutions were prepared in the presence of ultrasound and passed through filtration sheets. After the filtration, photographs of the filtration sheets were taken. Results are given in figures 3, 4 and 5.

When figures 4 and 5 were examined, it could be seen that cobalt and nickel naphthenates were dissolved completely in all dispersing agent concentrations. Therefore, the optimum dispersing agent concentration was determined to be 0.5 g/l. Although this brought forth the idea that dispersing agents could be

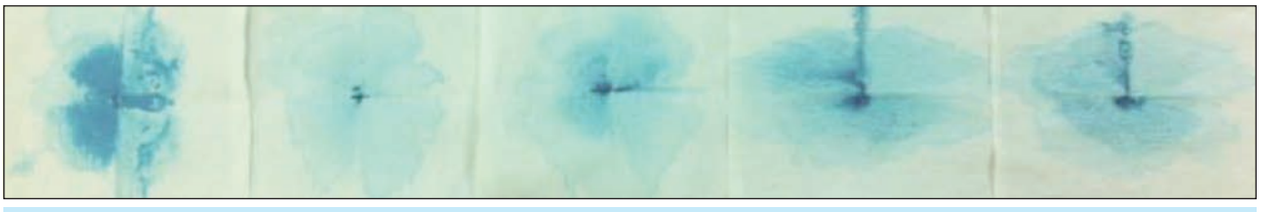

Fig. 3. Images of filtration sheets of dye solutions prepared in the presence of ultrasound with 5 different dispersing agent concentrations (0.5; 1; 1.5; 2; 2.5 g/l) at 6 g/l copper cyclohexane di carboxylate concentration and pH 7

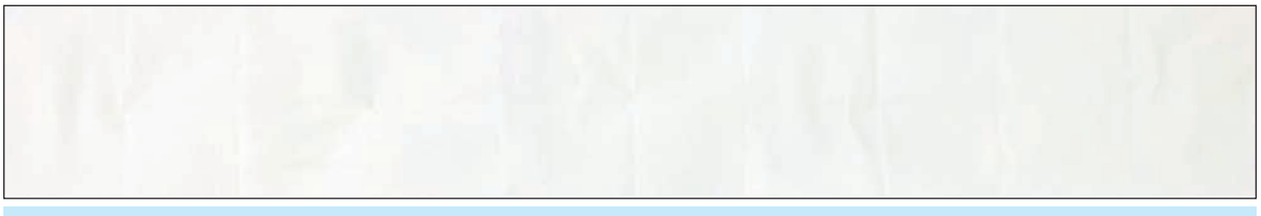

Fig. 4. Images of filtration sheets of dye solutions prepared in the presence of ultrasound with 5 different dispersing agent concentrations (0.5; 1; 1.5; 2; 2.5 g/l) at 6 g/l cobalt cyclohexane di carboxylate concentration and pH 7

Fig. 5. Images of filtration sheets of dye solutions prepared in the presence of ultrasound with 5 different dispersing agent concentrations (0.5; 1; 1.5; 2; 2.5 g/l) at 6 g/l nickel cyclohexane di carboxylate concentration and pH 7

used at lower concentrations, lower concentrations were not studied because it wouldn't be convenient to work at quite low concentrations in large-scale production conditions.

Effect of pH

To determine in which type of medium (acidic, neutral, basic) the best water solubility of the synthesized dye will be obtained, dye solutions were prepared at 5 different pH values (1; 4; 7; 10; 13) in the presence of ultrasound, at 6 g/l dye concentration containing 1 g/l dispersing agent. To observe whether undissolved dye remained, solutions prepared in mediums with and without ultrasound were passed through filtration sheets, afterwards photographs of the filtration sheets were taken. Results are given in figures 6, 7 and 8.

As a result of the evaluations, it was found that the colour of the dye changed in a strong acidic (pH 1) or strong basic (pH 13) medium. There was not a significant difference in terms of the dye solubility between pH 4, 7, and 10. It was seen that copper, cobalt and nickel cyclohexane di carboxylate compounds could be used in dyeing both acidic and basic environments depending on the fibre type. Furthermore, pH 7 could be considered as the optimum pH for solubility, due to the non-requirement of pH adjustment.

Effect of dye concentration

To determine the maximum solubility of the synthesized dye in water, solutions were prepared at 5 different concentrations (2; 4; 6; 8; 10 g/l) in the presence of ultrasound at pH 7 with 1 g/L dispersing agent and the colours of the solutions were evaluated visually. Images of filtration sheets of copper cyclohexane dicarboxylate solutions prepared in a medium with ultrasound at 5 different concentrations are given in figure 9. Similarly, in this experimental group, to observe whether undissolved dye remained, solutions prepared in the presence of ultrasound, were passed through filtration sheets, afterwards photographs of the filtration sheets were taken. Results are given in figures 9, 10 and 11.

Fig. 6. Images of filtration sheets of dye solutions prepared in medium without ultrasound at 5 different pH (pH 1; 4; 7; 10; 13) at 6 g/l copper cyclohexane di carboxylate concentration with 1 g/l dispersing agent

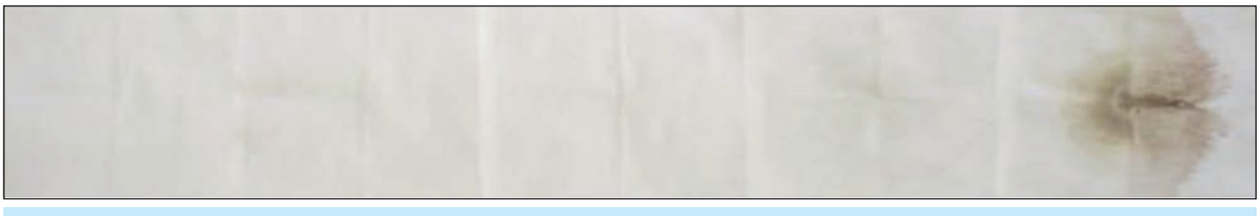

Fig. 7. Images of filtration sheets of dye solutions prepared in medium without ultrasound at 5 different pH (pH 1; 4; 7; 10; 13) at 6 g/l cobalt cyclohexane di carboxylate concentration with 1 g/l dispersing agent

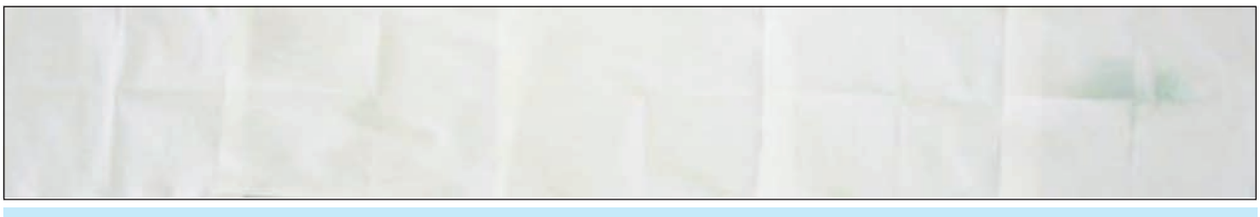

Fig. 8. Images of filtration sheets of dye solutions prepared in medium without ultrasound at 5 different pH (pH 1; 4; 7; 10; 13) at 6 g/l nickel cyclohexane di carboxylate concentration with 1 g/l dispersing agent

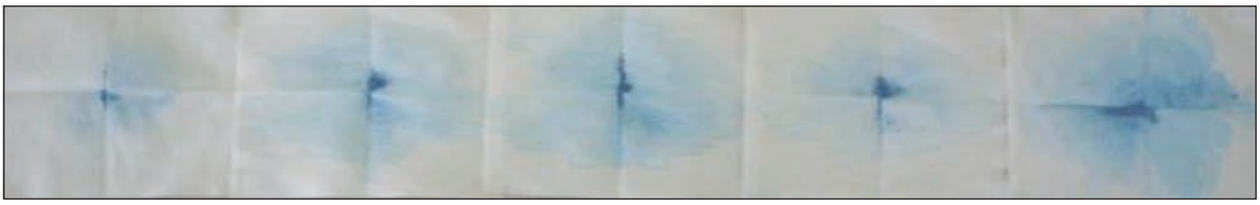

Fig. 9. Images of filtration sheets of copper cyclohexane dicarboxylate solutions prepared in medium with ultrasound at 5 different concentrations (2; 4; 6; 8; 10 g/l) at pH 7 with 1 g/l dispersing agent

Fig. 10. Images of filtration sheets of cobalt cyclohexane dicarboxylate solutions prepared in medium without\ ultrasound at 5 different concentrations (2; 4; 6; 8; 10 g/l) at pH 7 with 1 g/l dispersing agent

Fig. 11. Images of filtration sheets of nickel cyclohexane dicarboxylate solutions prepared in medium without ultrasound at 5 different concentrations (2; 4; 6; 8; 10 g/l) at pH 7 with 1 g/l dispersing agent

When all filter papers were examined, it could be seen that filter papers which contained cobalt and nickel naphthenates were dissolved completely in all dyestuff concentrations. It is of vital importance in textile dyeing, and it is required for dye to dissolve at high concentrations to get dark tones.

Results related to the usability of synthesized dyes in the dyeing of wool fibres

Wool fabric dyed with copper cyclohexane dicarboxylate compound can be seen in figure 12.

Fig. 12. Wool fabrics dyed with copper cyclohexane di carboxylate at 6 g/l dye concentration

From figure 12, it can be seen that the green colour was obtained in wool with copper cyclohexane dicarboxylate.

From figure 13, it can be seen that the red and yellow colours were obtained in wool with cobalt and nickel cyclohexane di carboxylates, respectively. The results of K/S and dCIELab are given in tables 1 and 2.

The results of washing, water and perspiration (acidic and basic) fastnesses of dyed samples are given in table 3

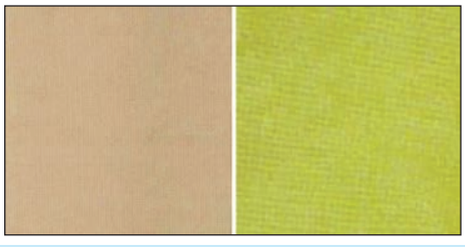

Fig. 13. Wool fabrics dyed with cobalt (on the left) and nickel (on the right) cyclohexane di carboxylates at 10 g/l dye concentration

Table 1

RESULTS OF K/S VALUES METAL CYCLOHEXANE DI CARBOXYLATE DYE			
The concentration of metal cyclohexane di carboxylate dye(g/l)	**Copper cyclohexane dicarboxylate**	**Cobalt cyclohexane dicarboxylate**	**Nickel cyclohexane dicarboxylate**
2	3.60	1.73	1.60
6	4.48	1.90	1.91
10	5.61	2.53	2.02

Table 2

RESULTS OF dCIELab VALUES METAL CYCLOHEXANE DI CARBOXYLATE DYE					
Metal Cyclohexane dicarboxylate dyed under optimum conditions	**L***	**a***	**b***	**C***	**h°**
Copper cyclohexane di carboxylate dye	66.12	–1.71	18.66	18.74	95.23
Cobalt cyclohexane di carboxylate dye	65.43	7.06	9.34	11.71	52.91
Nickel cyclohexane di carboxylate dye	71.94	1.97	19.14	19.24	84.11

Table 3

RESULTS OF WASHING, WATER AND PERSPIRATION (ACIDIC AND BASIC) FASTNESSES OF COPPER, COBALT, NICKEL CYCLOHEXANE DICARBOXYLATE DYE							
	Property	**Wo**	**PAC**	**PES**	**PA**	**Co**	**CA**
Copper cyclohexane di carboxylate dye	Washing Fastness	5	5	5	5	5	5
	Water Fastness	5	5	5	5	5	5
	Acidic Perspiration Fastness	5	5	5	5	5	5
	Basic Perspiration Fastness	5	5	5	5	5	5
Cobalt cyclohexane di carboxylate dye	Washing Fastness	5	5	5	5	5	5
	Water Fastness	5	5	5	5	5	5
	Acidic Perspiration Fastness	5	5	5	5	5	5
	Basic Perspiration Fastness	5	5	5	5	5	5
Nickel cyclohexane di carboxylate dye	Washing Fastness	5	5	5	5	5	5
	Water Fastness	5	5	5	5	5	5
	Acidic Perspiration Fastness	5	5	5	5	5	5
	Basic Perspiration Fastness	5	5	5	5	5	5

The results of dry and wet rubbing fastnesses and light fastnesses are given in table 4.

Table 4

RESULTS OF DRY AND WET RUBBING AND LIGHT FASTNESSES			
Dye	**Rubbing fastness**		**Light fastness**
	Dry	**Wet**	
Copper cyclohexane di carboxylate	5	5	4
Cobalt cyclohexane di carboxylate	5	5	3–4
Nickel cyclohexane di carboxylate	5	5	4

Due to the molecular structure of copper, cobalt and nickel cyclohexane di carboxylate dyes, it can be said that the metal atoms, whose coordination number is 4, form two bonds with the dye molecule and have got the opportunity to form two more bonds. These bonds will be formed with water molecules in aqueous medium. In the case of the presence of wool fibre in the environment, it can be bound to the free amino groups of wool fibre with coordinative bonds (figure 14). By taking into consideration that the most robust bond between textile dye and fibres is a coordinative bond, the obtained high wet fastness values could be well understood.

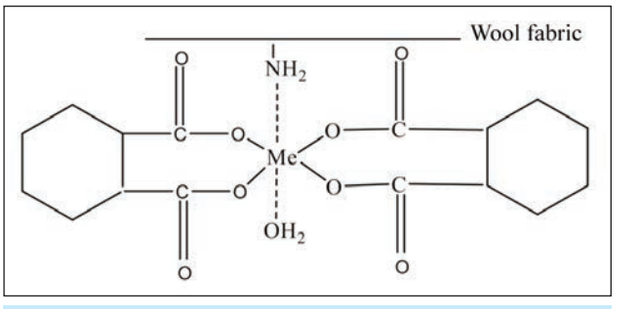

Fig. 14. Possible binding mechanism of metal cyclohexane di carboxylates to wool fibre

As generally known, the light fastness value depends on the dye chromophore. Although copper, cobalt and nickel cyclohexane di carboxylate showed medium light fastness values, by taking into consideration that wool products are not used in warm and hot climates, it can be said that the light fastness value of a dyed woollen material is not critical.

To determine the carcinogenic and/or allergic effect of dye, the aforementioned tests were carried out. According to the allergic test, it can be said that dyes did not cause any allergic reaction to the skin, since the obtained value was below the lowest measurable

value, 3 ppm. According to the carcinogenic test, it can be said that copper, cobalt and nickel cyclohexane di carboxylates did not cause any carcinogenic effect, since the obtained value was below the lowest measurable value, 2 ppm.

CONCLUSIONS

The study aimed to examine naphthenates (cyclohexane mono carboxylate) which were obtained from side fractions of petrol and brought in as a new dyestuff to the textile sector. For this aim, different metal naphthenates were synthesized first.

Maximum solubility of copper, cobalt and nickel naphthenate solutions was provided in an ultrasonic environment. Experimentations indicated that three dyestuffs could be used successfully in dyeing wool fibres. Therefore, a new colour gamut, which could be used in wool dyeing and was completely obtained via recycling from waste, was introduced. However, it can be said that the mentioned colour gamut could be used in dyeing only light and medium shades to have high colour fastness.

It should be considered that recycling waste and using it in various areas are going to be more important in the future when the restrictions increase. It can be concluded that the colour gamut synthesized in this study is rewarding under today's conditions where environmental consciousness is increasing.

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The impact of heterogeneous environmental regulations on China's textile industry CO_2 emissions

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ABSTRACT – REZUMAT

The impact of heterogeneous environmental regulations on China's textile industry CO_2 emissions

Environmental regulation is an important tool to reduce CO_2 emissions. To investigate the relationship between heterogeneous environmental regulations and CO_2 emissions of China's textile industry (CTI), this paper uses the threshold model and panel model to study the impacts of command-based, market-based and public-based environmental regulations (CER, MER and PER) on the total carbon emissions and carbon emission intensity of CTI from 2004 to 2019. Then it further explores their regional heterogeneity. The results show that: at the national level, CER has a forced emission reduction effect and a green paradox effect on CTI's total carbon emissions and carbon emission intensity, respectively. And MER shows a forced emission reduction effect on carbon emission intensity. But the coefficients of PER are not significant. At the regional level, the result verifies a U-shaped relationship between CER and CO_2 emissions in the eastern textile industry. And CER shows a forced emission reduction effect in the central and western regions. The impact of MER on the carbon emission intensity of the eastern textile industry is N-shaped, which means MER can lower carbon emission intensity only within a certain range. And its impacts on the central and western regions are also the forced emission reduction effect. There is an inverted U-shaped relationship between PER and the total carbon emission in the eastern textile industry. While PER has always had a green paradox effect on carbon emission intensity in the eastern region. Other coefficients are not significant. Finally, this paper puts forward the policy suggestions to mitigate the CO_2 emissions of CTI.

Keywords: *China's textile industry, CO_2 emissions, heterogeneous environmental regulations, green paradox effect, forced emission reduction effect*

Impactul reglementărilor eterogene de mediu asupra emisiilor de CO_2 din industria textilă a Chinei

Reglementările de mediu reprezintă un instrument important pentru reducerea emisiilor de CO_2. Pentru a investiga relația dintre reglementările eterogene de mediu și emisiile de CO_2 ale industriei textile din China (CTI), această lucrare utilizează modelul de prag și modelul panoului pentru a studia impactul reglementărilor de mediu bazate pe comandă, pe piață și pe bază publică (CER, MER și PER), privind emisiile totale de carbon și intensitatea emisiilor de carbon ale CTI din 2004 până în 2019. Apoi explorează în continuare, eterogenitatea lor regională. Rezultatele arată că: la nivel național, CER are un efect de reducere forțată a emisiilor și un efect de paradox verde asupra emisiilor totale de carbon și, respectiv, intensității emisiilor de carbon ale CTI. Și MER arată un efect de reducere forțată a emisiilor asupra intensității emisiilor de carbon. Dar coeficienții PER nu sunt semnificativi. La nivel regional, rezultatul verifică o relație în formă de U între CER și emisiile de CO_2 din industria textilă de est. Și CER arată un efect de reducere forțată a emisiilor în regiunile centrale și vestice. Impactul MER asupra intensității emisiilor de carbon din industria textilă de est este în formă de N, ceea ce înseamnă că MER poate reduce intensitatea emisiilor de carbon doar într-un anumit interval. Iar impactul său asupra regiunilor centrale și vestice este și reducerea forțată a emisiilor. Există o relație în formă de U inversă între PER și emisiile totale de carbon în industria textilă de est, în timp ce PER a avut întotdeauna un efect de paradox verde asupra intensității emisiilor de carbon în regiunea de est. Alți coeficienți nu sunt semnificativi. În cele din urmă, această lucrare prezintă sugestii de politici pentru atenuarea emisiilor de CO_2 din CTI.

Cuvinte-cheie*: industria textilă din China, emisii de CO_2, reglementări de mediu eterogene, efectul paradoxului verde, efect de reducere forţată a emisiilor*

INTRODUCTION

The textile industry is one of the traditional pillar industries of China's economy and also an important source of China's carbon (CO_2) emissions. Since the beginning of the 21st century, CO_2 emission in China's textile industry (CTI) has experienced a trend of growth followed by a decline. At present, CTI is still facing great pressure to reduce CO_2 emissions. The total CO_2 emissions in 2020 were still large at about 13 million tons. In the meantime, China set a green development goal in the "14th Five-Year Plan for the Development of Textile Industry" that the amount of CO_2 emissions per unit of CTI's industrial value-added decrease by 18% from 2021 to 2025. Cutting down CO_2 emissions is an important pathway to achieve the goal of CTI's green development.

Environmental regulation (ER) is an important tool to curb CO_2 emissions. According to existing studies, it can be divided into three heterogeneous regulations: command-based environmental regulation (CER), market-based environmental regulation (MER) and public-based environmental regulation (PER). There are different views on the relationship between ER and CO_2 emissions. The green paradox effect posits that ER cannot curb CO_2 emissions, but will push CO_2 emissions to increase instead [1]. But forced emission reduction effect insists that a well-designed ER can motivate an enterprise to carry out technological innovation to compensate for the cost induced by ER and reduce CO_2 emissions [2,3]. New studies argue green paradox effect and forced emission reduction effect coexist between ER and carbon emission and the influence of ER on CO_2 emissions depends on which is dominant. Thus, there is a dynamic, nonlinear relationship between them. Wang [4] proves that there is an inverted U-shaped relationship between ER and CO_2 emissions using the data from 282 cities in China. So, what is the role of each of the three ER tools in reducing CO_2 emissions in CTI? How do they influence CTI's CO_2 emissions? As there are significant differences in the development of textile industries in different regions of China, is there regional heterogeneity in the impact of these three ER tools? Therefore, it has great empirical significance to study the heterogeneous effects of different ERs on CTI's CO_2 emissions.

In the study of the impact of ER on CO_2 emissions, existing research is mainly carried out at the regional level, less at the industrial level. Moreover, most researches focus on the impact of CER. The literature on the impact of MER is relatively little and that of PER is rare. In terms of research on a single ER tool, Yang [5] concluded that the CER can significantly reduce China's CO_2 emissions from both temporal and spatial perspectives. Neves's [6] research on 17 EU countries also showed that MER could reduce CO_2 emissions in the long run. Zhang [7] proved that environmental information disclosure could help reduce CO_2 emissions, but there was regional heterogeneity.

Concerning multi-ER tools, the relevant literature mostly compared the impacts of CER versus MER or CER versus PER on CO_2 emissions. Few scholars performed a comparative study of the effects of all three ER tools together. Wu's [8] results demonstrated there was an inverted U-shaped relationship between CER, MER and PER and CO_2 emissions in China's iron and steel industry. The above results show that there is a wide divergence among academics regarding the mechanism of how ER affects CO_2 emissions. As for the study of carbon emissions in CTI, most scholars discussed the estimation of CTI's CO_2 emissions and its determinants [9,10]. But few literatures on the impact of ER on CTI's CO_2 emissions were found. Due to the lack of relevant literature, the relationships between the three ER tools and CTI's CO_2 emissions and whether there is regional heterogeneity are not clear. Therefore, it's of high theoretical value to study the impacts of heterogeneous ERs on CTI's CO_2 emissions.

To address the practical problems and fill the theoretical gaps as described above, this paper uses the threshold model and panel model to study the impacts of CER, MER and PER on CTI's total carbon emissions and carbon emission intensity from 2004 to 2019, then it further explores their regional heterogeneity. The contribution of this paper is that it investigates in detail the differences between these three ER tools in terms of their impact mechanisms on CTI's CO_2 emissions at national and regional levels, respectively. The results will also provide the basis for the Chinese government to make policy decisions on how effectively utilizes ER tools to mitigate carbon emissions for CTI's green development.

METHODOLOGY AND DATA SOURCES

Estimation model

This paper first uses a threshold model to study the impact of CER, MER and PER on the total carbon emissions and carbon emission intensity of CTI from 2004 to 2019. Compared with the traditional static panel model, the threshold model can be used to analyse whether the impact of ER on CTI's CO_2 emissions is dynamically nonlinear. If the threshold effect is significant, it means that this ER tool has a nonlinear relationship with CTI's CO_2 emissions. If not, it indicates a linear relationship between them. Then the paper further investigates whether the impact mechanism is a green paradox effect or a forced emission reduction effect using the panel model.

Referring to the method proposed by Hansen [11], this paper takes CER, MER and PER as the threshold variables and explanatory variables, CTI's total carbon emissions (TCE) and carbon emission intensity (CEI) as the explained variables. It constructs the following threshold model to investigate whether there is a nonlinear relationship between heterogeneous ERs on CTI's CO_2 emissions:

$$LnY_{it} = C_{it} + \beta_1 LnER_{it} \cdot I(ER_{it} \le \gamma_1) + \beta_2 LnER_{it} \cdot I(\gamma_1 < ER_{it} \le \gamma_2) + \cdots + \beta_n LnER_{it} \cdot I(\gamma_{n-1} < ER_{it} \le \gamma_n) + \beta_{n+1} LnER_{it} \cdot I(ER_{it} > \gamma_{n+1}) + \theta LnX_{it} + \varepsilon_{it} \quad (1)$$

where Y represents the total carbon emissions ($TCE_{i,t}$) and carbon emission intensity ($CEI_{i,t}$) of the textile industry of province i in year t, respectively. $ER_{i,t}$ represents the command-based, market-based and public-based environmental regulation (CER, MER and PER) of province i in year t. $X_{i,t}$ is the control variable and $\varepsilon_{i,t}$ is the residual. $I(*)$ is the indicator function that takes the value of 1 if the condition in brackets holds, and 0 otherwise. γ is the threshold value. $\beta_1 - \beta_n$ denote the estimation coefficients in different ranges of threshold variables. The paper can determine whether the threshold effect exists by testing if the estimation coefficients of $\beta_1 - \beta_n$ are significantly different or not. If the threshold effect is

significant, the impact mechanism is nonlinear. Otherwise, it's linear. Then the following panel model need to be constructed for further study:

$$LnY_{it} = C_{it} + \beta_1 LnER_{it} + \theta LnX_{it} + \varepsilon_{it} \quad (2)$$

The meaning of each indicator is the same as above. To explore the regional heterogeneity of *ER*, this paper first divides China into four regions: East, Central, West and Northeast according to the regional division standard of the State Council of China. Then it employs the threshold model and panel model to study the impacts of heterogeneous ERs on CO_2 emissions of the textile industry in each region of China.

Variables and data source

Explained variables

Total carbon emissions (TCE) refer to the amount of carbon dioxide emitted by CTI and are directly obtained from Carbon Emission Accounts & Datasets (CEADs).

Carbon emission intensity (CEI) measures the carbon emission efficiency of CTI and is calculated as the ratio of CTI's total carbon emissions to its gross output.

Core explanatory variables

Command-based environmental regulation (CER) regulates corporate environmental behaviours through administrative orders, including laws, policies and development plans. CER is measured by the ratio of investment completed in the treatment of industrial pollution in each province to the gross industrial output of industries above the designated size.

Market-based environmental regulation (MER) guides enterprises to make environment-friendly decisions through economic incentives including carbon tax and carbon emissions trading. Referring to Wu [8], MER is measured by the ratio of each province's sewage charges to the gross industrial output of industries above the designated size.

Public-based environmental regulation (PER) is a non-statutory agreement established between enterprises, governments, or non-profit organizations and it depends on public environmental awareness, public opinions and supervision. According to Pargal [12], it is measured by residents' income, population density and education level in each province. The objective weight-based entropy method is adopted to calculate the comprehensive index of PER.

Control variables

Economic development (PGDP) is usually accompanied by high CO_2 emissions and it's measured by GDP per capita. Urbanization (URB) is an important determinant of environmental problems and it's measured by the proportion of urban population in the total population. Energy structure (ES) is also the determinant of environmental pollution and it's reflected by the ratio of coal consumption to total energy consumption. Foreign direct investment (FDI) also affects the ecological environment of the host country and it's expressed by the total amount of foreign direct investment.

Data sources

The data on CO_2 emissions used in this paper are collected from CEADs. The data of ERs and the control variables are taken from China Statistical Yearbook and China Industrial Statistical Yearbook. The time series of data is 2004–2019.

THE TOTAL CARBON EMISSIONS AND CARBON EMISSION INTENSITY OF CTI

The total carbon emissions of CTI showed an increase first and then a decrease from 2004 to 2019, reaching its maximum (25.10 million tons) in 2008. The eastern region had always been the main source of CTI's CO_2 emissions, accounting for about 3/4. The western region ranked second, followed by the central and northeastern regions. In 2019, eastern total carbon emissions accounted for 76.89%, even higher than its proportion in CTI's total gross output (70.42%), which shows that cutting eastern CO_2 emissions was the key to achieving CTI's green development.

Unlike the trend of total carbon emissions, the carbon emission intensity of CTI has been decreasing from 1.781 kilotons/billion CNY in 2004 to 0.564 in 2019 with a drop of 68.33%. Meanwhile, those of all the regions were also on a downward trend. Eastern carbon emission intensity in 2019 was 1.09 times (0.616 kilotons/billion CNY) the national average, which means that it still had much room for decline. Central carbon emission intensity had dropped from 1.28 times (2.284 kilotons/billion CNY) the national average in 2004 to 0.42 times (0.238 kilotons/billion CNY) in 2019 and only it was lower than the national level. This shows that the central region has been the most productive in reducing CEI.

THE IMPACTS OF HETEROGENEOUS ERS ON CTI'S CO_2 EMISSIONS

This paper firstly tests the threshold effects of three ER tools on CTI's total carbon emissions and carbon emission intensity. The test results (table 1) show that only the threshold effect of CER on carbon emission intensity is significant and it's a single threshold effect. Then, this paper uses a panel model to do further research. The Hausman test results of the panel model (not presented here due to the limited space, similarly hereinafter) show that the fixed effect model is appropriate. The regression results are shown in table 2.

The impact coefficient of CER on CTI's total carbon emissions is significantly negative (–0.143, table 2). CER has a single threshold effect on carbon emission intensity. Only when CER is less than the threshold, the coefficient is significant (0.144). This implies that CER has the forced emission reduction effect and green paradox effect on CTI's total carbon emissions and carbon emission intensity, respectively. Formal government environmental regulation can

Table 1

THE THRESHOLD EFFECT TEST RESULTS						
Region	**Explained variables**	**Explanatory variables**	**Number of thresholds**	**Threshold**	**Lower**	**Upper**
China	CEI	CER	Single	3.269	3.240	3.274
Eastern	TCE	CER	Single	–0.364	–1.165	0.267
	CEI	CER	Single	–0.364	–1.165	–0.267
	CEI	MER	Double	–3.459	–3.466	–3.408
				–0.856	–0.948	–0.844
	TCE	PER	Single	–0.857	–0.883	–0.856
Northeastern	TCE	MER	Single	–1.067	–1.122	–1.059

Table 2

THE REGRESSION RESULTS OF CTI						
Coefficient	**TCE**			**CEI**		
CER	–0.143***			0.144** (ER≤3.269)		
				0.002 (ER>3.269)		
MER		–0.107			–0.303***	
PER			0.211			0.254
PGDP	–0.035	0.059	0.039	–0.746***	–0.845***	–0.930***
URB	–0.594	–0.544	–0.640	0.367*	–1.772***	–1.766***
FDI	–0.236***	–0.212	–0.216***	0.142***	0.042	0.045
ES	0.611***	0.598***	0.611***	0.160***	–0.309**	–0.252*
Model	FE	FE	FE	Single threshold	FE	FE

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

significantly decrease CTI's total carbon emissions, but not the carbon emission intensity. The coefficients of MER on the total carbon emissions and carbon emission intensity both are negative, but only the latter is significant (–0.303). This means that MER's impact on the carbon emission intensity is the forced emission reduction effect. The use of market-based tools such as carbon tax and carbon emissions trading effectively pushes textile enterprises to improve carbon emission efficiency and reduce carbon emission intensity. Both coefficients of PER are positive, but neither is significant.

THE IMPACTS OF HETEROGENEOUS ERS ON CO_2 EMISSIONS OF THE REGIONAL TEXTILE INDUSTRY

Based on the above research, this paper further investigates the regional heterogeneity of the impacts of the three ER tools on CTI's CO_2 emissions. First, the threshold effect test results (table 1) show that in the eastern region, the impacts of CER and PER on the total carbon emissions and CER and MER on carbon emission intensity are all the single threshold effect. In the northeastern region, MER has a single threshold effect on total carbon emissions. The others are not significant. Further, the Hausman test results show that the fixed effect model is more appropriate for most regression analyses except for a few that require a random effect model. The regression results are shown in table 3. Due to the limited space, table 3 only presents the estimation coefficients of the core explanatory variables (ER).

In the eastern region, the impacts of CER on the total carbon emissions and carbon emission intensity both present a single threshold effect. When CER is less than the threshold, the coefficients (table 3) are negative and the forced emission reduction effect plays a dominant role. After it exceeds the threshold, the green paradox effect is dominated. The results show a significant U-shaped relationship between CER and CO_2 emissions in the eastern textile industry. The reason is that the agglomeration of the eastern textile industry is the highest. And when CER exceeds the threshold, it will further increase environmental protection costs and cause a crowding-out effect on the green R&D investment of textile enterprises, which is not conducive to the carbon emission reduction of the eastern textile industry. A significant

Table 3

THE REGRESSION RESULTS ACROSS REGIONS

Region	ER	TCE			CEI		
Eastern	CER	–1.656*** (ER≤–0.364) 0.164*** (ER>–0.364)			–1.479*** (ER≤–0.364) 0.417*** (ER>–0.364)		
	MER		–0.032			0.165* (ER≤–3.459) –0.254** (–3.4590<ER≤–0.856) 0.571*** (ER>–0.856)	
	PER			0.467** (ER≤–0.857) –0.655 (ER>–0.857)			0.835***
Central	CER	–0.239**			–0.017		
	MER		–0.424**			–0.710***	
	PER			–0.485			–0.416
Western	CER	–0.354***			–0.342***		
	MER		–0.443**			–0.526**	
	PER			0.177			0.247
Northeastern	CER	–0.182			0.056		
	MER		–0.404 (ER≤–1.067) 0.218 (ER>–1.067)			–1.395***	
	PER			0.484			–0.630

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

double-threshold effect is observed between MER and carbon emission intensity. The impact is N-shaped, with coefficients successively positive, negative and positive, which means that only within a certain range can MER play a role in reducing carbon emission intensity. PER shows a single threshold effect on total carbon emissions. The coefficients are positive and negative before and after PER crosses the threshold, respectively, showing an inverted U-shape. The finding is similar to Wu's [8] research results in terms of the impact of PER on CO_2 emissions of China's iron and steel industry. When PER crosses the threshold, its impact mechanism changes from the green paradox effect to the forced emission reduction effect. Besides, its impact on the carbon emission intensity is significantly positive, indicating that its impact mechanism has always been the green paradox effect.

In the central region, the coefficient of CER on the total carbon emissions is significantly negative, indicating a forced emission reduction effect. Strengthening formal ER intensity helps mitigate CO_2 emissions of the central textile industry. The coefficient of CER on the carbon emission intensity is not significant. The coefficients of MER on the total carbon emissions and carbon emission intensity are both significantly negative, showing that the impact mechanisms are also dominated by the forced emission reduction effect. The coefficients of PER are insignificant.

Similar to the central region, CER and MER both exert a significant negative influence on carbon emissions of the western textile industry, suggesting that they both have the forced emission reduction effect on CO_2 emissions. It implies strengthening CER and MER can help lower the total carbon emissions and carbon emission intensity in the western region. The coefficients of PER are not significant.

In the northeastern region, the coefficients of CER and PER are not significant. Besides, MER has a single threshold effect on the total carbon emission, but it's also insignificant. The coefficient of MER on carbon emission intensity is significantly negative, indicating a forced emission reduction effect. MER tools can significantly reduce the carbon emission intensity of the northeastern textile industry.

CONCLUSIONS

This paper employs the threshold model and panel model to analyse the impacts of heterogeneous ERs on CTI's CO_2 emissions and explore their regional heterogeneity. The research results are as follows:

- At the national level, the study concludes CER has a forced emission reduction effect and a green paradox effect on CTI's total carbon emissions and carbon emission intensity, respectively. Strengthening the government's formal environmental regulation and supervision can significantly reduce CTI's total carbon emissions, but it cannot lower carbon emission intensity. MER shows a forced emission reduction effect on the carbon emission intensity. The use of market-based tools can effectively drive textile enterprises to reduce carbon emission intensity. The coefficients of PER are not significant.
- At the regional level, the result verifies a U-shaped relationship between CER and CO_2 emissions in the eastern textile industry. When the threshold is exceeded, CER's influence changes from a forced emission reduction effect to a green paradox effect. And CER shows a forced emission reduction effect in the central and western regions. The impact of MER on the carbon emission intensity of the eastern textile industry is N-shaped, which means MER can lower carbon emission intensity only within a certain range. And its impacts on the central and western regions are also the forced emission reduction effect. There is an inverted U-shaped relationship between PER and the total carbon emission in the eastern textile industry. After the threshold is crossed, the forced emission reduction effect begins to dominate. While PER has always had a green paradox effect on carbon emission intensity in the eastern region.

Based on the findings above, this paper puts forward the following policy suggestions:

- At the national level, China should continue to strengthen formal government environmental regulation to lower the total carbon emissions of the textile industry and make good use of market-based tools such as carbon tax and carbon emissions trading to reduce the carbon emission intensity of the textile industry.
- At the regional level, in the eastern region, formal government environmental regulation and the use of market-based tools should be kept moderate so as not to bring excessive environmental pressure on textile enterprises. And it's necessary to further improve public environmental awareness and supervision. In the central and western regions, it should further strengthen CER and MER to reduce CO_2 emissions in the textile industry. In the northeastern region, it's essential to utilize effectively market-based tools to reduce the carbon emission intensity of the textile industry.

So the government should fully consider the heterogeneity of ERs' impact on carbon emissions, formulate precise policies and use different ER tools flexibly to help CTI to curb CO_2 emissions and achieve the goal of green development.

The prospects for further research are to explore the heterogeneous impacts of ERs on CTI's sub-sectors and take more effective measures to reduce CO_2 emissions of CTI.

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Performance evaluation of sustainability in a textile firm via multi-criteria decision-making method

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ABSTRACT – REZUMAT

Performance evaluation of sustainability in a textile firm via multi-criteria decision-making method

Today, the sustainability approach is an integral part of business life. Especially, considering the damage that various events can cause to the environment, environmental sustainability (ES) is getting much more attention. From this aspect, the textile industry which can cause serious environmental damage, should integrate a sustainability approach into its management concept. Therefore, decision-makers and practitioners need to evaluate the sustainability performance of the industry. Multi-criteria decision-making (MCDM) methods help them to evaluate sustainability performance usefully. This paper evaluates the sustainability performance of a selected company in the textile industry over the years by environmental performance indicators. The technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methodology is used to evaluate sustainability performance.

Keywords: *sustainability, environmental indicators, performance evaluation, TOPSIS, textile*

Evaluarea performanței sustenabilităţii într-o firmă de textile prin metoda de luare a deciziilor cu criterii multiple

Astăzi, abordarea sustenabilității este o parte integrantă a mediului de afaceri. În special, având în vedere daunele pe care diversele evenimente le pot cauza mediului, sustenabilitatea mediului (ES) primește mult mai multă atenție. Din acest punct de vedere, industria textilă care poate cauza daune grave asupra mediului, ar trebui să integreze abordarea sustenabilității în conceptul său de management. Prin urmare, este foarte important ca factorii de decizie și practicienii să evalueze performanța de sustenabilitate a industriei. Metodele de luare a deciziilor cu criterii multiple (MCDM) îi ajută să evalueze util performanța sustenabilității. Această lucrare evaluează performanța sustenabilităţii unei companii selectate din industria textilă de-a lungul anilor, prin indicatori de performanță de mediu. Metodologia pentru preferința ordinii prin similitudine cu soluția ideală (TOPSIS) este utilizată pentru a evalua performanța sustenabilității.

Cuvinte-cheie: *sustenabilitate, indicatori de mediu, evaluarea performanței, TOPSIS, textil*

INTRODUCTION

The textile industry which is one of the oldest industries in the world is growing day by day. According to a market research company called IMARC Group, the global textile market reached a value of $ 960 billion in 2020. It expects the market to grow at a rate of 4.40 % over five years [1]. More than 400 thousand businesses are operating in the industry all over the world. Now, the global textile industry employs nearly 10 million people [2]. These data show us how the industry plays an important role in global social economic development. On the other side, despite the importance of market size in economic development, the textile industry not only uses huge amounts of resources [3, 4] but also creates harmful effects on the environment and natural resources [5, 6]. Zhang et al. [7] stated these environmental impacts over the life cycle of a cotton t-shirt from production stages consisting of collection, processing, application, replenishment, consumption, and disposal. Another study conducted by World Wide Fund for Nature (WWF) in Turkey [8] stated clearly and in detail that the textile industry is among the sectors that consume high use of water, energy and chemicals. Angelis-Dimakis et al. [9] and Fujimori et al. [10] also explained the aforementioned environmental problems related to high water, raw material and energy consumption, dust emission, waste generation and water pollutant discharge level. Briefly, large amounts of resource consumption in the textile industry can cause various environmental problems. For this reason, there is a growing awareness about the conservation of environmental health. In light of this awareness, there is an increasing push for sustainable methods in the textile industry.

The concept of sustainability, which emerged as a tool for a solution to environmental problems at first, brings together today's and future generations in the context of conscious resource consumption. It shows a direction from the sustainability of environmental resources to the sustainability of economic development over time. The term “sustainability” is first discussed in detail in Our Common Future report (Brundtland Report) prepared by the World Commission on Environment and Development

(WCED) in 1987. The report aimed to seek solutions to environmental problems and to transfer natural resources to future generations by using them consciously without completely destroying them [11]. The report defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [12, 13].

Today, the United Nations (UN) plays an important role based on the interest shown for sustainable development, for this purpose the UN has identified several topics supporting sustainable development [14]. As it is understood from these topics, social, economic and environmental relations are at the forefront of sustainable development. In other words, there must be an integration between economic, social and environmental systems [15, 16].

In fact, in Brundtland's report, it is seen that both “sustainability” and “sustainable development” concepts are used interchangeably from time to time, referring to their commitment to the environment, economy and social justice. It is also stated that while establishing the relationship between the environment and economic development, it is necessary to attach importance to sustainability. To define sustainability at this point, it shows the relationship between the ecosystem’s capacity and resource consumption according to Hawken [17]. Therefore, sustainability means that society should not use more resources than its renewal potential [18]. The aim here is to create a participatory process by creating and adopting a vision for this understanding in society by using all resources in a balanced way [19].

Sustainability is a process related to using resources economically and applying business models suitable for environmental health and social life. Companies need to turn to the environment, society and economy-friendly approaches in this process. Corporate sustainability, on the other hand, is defined as the corporate-level equivalent of the concept of sustainability. The contribution of sustainable development to corporate sustainability occurs in two ways. First, it helps companies to focus on environmental, social and economic performance. Secondly, it provides common goals for institutions, governments and civil society to ensure ecological, social and economic sustainability [20]. Signitzer and Prexl [21] have stated corporate sustainability as a permanent improvement process to ensure the integrity of the company's activities in terms of economic, social and environmental aspects. Since, environmental, economic and social sustainability are three interconnected factors [22], these factors should be a significant perspective in business decisions to reach targets.

As in other industries, there is an increasing awareness of sustainability in the textile industry.

Especially, the use of harmful chemicals, high materials, water and energy consumption, and waste generation can cause many environmental problems in the production of finished goods. In other words, the textile industry creates major environmental impacts. To gain ES, industry designers and managers must follow environmentally and socially responsible trends and focus on creating more innovative products. They should consider sustainability in their business practices [5]. Because, the demand for textiles is increasing according to the rise in consumer awareness. Today, customers are expecting better quality products along with their sustainable features. Textile firms must meet these needs with a sustainable approach. Among hundreds of thousands of textile companies in the world, some have taken priority ES in business practices. Periodic statistics are published to evaluate the importance given sustainability issues by research groups. One of them is Corporate Knights’ index of the world’s most sustainable corporations. Rating methodology is based on some key performance indicators covering ES, social responsibility, and financial management [23]. The list also creates an image element for the listed companies. The 2021 Global 100 list included three textile companies, Kering SA from France (ranked 7), Adidas AG from Germany (ranked 76) and Industria de Diseno Textil SA from Spain (ranked 92).

While the global market size of the textile industry creates a positive view for the sector, this view can sometimes be criticized due to the environmental effects that it causes. Therefore, it is necessary to evaluate ES correctly. But ES evaluation is complex for the textile industry because it uses high energy, water, raw materials and chemicals for production. The industry has a wide range of products. On the production side, a wide variety of materials, equipment and technologies have been included in the process of each one, with different environmental impacts. On the consumer side, the rapidly changing fashion and customer preferences have shortened product life. As a result, this has led to an increase in environmental burden and waste [24]. Many indicators affect ES to evaluate it. Zhang et al. [25], Wang et al. [26] and Thies et al. [27] have emphasized the simultaneous consideration of multiple factors when evaluating ES. Since sustainability is a complex concept involving multiple decision points, MCDM methods are also useful tools for evaluating performance in such situations.

In this study, TOPSIS, one of the MCDM methods widely used in the literature, is utilized to evaluate sustainability performance indicators of a selected company over the years by environmental performance indicators.

The objectives of using this method are: (i) being non-subjective; (ii) providing easy calculations based on Euclidean metrics; (iii) rapid assessment of environmental indicators; (iv) being a strong and simple mathematical structure [28]. Therefore, this study contributes significantly to the evaluation of ES through a structured approach. This includes both the mathematical model and technical solutions. This work was implemented for a particular textile manufacturing organization in Turkey.

For the application, a textile company traded in the Borsa Istanbul (BIST) sustainability index is selected. Data are obtained from the sustainability reports pub-

lished by the company between 2018–2020. The indicators used for the analysis are limited to those published by the company as they are easily accessible. The following can be said as the contribution of the study to the literature:

- An objective model is used in the performance evaluation of sustainability.
- Environmental indicators are determined from company data prepared in accordance with Global Reporting Initiative (GRI) content index. (GRI is an independent international organization that guides businesses and their stakeholders on important sustainability issues. It emphasizes global practices in sustainability reporting).
- A real case in the textile industry is used for performance evaluation.

This study is organized in the following order; the literature review is covered in the second section, followed by the research methodology which is detailed in the third section. Application and findings are covered in the fourth section and the fifth section details the conclusions.

LITERATURE REVIEW

Since the topic is of great importance, there are lots of studies conducted about ES and performance evaluation in the literature. It is seen from the literature that methods used in performance evaluation differ from each other. Here, some of the studies performed in the textile industry area using MCDM methodologies are explained in brief as follows.

Ilangkumaran and Kumanan [29] proposed an integrated fuzzy analytic hierarchy process (AHP) and TOPSIS approaches to select the optimum maintenance strategy in the textile industry. Four indicators were evaluated under 4 main areas; environmental conditions, component failure, training required and flexibility in their study. Shyjith et al. [30] discussed the same problem as the selection of an optimum strategy for maintenance in the textile domain. They used AHP and TOPSIS. Lu et al. [31] developed a fabric hand-based textile material evaluation model, and then the human machine measure hybrid fuzzy MCDM methodology proposed by them. They suggested that the proposed method and software can effectively support textile designers in selecting fabrics. Ünal and Güner [32] proposed the AHP approach which is utilised to select Enterprise Resource Planning (ERP) suppliers.

Tseng et al. [33] conducted this by using both fuzzy synthetic methods and the Decision Making Trial and Evaluation Laboratory (DEMATEL) approach. They tried to assess corporate sustainability performance by employing those methods. Results showed that the Taiwanese textile industry's performance is low because of a lack of social responsibility. Acar et al. [34] adopted TOPSIS to measure the sustainability performance of a textile firm by concentrating on some environmental factors. Their study covered the years between 2008 and 2012. They found that 2010 was the most effective year in terms of ES performance. In another study by Ergüden and Çatlıoğlu [35], the TOPSIS method is preferred and the corporate sustainability performance of the industry is examined.

Kumar et al. [36] focused on the supplier selection problem using fuzzy AHP in the Indian textile industry. Chakraborty et al. [37] study aimed to evaluate and select the best cotton fibre using integrated DEMATEL and VIKOR (VIšeKriterijumska Optimizacija I Kompromisno Resenje – Multicriteria Optimization and Compromise Solution) methodology. Kaplan et al. [38] studied about navel selection problem for rotor spinning. They used Elimination Et Choix Traduisant la Realité III (ELECTRE III) method to select the appropriate navel for Ne 12 rotor yarn spun to weave denim fabric. Zhu et al. [39] used the grey-based DEMATEL approach to structure and evaluate barriers to eco-friendly apparel production in the apparel industries. They emphasized on lack of human resource capabilities and difficulties faced to enter environmentally friendly clothing markets as important barriers.

Other studies performed in the textile industry can be listed as Rezaie et al. [40] used SWOT, DEMATEL, fuzzy AHP, and ELECTRE methods; Yin et al. [41] used DEMATEL, ISM, ANP methodologies; Adalı and Işık [42] utilized DEMATEL, ANP, and DEA (Data Envelopment Analysis) methods. All of these studies cope with different problems to make a judgment about optimum alternatives among the other alternatives by applying different MCDM methodologies. Kılıç and Yalçın [43] searched methods used in sustainability studies as assessment tools. They stated that MCDM techniques are the most frequently used techniques in the literature. It may be stated from the aforesaid statements that many significant studies have been performed in the textile industry in various countries. But, so few studies have focused on the sustainability aspect using MCDM methodologies, especially TOPSIS. Specifically, this study appears to be one of fewer studies using TOPSIS to evaluate sustainability performance over the years by environmental performance indicators.

RESEARCH METHODOLOGY

The research methodology has two main stages including determining the indicators and sustainability performance ranking. In the first step, the literature is reviewed to determine the environmental indicators. In the second step, the proposed method called TOPSIS is performed to rank the sustainability performance by years. The technical background of TOPSIS is given in this part of the study. Besides, before presenting the steps of TOPSIS, some information about the data set used is provided.

Data set

The research model is applied to a Turkish company which manufactures industrial textile products operating in 12 facilities throughout 5 countries with nearly 5.000 employees.

Table 1

ENVIRONMENTAL PERFORMANCE INDICATORS				
Material	**Energy**	**Waste (tonne)**	**Emission (tCO_2e)**	**Water (m^3)**
TCF chemical ratio	Electricity (kWh)	Hazardous waste	Greenhouse gas emissions	Consumption
NY salt/flake ratio	Natural gas (m^3)	Non-hazardous waste		Discharge
SEC chemical ratio		Recycling		Recycling
		Total disposal waste		
		Total waste		

Note: TCF – Tire Cord Fabric, NY – Nylon, SEC – Single End Cord.

Data, which covers the years between 2018 and 2020 are derived from sustainability reports of the firm [44]. The company has been preparing sustainability reports since 2014. When these reports are examined, it is seen that the content specification processes of reports presented in 2018, 2019 and 2020 show similarities. In addition, as a result of our review, it is understood that data in the relevant reports are useful for our research in terms of tracking trends more effectively. The summary of indicators is summarized in table 1.

In the study, TCF chemical ratio is represented as (C1), NY salt/flake ratio as (C2), SEC chemical ratio as (C3), electricity as (C4), natural gas as (C5), hazardous waste as (C6), non-hazardous waste as (C7), recycled waste as (C8), total disposal waste as (C9), total waste as (C10), greenhouse gas emissions as (C11), water consumption as (C12), water discharged as (C13) and recycled water as (C14). Finally, data obtained were analysed in the Microsoft Office Excel program.

TOPSIS

The TOPSIS method, proposed by Hwang and Yoon [45] is a well-known MCDM method in the literature. This method is later developed by some authors like Chen [46], Zavadskas, Turskis and Tamosaitiene [47], Hung and Chen [48]. The main point of TOPSIS is to identify the positive ideal solution which consists of all of the best values accessible to the criteria and the negative ideal solution which is composed of all worst values accessible to the criteria. The best alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution [49].

TOPSIS steps are summarized as follows [50].

Step 1. Construct a decision matrix shown in equation 1:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ A_i \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_2 & & X_jX_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1j}x_{1n} \\ \dots & \dots & \dots & \dots\dots \\ x_{i1} & x_{i2} & \dots & x_{ij}x_{in} \\ x_{m1} & x_{m2} & \dots & x_{mj}x_{mn} \end{bmatrix} \end{array} \quad (1)$$

where A_i – i^{th} alternative, x_{ij} – the numerical score of the i^{th} alternative concerning j^{th} criteria

Step 2. Normalize the decision matrix as in equation 2.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}(x_{ij})^2}} \quad (2)$$

Step 3. Calculate the weighted normalized decision matrix. In this step, the weighted normalized value is computed as given in equation 3.

$$v_{ij} = w_{ij} * r_{ij} \quad (3)$$

Step 4. Acquire the positive ideal solution (A^*) and negative ideal solution (A^-) as provided in equations 4 and 5.

$$A^* = \{(max\ v_{ij} \mid j \in J), (min\ v_{ij} \mid j \in J')\} \quad (4)$$

$$A^- = \{(min\ v_{ij} \mid j \in J), (max\ v_{ij} \mid j \in J')\} \quad (5)$$

Step 5. Compute the distance of each alternative from the positive ideal value and the negative one as in equations 6 and 7:

$$S_i^* = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_j^*)^2} \quad (6)$$

where $i = 1,2,\dots,m.$

$$S_i^- = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_j^-)^2} \quad (7)$$

where $i = 1,2,\dots,m.$

Step 6. Compute the relative closeness to the ideal solution as given in equation 8:

$$C_i^* = \frac{S_i^-}{(S_i^* + S_i^-)} \quad (8)$$

where $i = 1,2,\dots,m$

Step 7. Rank the preference order for each alternative according to the closeness coefficient. The bigger C_i^* value means better performance.

APPLICATION AND FINDINGS

TOPSIS is widely used in many different areas in MCDM problems. In this paper, this method is used to evaluate sustainability performance over the years by environmental performance indicators. The research methodology is applied under two main steps including determining the indicators and ranking of sustainability performance. Findings are provided in tables 2, 3, 4, 5 and 6.

When the closeness coefficients of the last three years are ranked, it is seen that 2018 is the most effective year for the company. The lowest performance

Table 2

THE INITIAL DECISION MATRIX														
Year	**C1**	**C2**	**C3**	**C4 (000,000)**	**C5 (000,000)**	**C6 (000)**	**C7 (000)**	**C8 (000)**	**C9 (000)**	**C10 (000)**	**C11 (000)**	**C12 (000)**	**C13 (000)**	**C14 (000)**
2018	1.04	1.11	1.11	599.49	61.36	435.28	10.17	2.56	7.59	9.22	10.07	3.48	2.03	189.44
2019	1.00	1.11	1.20	576.01	62.35	423.68	10.08	2.68	7.40	7.13	9.25	4.09	2.62	181.67
2020	0.91	0.92	0.79	490.18	54.27	357.05	10.88	2.30	8.58	6.73	10.59	2.90	1.99	184.10

Table 3

NORMALIZED DECISION MATRIX														
Year	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
2018	0.61	0.61	0.61	0.62	0.60	0.62	0.57	0.59	0.56	0.69	0.58	0.57	0.53	0.59
2019	0.59	0.61	0.66	0.60	0.61	0.60	0.56	0.61	0.54	0.53	0.54	0.67	0.68	0.57
2020	0.53	0.51	0.44	0.51	0.53	0.51	0.61	0.53	0.63	0.50	0.61	0.48	0.52	0.57

Table 4

THE WEIGHTED DECISION MATRIX														
Year	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
2018	8.53	8.52	8.62	8.69	8.32	8.64	7.89	8.23	7.78	9.65	8.13	8.03	7.38	8.24
2019	0.04	8.55	9.36	8.35	8.46	8.41	7.82	8.57	7.58	7.46	7.47	9.42	9.52	7.90
2020	0.04	7.07	6.16	7.10	7.36	7.09	8.44	7.35	8.79	7.03	8.55	6.69	7.25	8.00

Table 5

THE POSITIVE AND NEGATIVE IDEAL SOLUTIONS														
Solution	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
A^*	8.53	8.55	9.36	8.69	8.46	8.64	8.44	8.57	8.79	9.65	8.55	9.42	9.52	8.24
A^-	0.04	7.07	6.16	7.10	7.36	7.09	7.82	7.35	7.58	7.03	7.47	6.69	7.25	7.90

Table 6

THE RELATIVE CLOSENESS COEFFICIENTS		
Year	C_i^*	**Ranking**
2018	0.768	1
2019	0.384	2
2020	0.141	3

seems to be in 2020. It is understood from the results that the company is gradually moving away from its ES target.

CONCLUSIONS

In recent years, the sustainability approach is an integral part of business management. It is accepted that a well-organized management approach based on sustainability is crucial for stakeholders to evaluate the impacts of a company's activities. To set long-term strong relationships with stakeholders cares about not only the future of the company but also the future of the world. For this reason, there is an increasing trend based on the significance of the topic among practitioners. This is also available for the textile industry. At this point, the performance evaluation of sustainability over the years concerning environmental indicators becomes very important. Thus, it is focused on in the study.

Two main steps including indicators determination and sustainability performance ranking part are given in the research methodology. It is benefited from TOPSIS to achieve the study's goal.

The methodology is applied to a company from the Turkish textile industry. Data are derived from sustainability reports of the company for the years 2018 and 2020. However, it is seen that the content specification processes of reports vary and some detailed information in the reports does not exist in some years so it is difficult to make a complete comparison. Therefore, it has been thought that data from the 2018, 2019 and 2020 reports are useful for our research and if so, the used methodology would give more accurate results if these data are provided. The results show that the best sustainability performance for the company is received in 2018.

Although the textile industry is very important for the global economy, if the sustainability approach is ignored, it can lead to serious environmental problems. For instance, consuming resources unconsciously,

and creating harmful effects on natural resources and the environment are some of these problems. At this point, ES means the permanence of natural resources and therefore, it is very important for companies in the industry. Powerful strategies at the business level must be implemented in the textile industry. Also, at the national level governments must constitute and control these strategies. Moreover, they should not forget to update them. That's why, this study contributes to the sustainability performance evaluation process by providing a methodology which can systematically evaluate environmental performance indicators. In particular, the decision-makers from the textile industry should see their weaknesses, make business plans accordingly and ensure continuous improvement in terms of sustainability.

Eventually, this study is performed on a single company's data in the textile industry. As a future study, more companies can be elected in the same or different industries to see how their perspectives on the ES approach. Also, the same company can be studied with more sustainability dimensions like environmental, social and economic indicators. In addition to its use for the evaluation of sustainability performance by environmental indicators in the textile industry, the proposed methodology can also be used in other MCDM problems where their net scorings. If not, the proposed methodology can be modified and fuzzy technics can be utilized. Finally, the same study can be repeated several times over the same firm in different years. Thus, it can be observed whether the firm's policy on sustainability has changed over the years.

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Developed woven structures for denim materials

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ABSTRACT – REZUMAT

Developed woven structures for denim materials

Denim is a cotton or cotton-blend twill textile material that is very popular to use for manufacturing different fashionable clothing items, such as jeans, jackets, skirts, shirts, and caps, and it is worn by most people across all age groups. Unfortunately, this material causes damage to the environment and human health through the large quantities of water required to grow the cotton plant, the toxic substances needed to dye the textile, the process of sandblasting to give denim an old, worn look and the large amounts of waste that result from its vast usage.
This research aimed to develop advanced denim materials based on a blend of high-tech fibres, eco-friendly fibres with silver ions (Ag) and cotton fibres. The main purposes of developing these materials were to improve the mechanical potential under the repeated stresses of traction, friction, and tearing and to improve the psychosensory comfort by optimally combining the fabric pattern, the fibrous composition and the component yarn structure. By prolonging the life of these materials so that people can wear them longer, denim textile manufacturers can contribute to the global effort to become more sustainable. The textile structures were designed using the logical design scheme of a woven structure. The preparation of yarns for weaving and the weaving process was performed on equipment from the Experimental Station of the National Research and Development Institute for Textiles and Leather (INCDTP). Finally, the physio-mechanical characteristics of the fabric were examined, and the performances were validated.

***Keywords**: blue jeans/denim, circular economy, innovative textile structures, quality control, improved wearability*

Structuri țesute dezvoltate pentru materiale denim

Denimul este o țesătură cu legătura diagonal din bumbac sau amestec de bumbac, foarte populară pentru fabricarea diferitelor articole vestimentare la modă, cum ar fi blugi, jachete, fuste, cămăși, șepci etc. și este purtat de majoritatea clienților din toate grupele de vârstă. Din păcate, acest material pune mare presiune asupra mediului și sănătății umane prin cantitățile mari de apă necesare creșterii plantei de bumbac, prin substanțele toxice necesare pentru vopsirea acestuia, prin procesul de sablare aplicat pentru a da denimului un aspect vechi, uzat, cât şi prin cantităţile mari de deşeuri rezultate din purtarea sa vastă.
Scopul acestei cercetări a fost de a dezvolta materiale denim avansate, bazate pe un amestec de fibre high-tech, fibre ecologice cu conținut de ioni de argint (Ag) și fibre de bumbac. Principalele scopuri ale dezvoltării acestor materiale au fost îmbunătățirea potențialul mecanic la solicitările repetate de tracțiune, frecare, rupere, dar și îmbunătățirea confortului psihosenzorial prin combinarea optimă a modelului țesăturii, a compoziției fibroase și a structurii firelor componente. Prelungind durata de viață a acestor materiale, astfel încât clienții să le poată purta mai mult timp, producătorii de textile din denim pot contribui la efortul global de a deveni mai durabili. Structurile textile au fost proiectate folosind schema de proiectare logică a unei structuri țesute. Pregătirea firelor pentru țesere și procesul de țesere s-au făcut pe utilajele din Stația experimentală a Institutului Național de Cercetare-Dezvoltare pentru Textile și Pielărie (INCDTP). În final, au fost analizate caracteristicile fizico-mecanice ale țesăturii, iar performanțele au fost validate.

***Cuvinte-cheie:** blugi/denim, economie circulară, structuri textile inovatoare, controlul calității, comportare îmbunătățită la uzură*

INTRODUCTION

Denim is a unique and solid textile material made by using a twill weave and cotton fibre in both warp and weft directions. More recently, cotton yarns blended with other types of yarns, such as polyester, polypropylene, elastane, rayon, and wool, have been used in addition to the cotton fibre during denim production n a core-spun or double-core configuration, used in the weft direction. The blend of these yarns improves the elasticity, smoothness, and abrasion resistance, prevents wrinkles and reduces the weight of the overall fabric [1].
The history of denim fabric as it is recognized today began in the French city of Nimes, where denim was initially used for garments worn by specialists because of its high sturdiness; it was coloured with a blue dye made from the Indigofera tinctoria plant that originated in India [2]. All the developments, until today, were achieved by changes made to the processes of spinning, weaving, finishing, etc.; by improving and varying the visual aspects, the thermal management properties and the moisture management

Table 1

CHARACTERISTICS OF CONVENTIONAL DENIM OR DENIM TYPE FABRICS

Characteristic	Ref. 4	Ref. 5	Ref. 6	Ref. 7	Ref. 8	Ref. 9
Fibrous composition, warp/weft	100% cotton yarns	100% cotton yarns	100% cotton / double core yarns with elastane, polyester and cotton	100% cotton / core-spun yarns with 94.43% cotton and 5.56% elastane	100% combed cotton yarn / core-spun yarns of 70% cotton and 30% polyester	100% cotton / 100% bamboo yarn
Medium length density of yarns, warp/weft (tex)	7.38/9.22	32.62/ 42.18	73.81/32.80	43.74/36.9	29.52/36.9	29.52 × 2
Average technological sett, warp/weft (yarns/cm)	-	27/33	-/34.4	27.2/20	41/22	-
Specific mass (g/m^2)	225	251	378	-	216.90	256
Tensile strength, warp/weft (N)	-	-	1275/412	791/307	1327/678	560/450
Tearing strength, warp/weft (N)	15.01/12	-	64/58	54/36	46.06/48.54	58/100

properties; and by improving the sustainability of the production process by capitalizing on natural dyes for colouring the fabrics.

The denim fabrics addressed in this research were developed in the context of the circular economy and began from the principles of this internationally spread economic system. The design technique used in this study involves a combination of eco-design and design thinking to prevent waste production related to the LCA of the product category. Such prevention aims to change the goal of the design from the attributes of consumerism (pleasant appearance, low price and 6–10 month maximum use period) to the attributes of non-consumerism by reconsidering the time of use, maintaining the appearance of denim or styling it with minimum variations for weaving structures, or by optimizing the mechanical potential, which is the main vector of the "durability" of the textile material [3].

For the creation of the advanced denim material, the following characteristics of some existing denim fabrics on the market were considered:

- the use in the warp and weft directions of spun yarns of medium cotton fibres, with an average density of 50 tex;
- the use of both twisted and simple yarns in the warp direction, depending on the characteristics of the finished product;
- the specific mass of the grey fabric being, on average, 220–300 g/m^2, which is correlated with the density of the length of the yarns used;
- the technological sets in correlation with the weave must give an average degree of coverage in the grey fabric of 3 units, considering the existence of floats in the two yarn systems, with a jump of 2 units; and
- the representative physio-mechanical characteristics of tensile strength, tensile elongation, tear strength, warp and weft, friction behaviour and mass loss by friction [4–9].

Compared to a classic denim fabric, the advanced denim material has added value from the rational use of high-tech fibres blended (UHMWPE fibres and regenerated cellulose fibres with silver ions) with cotton to improve the mechanical and psychosensory properties and sustainable design to increase the life-cycle of the final products.

The technology required to make the advanced denim-type material is related to the processes of preparing the materials for weaving and weaving control to obtain the grey fabric. The developed woven denim-type structure can be made on any weaving machine, conventional or unconventional, as long as it allows the use of at least 8 (eight) heald shafts [10].

From a visual point of view, the woven structure retained the same look as denim products; however, in terms of functionality, the structure met specific and personalized requirements for some well-defined target groups, including fabric needed for professional activities (PPE, clothing for high-performance sports activities) and for the daily activities of people with special needs, such as people disabilities or elderly individuals [11].

The physio-mechanical characteristics of the conventional denim and denim-type fabrics, as identified from the literature and discovered using the aforementioned techniques, are presented in table 1.

MATERIALS AND METHODS

Raw materials

The following types of yarns were used in the two weave systems (weft and warp) to make the textile material:

- Yarns used in the warp system:
  – spun yarns 25×2 tex; 100% carded cotton (Fu1)

Table 2

THE PHYSIO-MECHANICAL CHARACTERISTICS OF THE YARNS USED FOR WARP AND WEFT

Yarn code	FU_1	FU_2	FB
Length density (tex)	25×2	20×2	30×1
Fibrous composition	100% carded cotton	80% cotton 18% regenerated cellulose 2% Ag ions	98% carded cotton 2% UHMWPE
Coefficient of variation, CV (%)	10.21	5.79	7.23
Tensile strength (N/tex)	6.67	5.61	5.98
CV (%)	10.21	5.79	5.61
Elongation at break (%)	6.56	5.76	7.65
CV (%)	10.42	7.23	5.45
Torsion (torsions/m)	831	864	700
CV (%)	3.82	2.85	2.20
Twist (twists/m)	490	469	-
CV (%)	4.36	3.43	-

– spun yarns 20×2 tex; 80% carded cotton, 18% regenerated cellulose, 2% Ag ions (Fu2).

• Yarns used in the weft system:

– spun yarns 30×1 tex, 98% carded cotton, 2% UHMWPE (Dyneema) (Fb).

The preparation of the yarns for weaving conventional denim and weaving the variants of woven structures was done using the equipment from the Experimental Station of INCDTP.

The characteristics of the yarns used in the warp (Fu1, Fu2) and weft (Fb) directions for making the denim-type fabric are presented in table 2.

Fabric design

For the weaving of the advanced textile material, a logical programming scheme was used (figure 1), which contains the technological information necessary to make a fabric in the form of drawings. In the programming logic scheme, the position of the drawing was determined by the technological characteristics specific to the weaving machine.

In principle, the programming scheme had three main drawings and two auxiliary drawings.

The main drawings were as follows:

– weave drawing, **DL**;

– the drawing of the warp reed denting in the shafts, **DN**; and

– order drawing, **DC**.

The auxiliary drawings were as follows:

– the drawing of the warp reed denting in the reed joints, **DS**; and

– the drawing of the binding of shafts to the forming mechanism of the shed, **LP**.

For processing, a conventional technological flow was used (figure 2), specific to the preparation of spun yarns for weaving (fabric preparation) and for weaving the final product. The processing operations in the technological flow (figure 2) were correlated with the logical programming scheme of the weave (figure 1), the type of yarns used and the existing

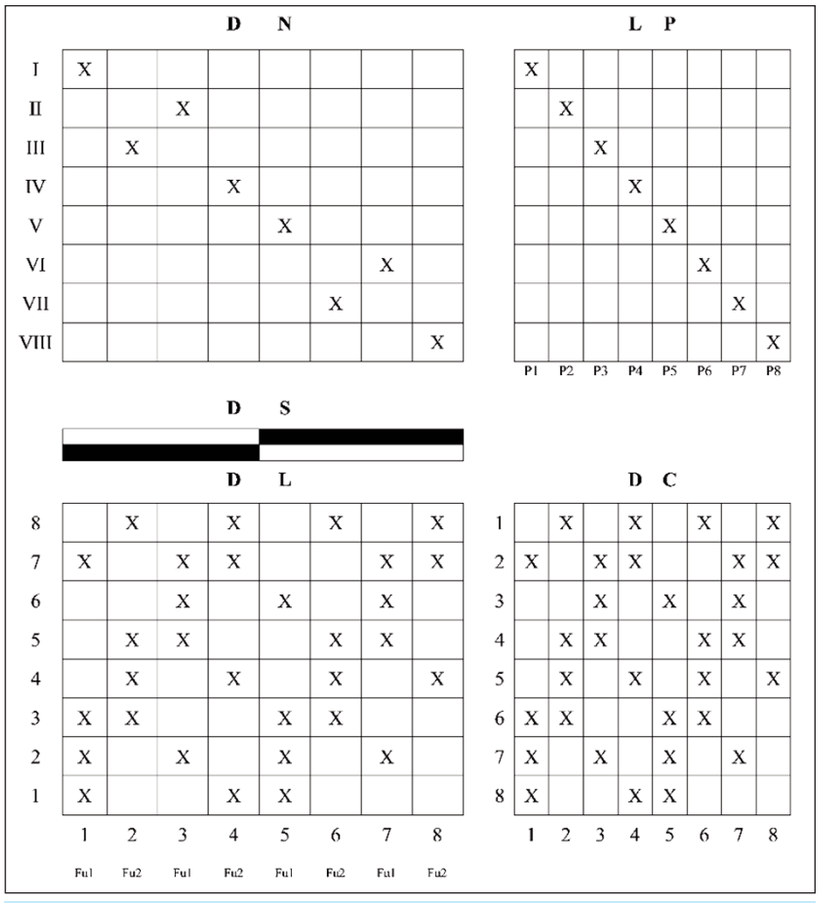

Fig. 1. Logical programming diagram of the weave

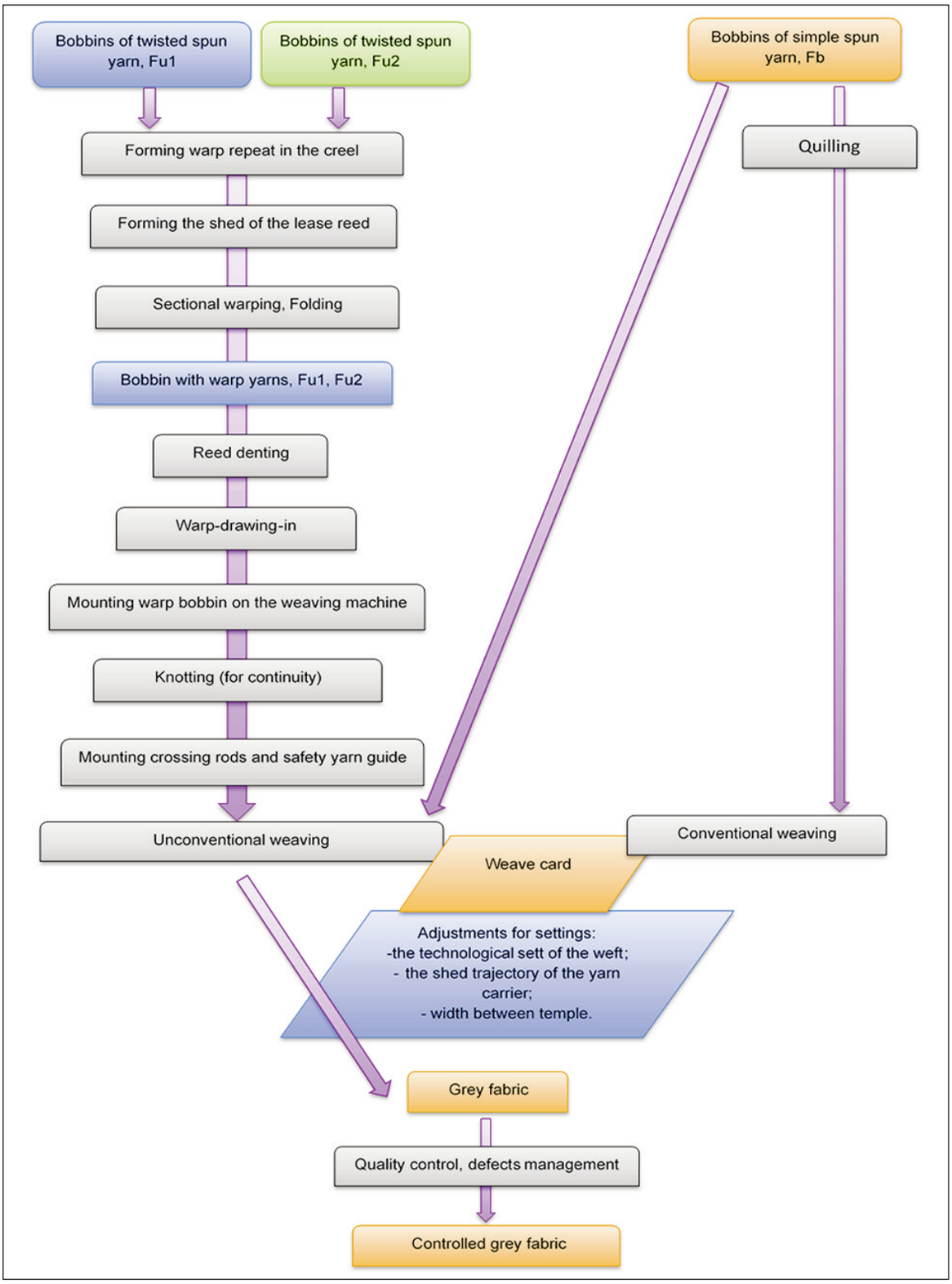

Fig. 2. Technological flow

endowment in the Experimental Station of INCDTP. The following machines were used to process the yarns and obtain the woven structure: sectional warping machine, quilling machine, folding machine, winding machine, shuttle or gripper weaving machine, control table and meter.

The processing of these yarns, even if they incorporated high-tech elements (2% Ag ions or 2% UHMWPE) to ensure performance and psychosensory comfort, did not require the use of accessories, special consumables or special adjustments of the machines.

In the processing, the yarns used behaved similarly to 100% cellulosic yarns, with the observation that the incidence of stops due to the breaking of weft yarns (those containing 2% UHMWPE) was zero.

The technological flow of manufacturing (figure 2) was valid both for weaving on the weaving machine with the shuttle and on the one with the grippers.
There were two main categories of settings:
– correlation adjustments to the operating diagram of the weaving machine; and
– adjustments adapted to the yarns in the two yarn systems and to the weave programming scheme.
An unusual component of processing was the use of 8–10 heald shafts, allowing for 2 additional heald shafts to reach the edge. Also, dyed or undyed yarns could be used. Environmentally friendly dyes could be used, including natural dyes. The chemical finishing of the fabrics was conventional and in compliance with environmental protection regulations.

RESULTS

Physio-mechanical characteristics of the fabric

The structure and mechanical potential characteristics were evaluated in the RENAR-accredited laboratories of INCDTP (figure 3).
The physio-mechanical characteristics of the grey fabric are presented in table 3.
The mechanical potential, in response to the repeated stresses of traction, friction, tearing, and repeated bending, was a result of two vectors: a) the weave of the structure that gave the surface effect of the fabric presented above; and b) the fibrous composition of the yarns used, which incorporated a percentage of max 10% high modulus synthetic fibre in the fibrous mass from the high-tech polyethylene class (UHMWPE), makes the dispersion of the characteristics that contribute to the mechanical potential, to be significantly minimized, at values of the coefficient of variation not specific to the spun yarns, but specific to the multifilament yarns.

Table 3

PHYSIO-MECHANICAL CHARACTERISTICS OF THE GREY FABRIC

Characteristic	Value
Specific mass (g/m^2)	200 +/– 5%
Technological sett, in the warp (yarns/cm)	28
Technological sett, in the weft (yarns/cm)	22
Tensile strength, in the warp (N)	960 – 1000
Tensile strength, in the weft (N)	980 – 1200
Elongation at break, in the warp (%)	9.8 – 12.2
Elongation at break, in the weft (%)	8.7 – 10.5
Tearing strength, in the warp (N)	46 – 52
Tearing strength, in the weft (N)	56 – 64
Received grade after testing after 20000 friction cycles, 9 kPa	4 – 5/5
Relative specific mass loss after friction (%)	4.8

a *b*

Fig. 3. The structure of: *a* – conventional denim fabric; *b* – prepared denim-type fabric

The fabric obtained had a specific mass comparable to a fabric composed of 100% cellulosic fibres (a specific mass usually obtained in denim fabrics), but with a mechanical tensile, abrasion and tear strength that was increased, on average, by 20% compared to a conventional denim-type fabric composed of 100% cellulosic yarn with a length density of 30 or 50 tex.
An excellent friction resistance was obtained for the fabric. The very low coefficient of friction of the high-tech fibre was conducive to obtaining and maintaining proper frictional behaviour, a minimised risk of fibre breakage, a minimised appearance of fibre ends on the side surface of the yarns, a pleasant touch (psychosensory comfort) and a pleasant appearance during the cycles of wearing, washing, and ironing the fabric.

Quality aspects and performance validation

Quality control of the fabric was done in accordance with the regulations in force or according to the particular requirements of the client/beneficiary. The types of defects (minor and major) in the grey fabric were found to be in accordance with the standard SR ISO 8498-96: Woven fabrics – Description of defects. If the fabric had a higher number of defects than permitted by the standard, it was delivered only with the consent of the beneficiary.
The performances of the created advanced denim material were validated by the following attributes that were specific to the requirements of the consumer and the manufacturer:
A. Requirements specific to the final consumer:
- preserving the surface appearance of the denim fabric, both on the front and on the back;
- maintaining the specific mass of denim-type fabrics;
- maintaining a composition of over 75–80% cotton; and
- ensuring safety and protection.

B. Requirements specific to the manufacturer:
- workability by conventional and unconventional technologies, without involving special accessories, adjustments, maintenance techniques or preparations;
- grey fabrics with 2% UHMWPE exhibiting behaviour caused by the frictional demands on the surface, similar to conventional denim fabrics; and
- 2–10% UHMWPE fabrics having a psychosensory feel similar to 100% cotton fabrics regardless of the

weave used, so the high-tech fibre will exhibit its high performance in wear/use as well as the eco-regenerated cellulose fibre with a content of silver ions.

When considering the manufacturing specifications and the characteristics of conventional denim fabric, it was estimated that the advanced material made of high-tech fibres met the customer requirements (end consumers and manufacturers).

CONCLUSIONS

The denim-type woven structure developed in this study preserved the types of yarns generally associated with these fabrics.

The advantages of this developed innovative denim-type structure are as follows:

- advantageous price-to-time ratio for the use of the final product;
- increases the amplitudes per sequence in LCA about both the textile fibres used and the products made from the textile;
- increases the use time while maintaining the comfort, safety and protection requirements, despite the decline in denim-type surface appearance;
- eliminates the need for finishing processes that improve the appearance but cause irreversible damage to the woven structure (e.g., prewashed or ripped jeans);
- minimises the vectors of consumerism and maximises the vectors of nonconsumerism, such as maintaining the mechanical potential and increasing/optimising the use time, thus redefining the concept of quality in the field of denim fabrics and denim-type fabrics;
- creates the possibility of making clothing products, including personal protective equipment (PPE), modified according to the requirements of use; and
- ensures a change in the aims of textile production from consumerism to sustainability and alignment to a circular economy.

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Fast textile pattern generation combining MRF-based and Gram-based methods

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ABSTRACT – REZUMAT

Fast textile pattern generation combining MRF-based and Gram-based methods

Textile pattern design is a tedious and challenging task for designers. This paper proposes a fast textile pattern generation algorithm that combines MRF-based and Gram-based methods. First, the reconstruction method based on image optimisation is determined after analysing the specific requirements of textile pattern design. The pre-trained VGG19 is selected as the style feature extraction neural network. Then, we compare the generation results of various combinations of style loss functions and propose a multi-resolution image optimisation method. Finally, the smoothing loss and colour histogram matching are added to improve the generation quality further, thus constructing an image generation algorithm for textile pattern design. Experimental results demonstrate that our algorithm can effectively generate complex textile patterns with global style and local detail features. The average image generation time is 575s, over 84.3% faster than traditional algorithms. At the same time, this algorithm is convenient for switching styles and requires lower computational capability. It can improve pattern design efficiency and promote the application of image generation technology in textile design.

Keywords: *artificial intelligence, computer-aided design, image generation, neural networks, textile pattern design*

Generare rapidă de modele textile, combinând metode bazate pe MRF și pe Gram

Designul modelelor textile este o sarcină minuţioasă și provocatoare pentru designeri. Această lucrare propune un algoritm de generare rapidă a modelelor textile, care combină metode bazate pe MRF și pe Gram. În primul rând, metoda de reconstrucție bazată pe optimizarea imaginii este determinată după analiza cerințelor specifice ale designului modelului textil. VGG19 pre-antrenat este selectat ca rețea neuronală de extracție a caracteristicilor de stil. Apoi, se compară rezultatele generării diferitelor combinații de funcții de modficare a stilului și propunem o metodă de optimizare a imaginii cu rezoluții multiple. În cele din urmă, diminuarea netezirii și histograma potrivirii culorii sunt adăugate pentru a îmbunătăți și mai mult calitatea generării, construind astfel un algoritm de generare a imaginii pentru designul modelelor textile. Rezultatele experimentale demonstrează că algoritmul nostru poate genera în mod eficient modele textile complexe cu stil global și caracteristici de detalii locale. Timpul mediu de generare a imaginii este de 575 de secunde, ceea ce este cu peste 84,3% mai rapid decât algoritmii tradiționali. În același timp, acest algoritm este convenabil pentru schimbarea stilurilor și necesită o capacitate de calcul mai mică. Se poate îmbunătăți eficiența designului modelului și se poate promova aplicarea tehnologiei de generare a imaginii în designul textil.

Cuvinte-cheie*: inteligență artificială, proiectare asistată de calculator, generare de imagini, rețele neuronale, design de modele textile*

INTRODUCTION

Textile patterns are extensively used in digital textile printing. Traditional textile pattern design requires designers to collect inspirational images to extract motifs or textures, then repeat and mend them to create a continuous textural design without seams appearing [1]. This work is time-consuming and requires designers with inventiveness, information extraction and expression skills, which need years of professional training [2]. In recent years, artificial intelligence has provided the textile and apparel industry with various methods and solutions [3–4], and neural style transfer has been steadily used in textile design [5]. This technology can automatically extract style features from a target style image and shows them on a content image. Visual style modelling and generation techniques of style transfer can be used in the design process of textile patterns. The pattern features in an inspirational image, which is the style image in style transfer, can be modelled and generated into a pattern image by reconstruction. With the help of pattern generation techniques, design efficiency can be significantly improved.

However, the current research object of style modelling and transfer focuses mostly on artistic painting, which cannot sufficiently meet the specific requirements for textile pattern design. To liberate human designers from laborious and time-consuming design work and to encourage the implementation of image-generating technology in textile design, it is crucial to research the generation algorithms for textile pattern design.

Texture generation is the foundation of pattern generation. Markov Random Field (MRF) [6] can model and extract simple texture features from images. However, generation with pixel-by-pixel matching

uses a great deal of time. With the significant advance in deep learning, more powerful neural style transfer became popular. Gatys et al. [7] found that colour and texture can describe the style features of an image. The style features were extracted by convolutional neural networks (CNN) and modelled with Gram matrices, which can be used to compute style loss and generate images. Li et al. [8] combined MRF with CNN for style transfer. Patches are obtained by CNN and then matched by MRF in the feature spaces to generate images with local detail features. Fayyaz et al. [9] used adversarial generative networks to generate complex textile patterns automatically but required a professional graphics processing unit (GPU) to train a neural model for an extended period. Jiang et al. [10] argued that compared to painting style transfer, fashion style transfer needs to generate not only the global features of style image but also the local details features of patterns.

Therefore, textile pattern generation should address the balance between global style and local pattern details. Secondly, designers visualise various inspirational images frequently. In addition to maintaining generation quality, increasing generation speed and facilitating style switching is required. Lastly, traditional deep learning relies heavily on the computational performance of GPU, and designers do not have specialised scientific computers to deploy large neural network models. The algorithm's model must consider the generation feasibility in the central processing unit (CPU), reducing GPU consumption.

Based on the specific requirements of textile pattern design, we propose a multi-resolution optimisation strategy to combine the MRF-based and Gram-based methods. Low-resolution image generation uses the MRF-based method for local pattern features. After upsampling to a high-resolution image, the Gram-based method is used to refine the global image style. This strategy significantly decreases time while preserving the quality of image generation, building a fast textile pattern generation algorithm with the smoothing function and histogram matching.

TEXTILE PATTERN GENERATION ALGORITHM

Style feature extraction neural network

Style extraction network is the basis of image style modelling. Wang et al. [11] discovered that new network architectures, such as residual neural network (Res-Net), are inappropriate for style feature extraction. The residual connection will reduce the entropy value of the feature map, which needs to add softmax layers to smooth the feature maps. However, the pre-trained Visual Geometry Group network (VGG) performs well in style feature extraction without additional layers. Therefore, pre-trained VGG19 is selected as the style feature extraction neural network, where '19' represents the number of convolutional layers. The original VGG19 network consists of 16 convolutional layers and 3 fully connected layers [12]. During the style extraction process, network layers for classification tasks after conv5_1 in the VGG19 are eliminated to save computational capability.

In VGG19, shallower feature maps capture more texture features, and deeper feature maps capture more sophisticated semantic features [13]. To fully cover textile pattern features, it is important to combine features from different layers in the VGG19.

Image reconstruction methods

After the style features are extracted, they need to be reconstructed into an image. Currently, image reconstruction approaches are divided into descriptive methods based on image optimisation and generative method based on model optimisation [14]. The first method reconstructs by iteratively optimising the initial image pixel by pixel. This method focuses on a target-style image, requires less computational capability and can be generated by CPU only. Moreover, it offers better image quality and is convenient to switch pattern styles. However, as this method involves multiple backpropagations, image generation takes a longer time. The second method can generate images using forward propagation after generative models are trained, resulting in significant time savings. However, model training needs large-scale datasets and professional GPUs. Each style demands hours or even days of training, making style changes difficult. In addition, many model-based methods employ the same setups as image-based methods [15–16], such as the feature extraction model and loss function. Due to the utilisation of images in the dataset rather than a specific style map during training, the image quality generated by the second method is inferior to the first one and lacks pattern details.

In conclusion, our research selected the reconstruction method based on image optimisation. It uses VGG19 to extract and model the style features of the generative and target style images. The style loss between these two images is computed using a specific loss function based on the extracted style features. The generative image will be optimised based on the style loss value. The initial image to generate uses a random noise image. This method does not need datasets or a significant amount of time to train generative models. Simultaneously, it can generate high-quality pictures, and it is convenient to switch styles, making it more suitable for textile pattern generation.

Comparison of style loss functions

Style loss is mainly divided into two types: Gram-based loss (L_G) and MRF-based loss (L_M) [17]. Gram matrix consists of inner products of specific vectors. The angular and directional relationships between two vectors can be expressed by their inner product. When computing style loss, a specific convolution kernel encodes the feature maps to Gram matrices. Its diagonal components represent the number of different features. The Gram matrix can therefore demonstrate the number relationship of each feature and the interrelationships between features, thus modelling the image's global style features. After

obtaining the respective Gram matrices for the style and generation images using VGG19, the style loss of each layer is calculated using mean square error. The sum of all layer losses is L_G between the generative and style images. The process details are shown in step 2 in figures 1 and 2 and the L_G can be expressed as follows:

$$L_G(\hat{y}, y_s) = \sum_l \left\| G^{[l]}(\hat{y}) - G^{[l]}(y_s) \right\|_2^2 \quad (1)$$

where $G^{[l]}(\hat{y})$ and $G^{[l]}(y_s)$ are the Gram matrices at layer [*l*] in the VGG19 of the generative image ($\hat{y}$) and target style image (y_s) respectively.

MRF is a classical texture modelling method. The generative and style images are extracted separately as patches. Each patch in the generative image is matched with the most similar patch from the style image patch library for filling or as a generation reference. Currently, MRF often combines CNN to calculate L_M. First is data augmentation for the style image, such as scaling and rotation. Then, style patches of the augmented style images and the generative image are obtained using VGG19. Utilising the feature maps of {conv3_1 and conv4_1} layers to extract patches for enhanced patch matching [8]. Patches of the generative and augmented style images are matched by computing the cosine similarity. It means encoding style features using MRF. Finally, the style loss is obtained by calculating the difference between the patches of the generative image and the matched patches of augmented style images. The process details are shown on step1 in figure 2 and L_M can be expressed as follows:

$$L_M(\hat{y}, y_s) = \sum_l \sum_k \left\| P_k\left(F^{[l]}(\hat{y})\right) - P_{MRF(k)}\left(F^{[l]}(Aug(y_s))\right) \right\|^2 \quad (2)$$

where $P_k\left(F^{[l]}(\hat{y})\right)$ is the *k*-th patch extracted by feature maps of $\hat{y}$ at layer [*l*]; $Aug(y_s)$ is a series of images obtained by y_s after image augmentation; $P_{MRF(k)}\left(F^{[l]}(Aug(y_s))\right)$ is the *k*-th MRF-matched patch extracted by feature maps of augmented y_s at layer [*l*].

Image generation using L_G and L_M, respectively. Target style image: Chinese pattern picture shown in figure 1, a; feature maps for L_G: {conv1_1, conv2_1, conv3_1, conv4_1, conv5_1} layers; rotation angles for L_M: 0°, 90°, –90° and 180°; optimiser: Adam; learning rate: 1e-2; number of iterations: 1000; deep learning framework: PaddlePaddle 2.2; programming language: Python 3.7; development platform: Baidu AI Studio; operation system: Ubuntu 16.04; GPU: NVIDIA Tesla V100; GPU memory: 16GB; CPU: Intel(R) Xeon(R) Gold 6148 @ 2.40 GHz; random access memory: 16 GB; hard disk drive: 100GB.

The results are shown in figure 1. It took 34 seconds with L_G and 1125 seconds with L_M for the size of 800*800 pixels. Generation using L_G is faster and more sensitive to global styles such as colour and texture. However, as shown in figure 1, *b*, L_G cannot generate local pattern details. It is challenging to generate intricate and specific pattern features, such as petals and stems. L_M is a patch-based loss that is more sensitive to local pattern features, but the portrayal of global features is inadequate, as shown in figure 1, *c*. Because substantial patches need to be extracted and matched for each round of iterative optimisation, image generation using L_M is time-consuming. Therefore, a combination of these two losses may speed up the generation process and satisfy the requirements for global style and local pattern features in textile pattern generation.

Combination of style loss functions

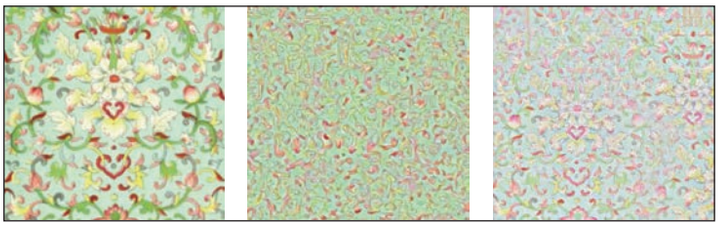
Previous research [18–19] has often added L_G and L_M to generate patterns with both global style and local features. However, direct summation can lead to mutual interference and reduce generation quality, since L_G and L_M have an adverse effect on the generation process. By referring to the image pyramids [20] and generative adversarial networks [21], we suggest five combination strategies to assess the quality and duration of image generation individually, as shown in table 1.

Figure 1, *a* is the target style image, 1000 times for each step, and the final image size is 500*500 pixels. The generated images are scaled to the same size, as shown in table 2. The generation time is shown in table 3 for every option.

In option 1, as the values of L_G and L_M have distinct orders of magnitude, it is simple for one loss to suppress another, resulting in a generated image representing just a single kind of feature. As shown in table 2, only global style features are shown after step 1. Local pattern features like petals and stems are absent from the generated image. It is difficult to

Table 1

STYLE LOSS FUNCTION COMBINATION STRATEGIES		
№	**Option descriptions**	
	Step1	**Step2**
1	L_G + L_M (high-resolution generation)	/
2	down-sampling, L_G (low-resolution generation)	up-sampling, L_M (high-resolution generation)
3	L_G (high resolution-generation)	L_M (high-resolution generation)
4	down-sampling, L_M (low-resolution generation)	up-sampling, L_G (high-resolution generation)
5	L_M (high-resolution generation)	L_G (high-resolution generation)



a *b* *c*

Fig. 1. Generation effects of different loss functions: *a* – target style image; *b* – generated image by L_G; *c* – generated image by L_M

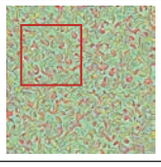
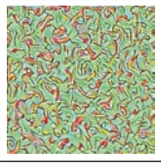
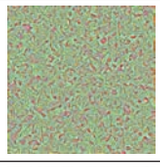
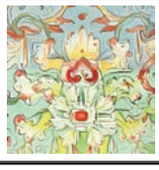
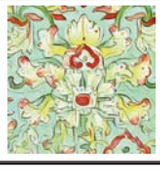
generation time is reduced by 75.5% compared to option 5.

In option 5, the generated image is similar to option 4, and the second step using L_G keeps the pattern basic structures generated in step 1. The generation process takes longer due to the use of L_M in the first step to generate a high-resolution image.

It can be found from the above experiments that using L_G is faster and easier to maintain

Table 2

IMAGES GENERATED BY DIFFERENT COMBINATION STRATEGIES, INCLUDING INTERMEDIATE RESULTS

Option №	1	2	3	4	5
Step1					
Step2	/				
Image details					

Note: The regions in red frames are magnified to provide more details.

optimise the balance between these two losses and to generate images with global style and local pattern features.

In option 2, the generated image of the step 1 is rough because of global features generation in low resolution. Pattern position information is missing in the subsequent step. The local pattern features in the generated image of step 2 are random and cannot follow the structures and shapes in the resulting image of step 1. The final effect tends to use L_M alone, and the image background appears colour cast. In addition, the patch exaction and matching process consume a long time due to using L_M to generate high-resolution image. Too many patches may easily cause memory overflow when an image reaches 500*500.

In option 3, the generated image is similar to option 2. The colour and other style features from step 1 are overwritten in step 2. Since both steps generate high-resolution image and L_G is insensitive to resolution increase, the total time savings is insignificant compared to option 2. Option 3 also has the problem of memory overflow.

In option 4, Local pattern features are generated in step 1, and global style is refined in step 2. As a result of reducing image resolution in step 1, the generation time of L_M is significantly shorter. The total

Table 3

GENERATION TIME FOR DIFFERENT COMBINATION STRATEGIES

Items	Option №				
	1	2	3	4	5
Step 1 time (s)	1354	18	34	240	1093
Step 2 time (s)	/	1121	1020	35	31
Total time (s)	1354	1139	1054	275	1124

pattern structural features in the initial image. Using L_M for generation is time-consuming and overwrites the original structural features. Therefore, based on the advantages and disadvantages of L_G and L_M, we proposed a multi-resolution image optimisation method. L_M for low-resolution generation, upsampling and L_G for high-resolution generation. The resulting images are similar to those generated at high resolution in both steps. This method can quickly generate textile patterns with global style and local detail features.

Algorithm framework

After the basic procedure is determined, the generated image contains noises. Therefore, a smoothing

function (equation 3) is needed to reduce noise by minimising the image's total variation [22].

$$L_{TV}(\hat{y}) = \sum_{i=1}^{h-1}\sum_{j=1}^{w}\sum_{c=1}^{3}(x_{i+1,j,c} - x_{i,j,c})^2 + \\ + \sum_{i=1}^{h}\sum_{j=1}^{w-1}\sum_{c=1}^{3}(x_{i,j+1,c} - x_{i,j,c})^2 \quad (3)$$

where h, w and c denote the generated image's height, width and channel.

Therefore, it is determined that L_M is used for low-resolution textile pattern generation in the first step, which is called the MRF-based method. L_G is is used for high-resolution generation in the second step, which is called the Gram-based method. Their loss functions are shown below, with equation 4 for the MRF-based method and equation 5 for the Gram-based method:

$$L'(\hat{y}', DS(y_s)) = L_M(\hat{y}', DS(y_s)) + \lambda_1 L_{TV}(\hat{y}') \quad (4)$$

$$L(\hat{y}, y_s) = L_G(\hat{y}, y_s) + \lambda_2 L_{TV}(\hat{y}) \quad (5)$$

where $\hat{y}'$ is the generative image of the first step; $DS(y_s)$ is a down-sampled image of y_s; the initial of $\hat{y}$ is an up-sampled image of $\hat{y}'$; λ_1 and λ_2 are the weights of the smoothing term.

Risser et al. [23] pointed out that Gram matrices do not store statistical information such as mean and variance, leading to unstable image generation. The statistical information of the style features is included after a histogram matching process, which can increase generation quality and stability. Therefore, adding histogram matching after the second step can bring the colours of the textile pattern image closer to the colours of the style image.

In summary, the workflow of the textile pattern generation algorithm is as follows:

(a) Down-sampling a target style image to reduce the size.
(b) Generating a low-resolution image with local pattern features by the MRF-based method.
(c) Up-sampling the resulting image of the MRF-based method to the final size by interpolation.
(d) Refining the global style of the up-sampled image by the Gram-based method.
(e) Histogram matching between the resulting image of the Gram-based method and the target style image.

The framework is shown in figure 2. Additional upsampling and optimisation processes can be added for higher resolution and more detailed portrayals.

DISCUSSION

Comparing the pattern generation quality and duration of Johnson's [15], Li's [8] and our algorithms. The generated image size is 500*500 pixels; 2000 times for each step; COCO2017 [24] for the model training set; and the critical hyper parameter settings are maintained. The generated images are shown in table 4. Johnson's algorithm takes longer to train the model, with an average total time of 21134 s for training and generation. The global style of the patterns in

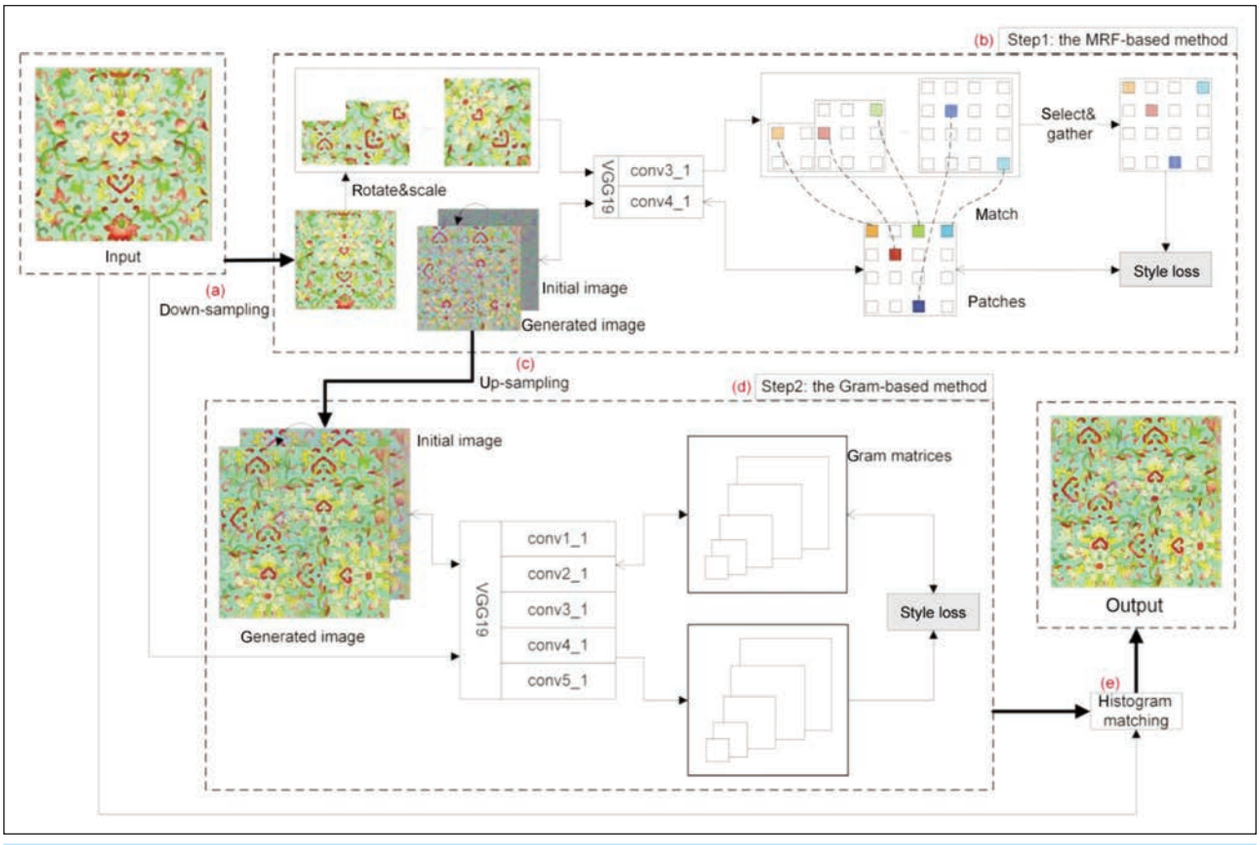
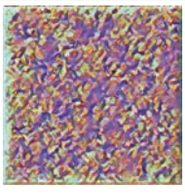
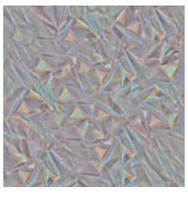
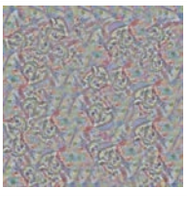
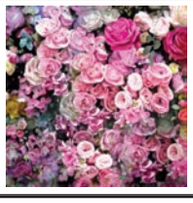
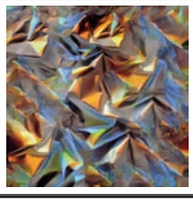
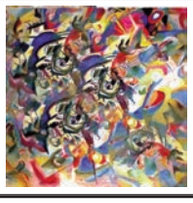
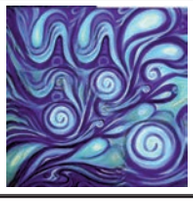
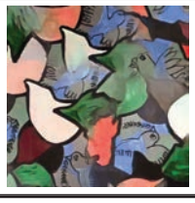


Fig. 2. Framework overview of the fast textile pattern generation algorithm (the bidirectional arrows are paths of backpropagation)

Table 4

EXAMPLES OF TEXTILE PATTERN GENERATION BY DIFFERENT ALGORITHMS

Option №	1	2	3	4	5
Style image					
Johnson's					
Li's					
Ours					

the generated images closely resembles that of the style images, but local detail features are absent. Li's algorithm takes an average of 3655 s to generate and does not need model pre-training. The generated images show local details but do not adequately refine the global style for various style images. Our algorithm also does not need to pre-train the model and the average generation time is 575 s. The resulting images with our algorithm generate global and local features of different target styles, which can be used as textile printings.

Limitations and future work

Three limitations in this paper could be addressed in future works:

1. Our algorithm does not solve the issue of the slow MRF-based method fundamentally. To increase efficiency, we will attempt to save patch-matching results for reuse in the following processes.
2. The patterns generated by the current algorithm are relatively random, and the algorithm's functionality needs to be expanded to generate more pattern effects, such as symmetry and gradients. It will enable the algorithm to be used in a broader range of design scenarios.
3. This algorithm can only generate patterns. In the future, we will include content loss to build a fashion style transfer algorithm for showing patterns directly on textiles or apparel.

CONCLUSIONS

This paper proposes a fast textile pattern generation algorithm combining MRF-based and Gram-based methods. With a multi-resolution optimisation strategy, this algorithm can generate complicated textile pattern images with global style and local details. The average generation time for a 500*500 pixels image is 575 seconds, more than 84.3% faster than traditional algorithms. In addition, it is simple to switch target styles and can generate images by CPU only. Therefore, it can increase the productivity of designers and encourage the application of artificial intelligence in textile design.

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An empirical assessment of consumer-brand engagement and brand knowledge through social media marketing activities: a study on online garments buyers

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ABSTRACT – REZUMAT

An empirical assessment of consumer-brand engagement and brand knowledge through social media marketing activities: a study on online garments buyers

The use of social media marketing (SMM) use in the garment sector is increasing daily, and well-known brands are shifting their marketing campaign to social media. This study aims to assert the relationship between SMM customer-brand engagement (CBE) and brand knowledge (BK). For this purpose, data were collected from online garment buyers through a questionnaire. Results of the study show that SMM significantly enhances the CBE and BK. Results further elaborate that the CBE substantially mediates the relationship between SMM and BK. This study will bridge the gap in the literature between SMM and CBE. Moreover, this study will help the management of garment brands to shift their marketing campaign on social media to meet the requirements of modern marketing tools. Although this study only focuses on garments brands, future researchers can apply the model of this study to other brands and also enhance the sample size.

Keywords: *brand knowledge, branding, social media, garments, textile marketing*

O evaluare empirică a angajamentului client-brand și a cunoștințelor despre brand prin activități de marketing pe rețelele sociale: un studiu despre cumpărătorii de articole de îmbrăcăminte online

Utilizarea marketingului pe rețelele sociale (SMM) în sectorul articolelor de îmbrăcăminte este în creștere în fiecare zi, iar brandurile cunoscute își mută campania de marketing către rețelele sociale. Acest studiu își propune să afirme relația dintre angajamentul client-brand (CBE) SMM și cunoașterea brandului (BK). În acest scop, au fost colectate date de la cumpărătorii de articole de îmbrăcăminte online prin intermediul unui chestionar. Rezultatele studiului arată că SMM îmbunătățește semnificativ CBE și BK. Rezultatele arată în continuare că, CBE mediază în mod substanțial relația dintre SMM și BK. Acest studiu va reduce decalajul din literatura de specialitate dintre SMM și CBE. Mai mult, acest studiu va ajuta managementul brandurilor de îmbrăcăminte să-și schimbe campania de marketing pe rețelele sociale, pentru a îndeplini cerințele instrumentelor moderne de marketing. Deși acest studiu se concentrează doar pe brandurile de articole de îmbrăcăminte, viitorii cercetători pot aplica modelul acestui studiu altor branduri și, de asemenea, pot spori dimensiunea eșantionului.

Cuvinte-cheie*: cunoașterea brandului, branding, reţele sociale, articole de îmbrăcăminte, marketing textil*

INTRODUCTION

Marketers recognize the advantages of social media marketing (SMM) over traditional advertising in terms of reaching customers and developing a powerful brand [1]. The majority of social media marketing research done up to this point has concentrated on the following topics: the attraction of user-generated content, content analysis, creative techniques, and customer behaviour as members of a social media brand community. As a consequence, social media marketing is still considered a fresh form of advertising, and its influence on CBE is not well understood. Research on consumer-brand engagement, also known as CBE, is a topic that is currently popular in the field of marketing. Over the next five years, more than eighty percent of marketers plan to emphasize client participation. If this is done, it is anticipated that there will be a 40% rise in annual visits and a 20% gain in profitability [2].

CBE is an acronym for “brand-related cognitive, emotional, and behavioural activity associated with focal brand interactions” [3]. CBE is a multidimensional construct with cognitive, emotional, and behavioural dimensions. The significance of CBE for marketing strategy, which includes creating positive relationships between brands and their target customers, has interested academics. Marketing researchers have singled out CBE as a prominent topic of investigation because it can boost companies' bottom lines and the level of consumer pleasure and brand loyalty [4]. For this reason, marketers must get a more in-depth grasp of the processes that give rise to and maintain CBE. As a direct result, there have been numerous calls for additional empirical evidence to

support the theoretical framework that underpins CBE, particularly its causes and effects. It is possible to make the case that further empirical research on CBE is required to gain a deeper understanding of the concept, the factors that drive it, and the strategies used to implement it, such as the promotion of consumer-brand relationships through marketing communications [5].

The purpose of this research is to investigate the impact that elements of social media marketing, specifically user-generated content, personalization, electronic word-of-mouth (EWOM), and fashionable content, have on the level of involvement and familiarity that consumers have with the brands that they shop for online in Pakistan. After that, we do a complete literature review to locate any gaps in the research. As a consequence of this, a conceptual model is developed in which the characteristics of SMM have an impact on CBE and brand awareness. Finally, the work concludes after a discussion of the work's limits, implications for theory and practice, and future research opportunities.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

The phrase “a set of Internet-based apps that extends the underlying ideology and technology of Web 2.0 to ease the development and transmission of user-generated content” is what is meant to be referred to when someone uses the acronym “social media” [6]. Its interactive capabilities enable collaborative, participative, and knowledge-sharing activities, which makes it one of the most critical communication channels for brand information because it reaches a larger audience than traditional media such as print, television, and radio. Traditional media include print, television, and radio. The term “social media” refers to various online communities and platforms, from customer review sites to complete encyclopedias and discussion boards to microblogging platforms like Facebook, LinkedIn, and Twitter [7]. The term “social media” encompasses many online communities and platforms. Advertisements on social media platforms (like YouTube and Facebook), endorsements from bloggers, and the management of user-generated content are a few examples of the types of SMM activities that businesses partake in to increase awareness of their brands and, ideally, positively influence customers.

The use of social media marketing (SMM) has gained widespread favour in Asia as a means of boosting sales and improving consumer loyalty and satisfaction. For example, Kyriakopoulos et al. [8] researched social media marketing (SMM) terminology in Hong Kong and presented an SMM framework for marketers to use in promoting favourable brand perception and repeat sales. In addition to providing consumers with personalized and interactive material that can go in either direction, Kyriakopoulos et al. [8] suggest that marketers should also share captivating movies and photographs with customers. Because they capture consumers' attention and fortify the link between the brand and the consumer, advertisements of this kind can boost consumers' intentions to make additional purchases.

SMM activities and customer-brand engagement

The notion of customer brand efficacy, commonly known as CBE, is gaining traction in the marketing industry, both academically and practically. CBE is a psychological condition defined as customers' affection for the brand and emerges from the strength of the consumer-brand connection. One way to think about CBE is customers' affection for the brand. CBE is gaining popularity in the marketing world, both academically and in the real world. The phrase “consumers' particular level of cognitive, emotional, and behavioural involvement in brand interactions” is what this notion alludes to. It is essential in determining customer behaviour, particularly self-brand connection, purchase intent, and brand loyalty. To be more specific, the term “self-brand connection” refers to the extent to which individuals identify with their brand [9–11].

The literature discusses the reasons for and the consequences of CBE, including the role that brand communication through social media, may play in the development of CBE and consumer familiarity with the name of a product [12]. Also included in this discussion is the role that CBE may play in developing CBE [13]. The potential part that CBE could play in the expansion of CBE is another topic that will be covered in this debate. For instance, Harrigan et al. [14] asserted that social media might function as a valuable medium for strengthening the connection between customers and businesses, increasing CBE. They were under the impression that this would increase CBE [15]. However, the guidance provided by Harrigan et al. [14] supported emphasizing social media content to encourage customers to engage with brand community postings and, consequently, increase CBE. They could accomplish this according to the directions provided by Ashley and Tuten [16]. Hence, we proposed the following hypothesis:

H1: SMM activities significantly strengthen Customer-Brand Relationship.

SMM activities and brand knowledge

Brand communications with funny elements viewed as pleasant and playful enable customers to expend more significant cognitive effort to understand more about the firm, which is consistent with the findings of the earlier assessment of SMM aspects [17]. Furthermore, exciting information shared via social media can give customers amusing and helpful details, thereby boosting the customers' devotion to the company [18]. According to the research findings, site visitors are likelier to share and enjoy brand pages that include games, stories, contests, freebies, dynamic animations, photographs, and videos [19, 20]. These elements appeal to clients' aspirations to experience visual pleasure and emotional release [21]. Therefore, the humorous nature of brand pages

contributes to overall favourable user experiences, increasing consumers' emotional investment in the brand and their awareness of it. Consequently, we suggest the following hypothesis:

H2: SMM activities significantly enhance Brand Knowledge.

Consumer-brand engagement and brand knowledge

The mental representations that consumers have of a brand, including their perspectives on the brand's characteristics, benefits, and attitudes, and how those mental representations compare to those of competing brands, are included in the overall brand image of the brand [22]. The features and traits that customers associate with a brand and employ when describing the brand are referred to as the brand's attributes [23]. Customers associate the brand with a variety of characteristics and characteristics [24]. Customers' perceptions of a brand's benefits are influenced in various ways by the values they connect with that brand, including those that are sensory, practical, and symbolic [25]. When we talk about how customers feel about a brand, we are referring to their impressions of the product's qualities and advantages and the total of their recollections of everything associated with the brand [26]. When we talk about how customers feel about a brand, we refer to their impressions of the product's qualities and advantages [27]. When we discuss how customers think about a specific brand, we refer to how they feel about the particular item they sell [17].

Consumers will give more weight to brands and retailers with a solid reputation when making purchases, as stated by Koçak et al. [28]. Therefore, marketers are incentivized to build customer-brand engagement (CBE) across all media to provide their customers with powerful and meaningful interactions with their brands [29]. Arguably, the interaction between customers and brands during the course of CBE development is an essential part of constructing a brand identity. This is because CBE development occurs during customer-based experience (CBE) development. As a result, an increase in CBE is advantageous to customers since it enables them to build a fuller mental picture of the qualities and benefits of the product [30].

Furthermore, consumer-based advertising makes customers more likely to have a favourable impression of a brand if they feel a personal connection. This increases the likelihood that the customer will have a reasonable opinion of the brand (CBE). Hence, we proposed the following hypotheses:

H3: CBE is associated with Brand Knowledge.

H4: CBE mediates between SMM activities and Brand Knowledge.

RESEARCH METHODOLOGY

This paper explores how social media marketing (SMM) influences consumer behaviour and brand understanding. Online questionnaires were filled out by students attending several universities in Pakistan. The administrations of the v various universities and the directors of the relevant departments approved the research. Before questionnaires were sent out, participants in the study were briefed about the aims of the investigation. Everyone who participated in the survey gave their informed consent. When gathering the data, the researchers made sure to abide by all relevant ethical norms. The data collection took longer than five weeks to complete (25 June 2022 to 29 July 2022). The total number of distributed questionnaires was 638, and 517 were subsequently returned. Surveys that were not filled out on their whole were excluded. Therefore, only 460 surveys were eligible for inclusion in the final data pool after the outliers were considered. There were two different programs utilized to perform the analysis of the data. First, AMOS was used to analyze descriptive data. A framework for Structural Equation Modeling (SEM) was established in the second step. This framework was named Partial Least Square Path Modeling (PLS) and was based on components.

SMM activities were adopted from a previous study [31] and calculated with eleven items. CBE was adopted by Yeh et al. [32] and was computed with six items. Brand knowledge was also adopted from Sarstedt et al. [33], which comprised six items.

RESULTS

In this study, the 2-step approach was evaluated using Smart PLS 3.3.2 [34], which was used to assess the measurement and structural models. PLS was chosen as the statistical method of choice because this study aimed to find a strategy to predict customers' level of familiarity with a specific brand [34]. Calculating the common method variance allowed us to establish the Method bias, which was also determined using the individual factor technique. It was measured using exploratory factor analysis, with each item of the latent components being placed into a single factor. As a result of the fact that 81% of the variance explained had a significant difference from the mean, there was no systematic bias in the approaches used. After running an analysis on the individual factor model in AMOS, the model fitness indices were as follows: 2 = 1647.51, DF = 901, CFI = 0.881, NFI = 0.761, and RMSEA = 0.209. The findings from the earlier study are supported by these indices, which claim in Hair et al. [35], that there is no evidence of bias in the data caused by a common method. The non-response bias was supported by the t-test, which found that respondents who did not provide all of their demographic values were considered non-respondents.

Measurement model

When examining reflective constructs, it is recommended [36] to conduct a confirmatory composite analysis (CCA). This study considers item loadings, composite reliability, AVE, discriminant validity,

nomological validity, and predictive validity [37]. To conduct additional research on the measurement model, the factor loadings, Cronbach's Alpha composite reliability (CR), and the average variance extracted (AVE) of the latent components were all calculated. In table 1, the factor loadings displayed on the various latent structures may be seen. These loadings are analyzed to determine the degree to which individual survey questions can be trusted. Cronbach's Alpha and Composite reliability are two more indicators generally employed in PLS-SEM to examine the construct dependability of the measurement model. Both of these indicators can be found in the reliability statistics section. The findings of this research show that both indicators have values higher than 0.7, which indicates that they fall within a suitable range and validate the overall reliability of the measurement model. In addition, Cronbach's Alpha and Composite reliability are two more indicators frequently utilized in PLS-SEM to analyze the construct dependability of the measurement model. Both of these indicators are reliability composites.

Validity of the constructs

When assessing the dependability of instruments in smart pls, two measures are commonly utilized. First, we determined the convergent validity of the measurement model by looking at the values of the average variance extracted (more than 0.5) and the composite reliability (more than 0.7). This was done by. It can be seen from the information shown in table 1 that all of the findings are greater than the cutoff value, which is evidence of the convergent validity of the method. The procedures specified by Hu and Trivedi [38] were followed to determine the discriminant validity of the study. It is expected that the square root of the extracted average variance will be bigger than the row and column values of the correlations. The results shown in table 2 demonstrate that all diagonal values fared better than the row and column values, which is evidence of excellent discriminant validity.

Structural model

The hypothesized paths in the study framework are mirrored in the structural model. R2, Q2, and path significance are the three metrics used to evaluate a structural model. The value of the coefficient of determination, or R2, for the dependent variable, can be used to measure the strength of the structural route [33]. This allows the quality of the model to be evaluated. R2 must have a value that is either higher than or equal to 0.1. The information can be found in table 3. An R2 value of more than 0.1 indicates that the structural model's predictive capacity is more significant than 0.1, thus demonstrating that the model's predictive ability is more important than 0.1.
In addition, the results of Q2 illustrate that the endogenous constructs have predictive significance. For example, the results show that the structural model has predictive relevance with a Q2 of 0.469, as demonstrated by the results (table 3). In addition, SRMR was utilized to do the model fit evaluation. As a result, it was determined that the SRMR was 0.071, which is considerably less than the threshold value. Ten and is suggestive of a satisfactory model fit [33].

Hypotheses testing results

Calculating the standard error with T and P-values and the significance of the path coefficient Bootstrapping (1000 subsamples) was used, which provided direct evidence of the hypotheses being accepted or rejected. In addition, immediate effect analysis was performed to assess the relation between latent constructs. The results indicate a significant relationship between SMMA and CBE ($\beta = 0.629$, $t = 10.241$, $p < 0.01$); SMMA and BK ($\beta = 0.241$, $t = 2.961$, $p < 0.01$); and CBE and BK ($\beta = 0.409$, $t = 4.151$, $p < 0.01$). Hence, it can be concluded that H1, H2, and H3 were supported for this study, as shown in table 3. Furthermore, table 3 indicates that SMMA → CBE → BK ($\beta = 0.109$, $t = 0.361$, $p < 0.000$). This demonstrates that CBE mediates the relationship between SMMS and BK.

Table 1

RELIABILITY AND VALIDITY, DESCRIPTIVE OF THE MEASURES

Constructs	Skewness	Kurtosis	Cronbach's Alpha	CR	AVE	Skewness	Kurtosis
SMM activities	–0.6949319	0.211971	0.899	0.945	0.881	0.0979498	0.31639
CBE	–1.5161892	2.195919	0.841	0.729	0.649	0.0979498	0.31639
Brand Knowledge	–1.0921892	0.413119	0.781	0.901	0.631	0.0979498	0.31639

Table 2

DISCRIMINANT VALIDITY
(FORNELL LARKER CRITERION)

Criterion	COO	CBP	CUO	EO	IO
COO	**0.779**				
CBP	0.639	**0.831**			
CUO	0.559	0.811	**0.839**		
EO	0.441	0.681	0.551	**0.709**	
IO	0.589	0.561	0.561	0.769	**0.891**

DISCUSSION AND IMPLICATIONS

In addition to having an impact on consumers' ability to identify a particular brand, the incorporation of social media optimization (SMM) elements was discovered

Table 3

HYPOTHESIS TESTING RESULTS								
Hypotheses	**Relationship**	**Beta**	**St. Dev**	**T Statistics**	**P Value**	**BCI LL**	**BCI UL**	**Accepted/ Rejected**
Hypothesis 1	SMMA → CBE	0.629	0.149	10.241	0.000	0.531	0.731	Accepted
Hypothesis 2	SMMA → BK	0.241	0.210	2.961	0.004	0.141	0.329	Accepted
Hypothesis 3	CBE → BK	0.409	0.181	4.151	0.000	0.261	0.559	Accepted
Hypothesis 4	SMMA → CBE → BK	0.109	0.149	0.361	0.000	0.209	0.191	Accepted
Endogenous Construct		R^2	Q^2					
CBP		0.789	0.469					

to have a substantial effect on the growth of customer-based experiences (CBE) in the course of this research project's findings [5]. This study confirms the results of other studies by demonstrating that contact, EWOM, and trendiness all contribute to strengthening CBE and promoting brand awareness and image. This study confirms the findings of other studies by showing that connection, EWOM, and trendiness enhance CBE. This study demonstrates the results of other studies by establishing that contact, EWOM, and trendiness all contribute to strengthening CBE. This study provides broad confirmation of the findings of earlier studies. This study provides comprehensive verification of the conclusions of earlier studies by establishing that contact, EWOM, and trendiness are all contributors to the strengthening of CBE. This discovery confirms the findings of other studies [38]. The conclusions of previous investigations are secured to a large extent by this latest research. Because they improve consumers' cognitive processing, attachment, and activation of the target brand, it is reasonable to consider interaction, EWOM, and trendiness to be successful strategies for influencing consumers' brand impressions. These factors improve consumers' cognitive processing, attachment, and activation of the target brand. These aspects strengthen customers' cognitive processing of the target brand, their connection to it, and their activation of it [20].

According to the findings, CBE has a significant influence, which may be construed either positively or negatively, on the brand's image and the level of awareness regarding the brand. This study lends credence to the hypothesis that CBE plays a significant role in creating brand knowledge [36]. The abbreviation “CBE” refers to “customer-based education”. In addition to this, the findings indicate that the characteristics of interaction, word-of-mouth marketing, and fashion have an indirect influence on the opinions that people have regarding the brand.

The researchers got to this conclusion after conducting a study of the data and finding that it was, in fact, the case that this was the situation. Regarding social media branding, these findings offer even more validity to the value of word-of-mouth marketing, updates relevant to current events, and interactive material [39]. This investigation did not reveal any link between humorous content shared on social media and increased brand awareness, which contrasts with the conclusions of other studies that looked into the same topic. The significance of this observation lies in the fact that it suggests no association between the two variables. The nature of customer value can explain this finding; in particular, the possibility that company-initiated entertainment content does not favour customers' ideas about a brand that is linked with the company [40]. This finding was made possible by a survey conducted in the United States. Even though humorous marketing communications on social media may be engaging, the reason for this is most likely because the humour results from the reader enjoying the content without actively participating in the experience. In other words, the reader is merely a passive observer. In other words, the reader enjoys the humour without actively participating. Although this might be the case, the primary reason why humorous marketing messages posted on social media might be attractive to customers is not because of this circumstance. Yoshida et al. concluded that the fulfilment that one derives from entertainment might be a lonely, non-social behaviour that is best characterized as “passively consuming” [41].

According to the study's findings, high-engagement devices such as smartphones may benefit from using characteristics of social media marketing (SMM), such as interactive content, word-of-mouth marketing, and trending content, from increasing customer base expansion and brand comprehension [41]. It is possible to boost the likelihood of a successful marketing effort by encouraging positive word-of-mouth (EWOM) and producing popular and participatory material. One way to do this is through social media. It is hoped that this will increase the number of customers who can identify the brand, as well as increase the processing of the brand by those customers, their connection to the brand, and their activation of the brand by those customers. As a direct consequence of this fact, we propose that marketers should make it easier for customers to access the information they seek, such as product-specific EWOM, and that they should offer support whenever it is essential.

In addition, it has been suggested that businesses attempt to mould consumers' opinions of their brands by employing social media in an organized and deliberate manner. This would be carried out to provide a

higher level of service to the clientele. Businesses have the capability of carrying out activities such as this one, which involves the utilization of social media. For example, a company could offer an incentive to customers who generate positive word-of-mouth publicity for the company by providing the customers with additional information, increased value, or information that is easier to assimilate so that they can share it on the social network of their choice. This could be done by giving the customers additional information, increased value, or information that is easier to assimilate. This could be accomplished by providing the customers with more details, elevating the value of the information they already have, or simplifying the information to make it easier to understand. This could be accomplished by providing the customers with additional information, enhancing the value of the data, or making it more straightforward for the customers to assimilate the information.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Because the data were collected using a cross-sectional methodology, the findings can only be used to make conclusions about Hong Kong. No further data were available. Future studies may reach a higher degree of generalizability if they combine long-term and international comparisons. Furthermore, this inquiry focuses entirely on smartphones, cutting-edge mobile devices that can perform various functions. As a consequence, the findings cannot be extrapolated to apply to other product categories, particularly those with a lesser level of complexity. A future study might extend the number of product categories to generalize the results to broader contexts. Additionally, the study could account for products with varying engagement levels. Likely, additional theoretical constructs or potential moderators (such as consumer experience) may affect the SMM aspects and/or the constructions that were studied in this article, and this might be the focus of research conducted in the future.

In this research endeavour, there was no attempt to assess the efficacy of traditional marketing strategies, either in conjunction with SMM or independently. Future research should compare and contrast the effects of SMM elements and traditional marketing elements, such as traditional advertising and distribution intensity, to determine whether marketing variables influence CBE and brand awareness. This will allow researchers to determine whether or not marketing variables affect CBE and brand awareness.

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Evaluation of ergonomic criteria with an AHP-based approach in the textile industry and ordering alternatives

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ABSTRACT – REZUMAT

Evaluation of ergonomic criteria with an AHP-based approach in the textile industry and ordering alternatives

The textile sector, which has a wide application area worldwide and in Turkey, is one of the most critical sectors. Ergonomic risks, which are the most important risk factors of the sector, which contain many dangers in terms of work accidents and occupational diseases, affect the health and safety of the employee. In this area where human dependence continues, and labour-intensive production exists, it is aimed to make an ergonomic risk ranking of the sections of a textile factory within the borders of Yozgat province. Within the scope of this target, alternatives, criteria, and sub-criteria were determined after scientific literature, expert opinions, interviews with managers and employees, and a detailed examination of the textile factory, and the ranking of alternatives was made with the AHP method. Alternatives include sewing, ironing, quality control, packaging and shipping, slaughterhouse, and printing. The riskiest section has emerged as the sewing workshop. This study will not only increase the awareness of ergonomics and reduce occupational health and safety problems but also contribute to reducing workplace costs and losses.

Keywords: *textile industry, occupational health and safety, AHP method*

Evaluarea criteriilor ergonomice cu o abordare bazată pe AHP în industria textilă și alternative de comandă

Sectorul textil, care are o arie largă de aplicare la nivel mondial și în Turcia, este unul dintre cele mai critice sectoare. Riscurile ergonomice, reprezentând cei mai importanți factori de risc ai sectorului, care conțin multe pericole în ceea ce privește accidentele de muncă și bolile profesionale, afectează sănătatea și siguranța angajatului. În această zonă, în care dependența umană continuă și există producție cu forță de muncă intensivă, se urmărește realizarea unei ierarhizări ergonomice de risc a secțiilor unei fabrici textile de la granița cu provincia Yozgat. În sfera acestui obiectiv, alternative, criterii și subcriterii au fost determinate pe baza literaturii științifice, opiniilor experților, interviurilor cu managerii și angajații și a unei examinări detaliate a fabricii textile, iar ierarhizarea alternativelor a fost realizată cu metoda AHP. Alternativele includ: zona de asamblare, zona de finisare, zona de control a calității, zona de ambalare și expediere, depozitul și zona de imprimare. Zona cu cel mai mare risc a apărut ca fiind cea de asamblare. Acest studiu nu numai că va crește gradul de conștientizare asupra ergonomiei și va reduce problemele de sănătate și securitate în muncă, dar va contribui și la reducerea costurilor și pierderilor la locul de muncă.

Cuvinte-cheie*: industria textilă, sănătate și securitate în muncă, metoda AHP*

INTRODUCTION

The textile sector has a wide application area worldwide and in Turkey. The products produced in the sector are clothing, decoration products, and various accessories. They find a comprehensive production and usage area, including the defence industry. The textile sector, one of the most critical sectors of Turkey, started to proliferate with the implementation of the export-oriented development policy in 1980. The number of companies in the sector, which continue their activities with small and medium-sized enterprises is around 58.000 and continue their activities with approximately 1.100.000 employees. As of 2018, Turkey has become the seventh country in the world in the ready-to-wear sector, with an export rate of 3.2% [1]. OHS Law No. 6331 [2] states that risk is “the probability of loss, injury or other harmful result arising from danger”. The hazard class as “the potential for harm or damage that exists in the workplace or may come from outside, which may affect the employee or the workplace” is “in terms of OHS, the characteristics of the work done, the materials used or emerging at every stage of the work, work equipment, production methods and forms”. It is defined as the “hazard group determined for the workplace”, taking into account other issues related to the working environment and conditions. When identifying hazards, information about employees, work environment and workplace is collected. There are “hazards caused by physical, chemical, biological, psychosocial, ergonomic and similar sources of danger” in the working environment [3]. Although the sector is in the less dangerous class according to the hazard classification, it contains many dangers regarding occupational diseases and work accidents. Ergonomic risk factors are the leading risk factors that should be taken seriously. The risk factors in the workplace are numerous and affect the health and safety of the employee.

Ergonomics is defined in different ways by Singleton [4] as the technology of work design, Tayyari and Smith [5] as a branch of science concerned with obtaining the most appropriate relations between employees and work environments, Attwood et al. [6] where people perform their tasks by using the equipment effectively, defines it as a systematic design process that manages safe and efficient operations operates systems, and applies their knowledge to improve environments. Lee [7] promoted compatibility between people and systems. Fernandez [8] defined workplace, machinery, equipment, tools, environment, product, and system design as optimizing the efficiency and effectiveness of work systems while ensuring the health, safety, and well-being of workers, taking into account the physical, physiological, biomechanical and psychological abilities of people. Koningsveld [9], in the definition of ergonomics approved by the International Ergonomics Association (IEA) and announced at the 2000 IEA Congress in San Diego, uses ergonomics as the scientific discipline concerned with understanding the interactions between humans and other elements of a system, and the theory for optimizing human well-being. They defined it as the profession that applies principles, data, and methods to design and overall system performance. The generally emphasized view of the definition of ergonomics; is mainly concerned with the working environment, job design, and the relationship between machine systems and people. Ergonomics aims to optimize the employee's health, safety, and productivity while ensuring the employee's comfort [10]. Employees' health and safety are essential for any organization's smooth and effective operation [11]. Improving worker health in the textile industry involves addressing musculoskeletal risk factors through ergonomic interventions [12]. Today's global approaches focus on integrating practices and models to improve occupational safety, health, and ergonomics, improve work quality, create a healthy workplace environment, and eliminate or minimize the risks associated with exposure to a bad work environment. Unacceptable working conditions, psychosocial, psychosomatic, cognitive environment, etc., when neglected, can inevitably cause concerns that lead to deficiencies in the production rhythm and the emergence of musculoskeletal disorders or disorders. All these cause economic and social losses [13]. Musculoskeletal Disorder (MSD), an occupational and public health problem in developed and developing countries, significantly impacts productivity and quality of life by losing working hours and creating an economic burden [14].

One way to improve worker health in the industry is to address work-related risk factors of the musculoskeletal system. This study aims to rank the departments of textile workers in a textile factory within the borders of Yozgat province regarding ergonomic risk. The criteria weights were determined with the Analytic Hierarchy Process (AHP), one of the Multi-Criteria Decision Making (MCDM) methods, and the ranking of the alternatives was made.

The study consists of five parts. The first part is the introduction and the second part is the literature review. The third section explains the method followed in this research. In the fourth section, the application is given. In contrast, the conclusions and suggested studies are included in the fifth and last sections.

LITERATURE SEARCH

Taşkıran et al. [15] compared the findings of ergonomic job analysis in which 82 male and 143 female textile workers evaluated working conditions and functional hand capacities of workers. Metgud et al. [16] investigated the ergonomic risks affecting sewing machine operators in the sewing department of a textile factory. Kitis et al. [17] evaluated the construct validity and reliability of the arm, shoulder, and hand disability questionnaire in textile workers by correlating it with the Medical Outcomes Study Short Form-36 in industrial workers. Malik et al. [18] aimed to investigate the employees' problems, needs, etc., to ensure the employees' Occupational Health and Safety (OHS) in the textile industry. In their cross-sectional study, Öztürk and Esin [19] investigated the ergonomic risks of female sewing machine operators in a textile factory and the prevalence of musculoskeletal disorders (MSD) symptoms in their cross-sectional study. Sealetsa and Thatcher [20] aimed to identify the perceptions of workload and bodily discomfort and possible ergonomics deficiencies in sewing machine operators' workstations in Botswana's textile industry. Meenaxi and Sudha [11] aimed to provide information about musculoskeletal disorders, their causes, and preventive measures in their study. They stated that static and inappropriate postures, working time, furniture design, and not giving enough rest in the sitting or standing position of employees in the textile industry are associated with the emergence of musculoskeletal disorders. In their study, [21] evaluated the risk factors for upper extremity musculoskeletal system diseases of employees undertaking various tasks in a textile factory. Vandyck and Fianu [22] examined the ergonomic problems and work practices experienced by garment workers in Ghana. They examined noise, ventilation, light, wall and ceiling colour, temperature, height and depth of seats, posture and repetitive movements, and design of workplaces. Keawduangdee et al. [23] aimed to determine the prevalence of low back pain and associated risk factors for the Textile Fishing Net assembly worker population. Tompa et al. [24] worked in a clothing factory in Canada with approximately 300 employees. They presented an economic evaluation of the participatory ergonomics process. Comper and Padula [25] conducted their study in two production departments of a textile factory to determine the level of exposure to ergonomic risk factors. Langford et al. [26] summarized efforts to reduce and prevent musculoskeletal injuries in textile protectors through changes in culture, education, specific practices, and equipment (Historic Royal Palaces, HRP). Matebu

and Dagnew [27] used 3D Static Strength Prediction Program software to analyze the manual material handling work posture of the operators and to identify the main areas that cause long-term injury to the operators. Thangaraj et al. [28] aimed to evaluate the general health status of female textile workers with particular reference to MSD disorder. Balasundaram et al. [29] aimed to reveal the ergonomic problems affecting the workers in the production department (Weaving Unit) of Ethiopia's Dire Dawa textile factory. On the other hand, Kaya and Özok [30] determined the ergonomic risk factors related to the physical ailments experienced by the employees in the production department of the textile factory in their study and presented sector-specific evaluations and recommendations. Nagaraj et al. [31] conducted a study to evaluate the musculoskeletal prevalence and associated ergonomic risk factors among standing sewing machine operators in the Sri Lankan textile industry. Aksüt et al. [32]determined the ergonomic risks of women working in a textile factory using the Analytic Network Process (ANP) method, which is one of the multi-criteria decision-making methods. Aksüt et al. [33] evaluated the textile factory regarding ergonomic risk. Okareh et al. [34] aimed to evaluate textile sewing machine operators' persistent pain, health, and safety hazards. Aksüt et al. [35] prepared staff scheduling to improve the health and safety of workers exposed to high ergonomic risks in a textile factory. Kazemi et al. [36] aimed to make a macro ergonomic risk assessment using the textile industry's Relative Stress Index (RSI).

The literature study showed that using multi-criteria decision-making methods for risk assessment was limited to a small number. Using multi-criteria decision analysis provides a link between working conditions, risk assessment, and workplace safety. Using this method in decision-making in workplace safety, identifying and correcting ergonomic risks will provide essential contributions in terms of OHS. Using the AHP method, one of the most popular decision-making methods, to identify the most challenging part for the workers in the textile factory will contribute to the literature. It will be an essential factor in the widespread use of the method in this area.

AHP METHOD

The criteria weights were determined by scientific literature, expert opinions, a detailed examination of the textile factory, and interviews with managers and employees by the AHP method. The ranking of the alternatives was made.

The study on the applications of MCDM methods in the literature revealed that one of the most common and popular methods in practice is the AHP (Analytical Hierarchy Process) method developed by the American mathematician Saaty [37]. AHP is a measurement theory. It decomposes a complex problem into a multilevel hierarchical structure of objectives, criteria, sub-criteria, and alternatives to help define the overall decision process [38]. In a traditional group decision-making method, experts must rank many alternatives according to their preferences [39]. Two features make the AHP method different from other decision-making approaches. First, it creates a comprehensive structure by combining intuitive, rational, and irrational values. The second is that the method can judge the consistency in the decision-making process [40]. The advantage of AHP is its ease of use, flexibility, and ability to measure the consistency of the decision maker's decision [41]. In addition, this method ensures that intangible and tangible factors are included that would otherwise be difficult to consider [42].

The application steps of the AHP method are given below [38, 43–47].

Step 1: The problem is clearly defined. A particular hierarchical order is followed by the main criteria starting from the purpose and the alternatives at the lowest level.

Step 2: According to the hierarchical structure created in Step 1, decision matrices are formed by comparing the alternatives for the criteria and among each criterion. The comparison matrices (nxn) are of square matrix size.

Step 3: To normalize each column, column sums are taken in the binary comparison matrix. The normalized matrix is formed by dividing the elements of the matrix by the corresponding column sum. The priority vector matrix is obtained by taking the row sums of the normalized matrix created for each criterion or alternative. The priority values created for each alternative or criterion in the priority matrix obtained by the weighted total matrix priority vector are obtained by multiplying the column elements of the binary comparison matrix belonging to that alternative or criterion.

Step 4: It is checked by calculating the consistency ratios for the comparison matrices. First of all, the Consistency Index CI value is found.

CI: Consistency Index

$CI = (\lambda \text{ max} - n)/(n-1)$

$CR = CI/RI$

The Consistency Ratio can be calculated using the CI and the Random Table values expressed in table 1.

Table 1

RI VALUES FOR DIFFERENT VALUES OF n															
n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

CR: Consistency Indicator
RI: Randomness Indicator
CR values less than 0.1 are considered consistent.

Step 5: As a result of the AHP method, the alternative with the highest importance weight is selected as the best alternative.

APPLICATION

The flow chart for the solution of the problem is given in figure 1.

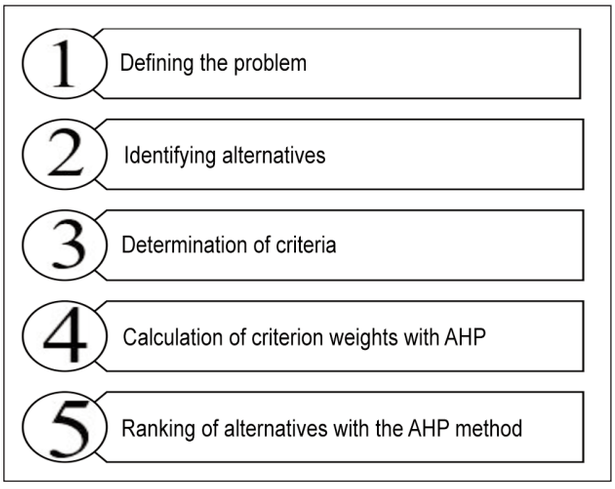

Fig. 1. Flow chart of the problem

Problem definition

Musculoskeletal diseases significantly impact the quality of life and productivity due to the loss of working hours, which creates a significant economic burden as essential public health and occupational health problem in both developed and developing countries [14]. Despite the developing technology, the textile sector is a labour-intensive industry. With the increasingly competitive environment, situations such as unsuitable working postures, continuous and repetitive jobs, and time pressure in the sector cause musculoskeletal problems. In this context, ergonomics is essential in preventing work-related physical discomfort [30]. It is essential to detect and eliminate ergonomic problems, thus ensuring employees' occupational health and safety. For this reason, in our study, the problem of determining the ergonomic risk ranking of a factory operating in the province of Yozgat, which is one of the most important working areas of Turkey, with 338 employees, consisting of 4 buildings, working on combed cotton production and marketing the produced products abroad, has been discussed. The problem is solved based on AHP, a Multi-Criteria Decision-Making approach.

Identification of alternatives

This study discusses the problem of determining the working areas regarding ergonomic risk factors in a textile factory in Yozgat province, which exports the products they produce. As a result of the information obtained from the textile factory managers and the

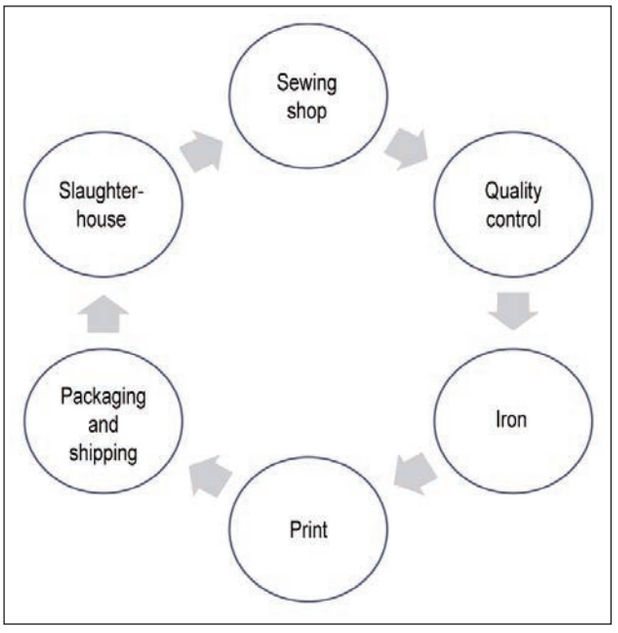

Fig. 2. Textile factory sections

detailed examination of the factory, the research was carried out by dividing the factory into six alternative sections. The alternatives are shown in figure 2, starting from the slaughterhouse and ending in the sewing room.

The criteria and sub-criteria were determined after scientific literature, expert opinions, interviews with managers and employees, and a detailed examination of the textile factory [9, 10, 48–65]. The study consists of 6 criteria and 36 sub-criteria. The criteria and sub-criteria are listed below.

Physical Factors: Inappropriate posture, material use, repetitive movements, static posture, force, compression, excessive force, prolonged standing work, and long sitting work.

Cognitive Factors: Decision making, mental workload, work stress, education, human-computer interaction.

Organizational Factors: Study design, job rotation, monotonous work.

Environmental Factors: Noise, Thermal Comfort, sensory risk, dust, vibration, chemicals.

Personal Factors: Body Mass Index, age, smoking, gender, left-handedness, diabetes, pregnancy, fatigue.

Psychosocial Factors: High professional expectations, job stress, job dissatisfaction, inadequate management, social support, compensation, and pay.

Finding criterion weights with the AHP method

Creation of decision hierarchy

Excel program was used in AHP calculations. The hierarchical structure is given in figure 3.

Analysis of pairwise comparison matrices of criteria

First of all, the main criteria were compared. Then, the sub-criteria were compared based on the main criteria. The consistency index and priority values

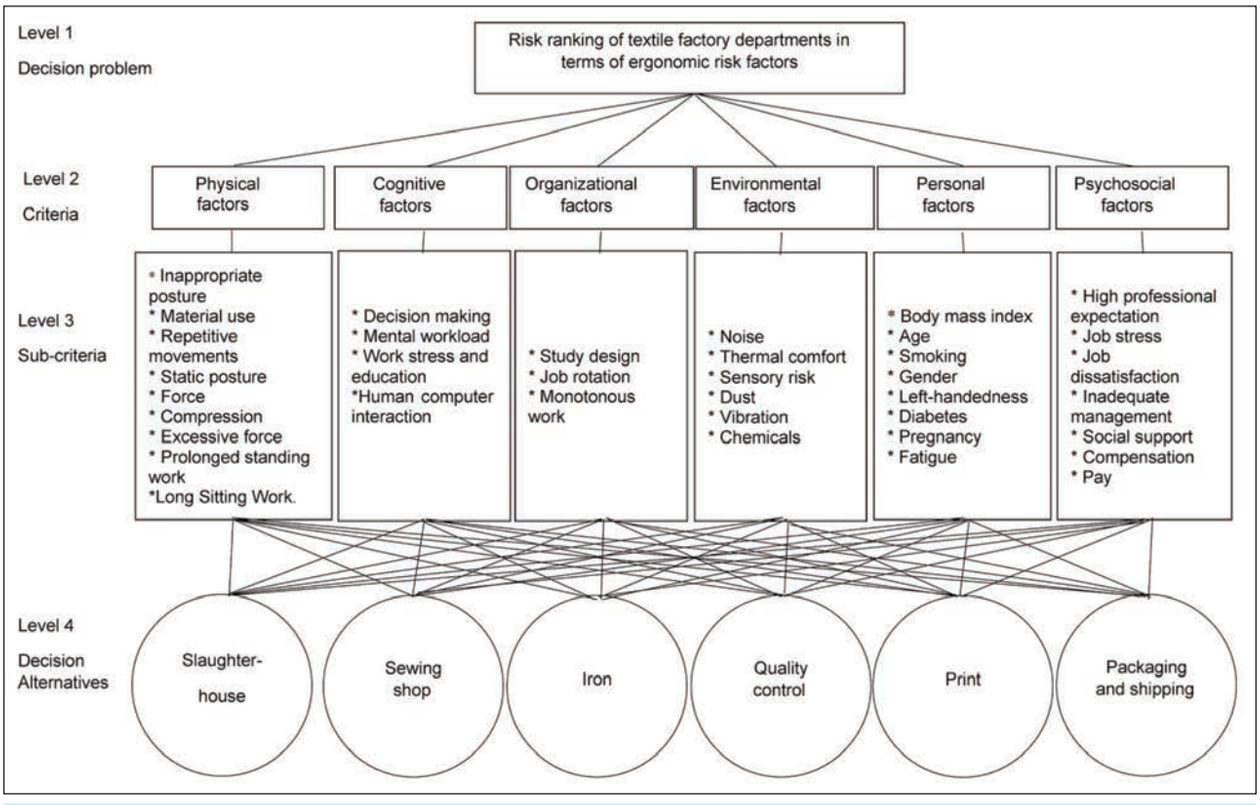

Fig. 3. Determination of the mostrisky area in terms of ergonomic risk factors in the textile factory

were calculated using the Excel program. The importance levels of the criteria are presented in table 2.

According to table 2, all consistency indices were less than 10% (0.1). According to the AHP method, the consistency index is less than 0.1, which indicates a consistent comparison. In the study, "physical factors" were the primary essential criteria with a degree of importance of 0.40895. Other criteria in order of importance are environmental, organizational, cognitive, personal, and psychosocial risk factors, respectively. From a physical point of view, the most crucial sub-criterion was "working standing for a long time", with a degree of importance of 0.23012148. The most crucial sub-criterion from the cognitive point of view was "mental workload", with a degree of importance of 0.495991508. The most crucial sub-criterion of organizational factors is that with the significance value of 0.665070243, "monotonic work" has taken place. The most crucial sub-criterion of the leading environmental criterion was "noise", with a value of 0.383258719. While the most critical sub-criterion from an individual point of view was "fatigue", with a significance level of 0.241605284, the most crucial factor in psychosocial terms was found to be waged with a significance level of 0.312314.

Ranking of alternatives with the AHP method

The creation of the hierarchical structure is given in figure 3. The items are compared with each other to determine the weights. The data in the problem are evaluated using the importance scale developed by Saaty [43], known as the "1–9" scale in table 3. Consecutive jurisdictions are to be used when compromise is required.

Pairwise comparisons are made in line with the opinions of experts. The comparison matrix of the criteria is given in table 4.

Table 5 shows the weights of the criteria.

To make a consistent comparison, the AHP method requires all consistency indexes to be less than 10% (0.1), according to the evaluations. Consistency values were less than 0.1, as shown in table 6 in the study. This result shows that a consistent comparison has been made.

Table 7 shows the weight matrix of alternatives by criteria. The most important criterion was determined by giving the Weight of the Criteria result in table 5. Table 8 shows the ranking result of the Alternatives.

In ordering the alternatives in terms of ergonomic risk, the riskiest place was the sewing department. In contrast, the others were the ironing, quality control, packaging, shipping, slaughterhouse, and printing departments.

CONCLUSION

In the study, a multi-criteria model was presented to rank the factory sections in terms of risk by determining the ergonomic risk factors for the protection of the safety and health of the employees with the MCDM method. A mathematical model consisting of six main criteria, 37 sub-criteria, and six alternatives was prepared. To evaluate our model, we applied our approach based on a popular MCDM, AHP. As a result of the application, the importance levels of the

Table 2

IMPORTANCE OF CRITERIA		
Criteria		**Degrees of importance**
Main criteria	Physically	0.40895
	Cognitive	0.114981
	Organizational	0.13822
	Environmental	0.221541
	Personal	0.063716
	Psychosocial	0.052593
	Consistency index	0.064783
Physical main criteria sub-criteria	Inappropriate posture	0.131819561
	Material use	0.038350695
	Repetitive movements	0.164330234
	Static posture	0.10189844
	Force	0.060670722
	Compression	0.042926561
	Excessive force	0.057147239
	Prolonged standing work	0.23012148
	Long-sitting work	0.172735068
	Consistency index	0.093540971
Cognitive main criteria sub-criteria	Mental workload	0.495991508
	Decision making	0.071016484
	Human computer interaction	0.154607892
	Work stress and education	0.278384116
	Consistency index	0.070866
Organizational main criteria sub-criteria	Study design	0.103847382
	Job rotation	0.231082375
	Monotonous work	0.665070243
	Consistency index	0.074956387
Environmental main criteria sub-criteria	Noise	0.383258719
	Thermal comfort	0.162709708
	Sensory risk	0.093630388
	Dust	0.250065228
	Vibration	0.06670644
	Chemicals	0.043629517
	Consistency index	0.098621
Personal main criteria sub-criteria	Body mass index	0.095418683
	Age	0.071162316
	Smoking	0.145926778
	Gender	0.088177488
	Left-handedness	0.035854625
	Diabetes	0.121555277
	Pregnancy	0.200299548
	Fatigue	0.241605284
	Consistency index	0.097466
Psychosocial main criteria sub-criteria	High professional expectation	0.089461
	Job stress	0.253684
	Job dissatisfaction	0.15296
	Inadequate management	0.043951
	Social support	0.079287
	Compensation	0.068342
	Pay	0.312314
	Consistency index	0.062501

Table 3

AHP PAIRWISE COMPARISONS SCALE		
Importance degree	**Definition**	**Explanation**
1	Equal importance	The two activities contribute equally to the goal.
3	Moderately more important than the other	Experience and judgment moderately favour one activity over another.
5	Strong importance	Experience and judgment strongly favour one activity over another.
7	Very strong importance	An activity is conveniently preferred and seen with ease in exercising a strong dominance.
9	Extreme importance	The evidence for favouring one activity over another is very credible.
2, 4, 6, 8	Average values	Value falling between two consecutive jurisdictions to be used when compromise is required.

Table 4

COMPARISON MATRIX OF CRITERIA						
Criteria	**Physically**	**Cognitive**	**Organizational**	**Environmental**	**Personal**	**Psychosocial**
Physically	1	5	4	3	5	4
Cognitive	1/5	1	1/2	1/2	3	3
Organizational	1/4	2	1	1/3	3	3
Environmental	1/3	2	3	1	4	4
Personal	1/5	1/3	1/3	1/4	1	2
Psychosocial	1/4	1/3	1/3	1/4	1/2	1
Total	2.23	10.67	9.17	5.33	16.50	17.00

Table 5

CRITERION WEIGHTS	
Criterion	**Weight**
Physically	0.408949875
Cognitive	0.114981077
Organizational	0.138219996
Environmental	0.221540803
Personal	0.063715666
Psychosocial	0.052592582

Table 8

RANKING OF ALTERNATIVES	
Alternatives	**Conclusion**
Slaughterhouse	0.119179581
Sewing Shop	0.252835646
Iron	0.2173188
Quality Control	0.176029416
Print	0.075884794
Package and Shipment	0.158751763

Table 6

CONSISTENCY INDEX OF ALTERNATIVES WITH CRITERIA						
Alternatives	**Physically**	**Cognitive**	**Organizational**	**Environmental**	**Personal**	**Psychosocial**
Slaughterhouse	0.090629	0.314519	0.058289	0.084951	0.156459	0.17317463
Sewing Shop	0.316382	0.103446	0.263188	0.238586	0.235179	0.13952079
Iron	0.23203	0.097009	0.240861	0.295746	0.103542	0.11156026
Quality Control	0.165247	0.220513	0.079791	0.17019	0.314304	0.27262518
Print	0.050279	0.101375	0.101859	0.093992	0.065222	0.08763681
Package and Shipment	0.145433	0.163138	0.256012	0.116535	0.125295	0.21548232
Consistency Index	0.04921	0.054047	0.07327	0.026629	0.073913	0.043866

Table 7

WEIGHT MATRIX OF ALTERNATIVES BY CRITERIA						
Alternatives	**Physically**	**Cognitive**	**Organizational**	**Environmental**	**Personal**	**Psychosocial**
Slaughterhouse	0.090629	0.314519	0.058289	0.084951	0.156459	0.17317463
Sewing Shop	0.316382	0.103446	0.263188	0.238586	0.235179	0.13952079
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criteria were listed as physical, environmental, organizational, cognitive, personal, and psychosocial factors. The order of the alternatives is given in figure 4. Alternatives include sewing, ironing, quality control, packaging and shipping, slaughterhouse, and printing.

Physical ergonomic risks have the highest criterion weight in the sewing shop, which is the riskiest section. Working by sitting all the time is a danger that needs to be prioritized. In this section, the features of chairs and tables are significant, and they should be adjustable and suitable for health and safety. In the ironing section, environmental ergonomic risks are the most crucial factor. With the effect of heat and steam coming out of the iron, negative aspects of thermal comfort are experienced in working conditions. This situation may adversely affect the health and working efficiency of the employees. To eliminate this negativity, an air conditioning system can be installed to keep the humidity and air in the environment stable. Since ironing is heavy, requires more workforce, and causes fatigue, women workers are not employed here. In the quality control section, features originating from personal factors came to the fore. Since it is a job that requires constant standing and attention, people have difficulties in this section, pregnant women, and smoking. Continuous standing work is carried out in the package and shipping departments. While men work in the shipping department, women work in the packaging department. There are ergonomic risks associated with improper posture during packaging and the use of force during loading. In this section, risks arising from organizational reasons have emerged as a priority.

Since standing work is carried out continuously in the packaging and shipping departments with quality control, ergonomic mats can be used to reduce the load on the feet and legs, and chairs can be placed at specific intervals. Cutting by machine in the slaughterhouse avoids many ergonomic risks. However, human-computer interaction is present in this section, and the risks associated with cognitive factors are higher. In the printing section, water-based paints that pass the test are used. There are two different printing machines with 17 and 14 heads. A small amount of existing digital printing machines can also be used. The complete digitalization of the printing department will effectively reduce the risks. The low number of employees in this department, the fact that women are more sensitive to chemicals, and job rotation reduce the risk level.

In the future, new studies can be conducted using different MCDM methods on ergonomic risks in textiles. MCDM is reaching the best possible result according to the established rules. Problems encountered in real life often involve conflicting criteria that cannot be expressed on the same scale. Therefore, finding a solution that meets all the selection criteria is problematic. Generally, a conciliatory solution is sought for such problems in light of established rules [66]. MCDM methods examine decision-making problems with all dimensions and process every aspect of the problem in terms of the decision maker's preferences to reach the best compromise solution. In cases with many criteria for the best compromise solution, the decision maker

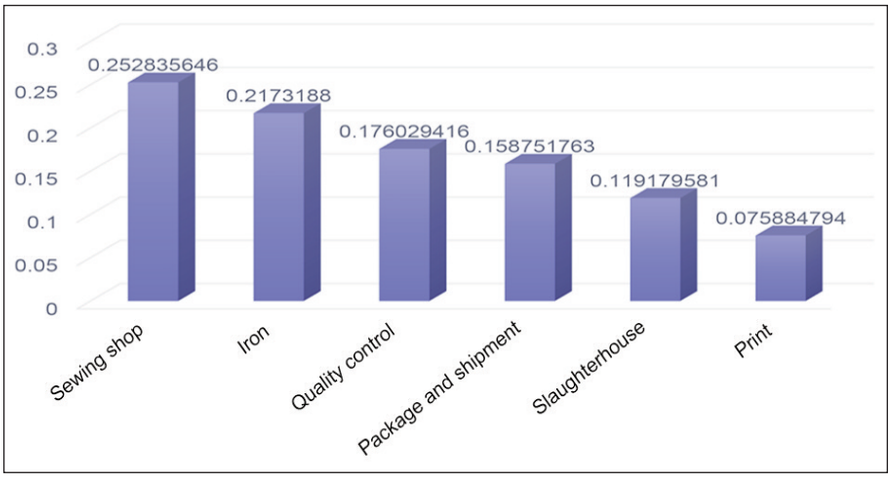

Fig. 4. Ranking of alternatives

can group, rank, or choose from among the alternatives by combining and balancing the conflicting criteria [67]. Considering the advantages and disadvantages of the methods in different conditions according to their applicability, the results obtained from using different methods can be evaluated comparatively. The relationship between accidents in textile factories and ergonomic factors can be investigated.

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Antimicrobial property of functional viscose fibre by using mint extract

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AZMAT HUSSAIN
SHANSHAN XU

ABSTRACT – REZUMAT

Antimicrobial property of functional viscose fibre by using mint extract

The use of cellulosic fibres treated with natural extracts can kill bacteria. Viscose is a regenerated cellulosic fibre with excellent biodegradability. The use of mint extract makes viscose a functional fibre, which gives beneficial results and can be used as an antimicrobial textile. The results clearly showed that the increasing ratio of the mint extract also increased the bacteriostatic ratio so that the antimicrobial property against E. Coli and S. Aureus for 100% viscose fabric is 97% and 94%, respectively. The bacteriostatic ratio against 50/50 cotton/functional viscose is proportionally lower, i.e., 85% and 81% against E. Coli and S. Aureus. The different number of washings affected the antimicrobial property of the fabrics in such a way that: the fabric with 100% functional viscose indicated a reduction of 14% for E. Coli, whereas the antimicrobial property decreased by 15% against S. Aureus after 5 to 20 washes as compared to the fabric with the blend 50/50. All the samples exhibited antimicrobial property more than 60% after 20 washes. The breaking strength of the functional viscose fibre decreased by about 12.9% in dry form and 14% in wet state compared with standard viscose fibre. However, the elongation of functional viscose fibre improved by 6.4% in dry form and 3.7% in the wet state, resulting in the low modulus of functional viscose fibre. The mosquito repellency rate ranges from 70–90% against 100% functional viscose fabrics, whereas 60–80% against the fabric is made up of a 50/50 blend for 5 to 20 washes. The overall results show acceptable behaviour against mosquito repellency. A simple approach was applied to develop antimicrobial textile products with cost-effectiveness and fruitful results.

Keywords: *viscose fibre, mint extract, anti-bacterial activity, anti-mosquito behaviour*

Proprietatea antimicrobiană a fibrei de viscoză funcţională prin utilizarea extractului de mentă

Utilizarea fibrelor celulozice tratate cu extracte naturale poate ucide bacteriile. Viscoza este o fibră celulozică regenerată cu o excelentă biodegradabilitate. Utilizarea extractului de mentă face din viscoză o fibră funcțională, care dă rezultate benefice și poate fi folosită ca material textil antimicrobian. Rezultatele au arătat în mod clar că proporția în creștere a extractului de mentă, a crescut și raportul bacteriostatic, astfel încât proprietatea antimicrobiană împotriva E. Coli și S. Aureus pentru materialul textil din viscoză 100% este de 97% și, respectiv, 94%. Raportul bacteriostatic față de materialul textil din 50/50 bumbac/viscoză funcțională este proporțional mai scăzut, adică 85% și 81% față de E. Coli și S. Aureus. Numărul diferit de spălări a afectat proprietatea antimicrobiană a materialelor textile în așa fel încât: materialul textil din 100% viscoză funcțională a indicat o reducere de 14% pentru E. Coli, în timp ce proprietatea antimicrobiană a scăzut cu 15% față de S. Aureus, după 5 până la 20 de spălări în comparație cu materialul textil din amestec 50/50. Toate probele au prezentat proprietăți antimicrobiene peste 60%, după 20 de spălări. Rezistența la rupere a fibrei funcționale de viscoză a scăzut cu aproximativ 12,9% în formă uscată și cu 14% în stare umedă, comparativ cu fibra de viscoză standard. Cu toate acestea, alungirea fibrei funcționale de viscoză s-a îmbunătățit cu 6,4% în formă uscată și cu 3,7% în stare umedă, rezultând un modul scăzut al fibrei funcționale de viscoză. Rata de respingere a țânțarilor variază de la 70–90% în cazul materialelor textile din viscoză funcțională 100%, în timp ce rata este de 60–80% în cazul materialelor textile din amestec 50/50, pentru 5 până la 20 de spălări. Rezultatele generale arată un comportament acceptabil împotriva respingerii țânțarilor. O abordare simplă a fost aplicată pentru a dezvolta produse textile antimicrobiene cu rentabilitate și rezultate corespunzătoare.

Cuvinte-cheie: *fibră de viscoză, extract de mentă, activitate antibacteriană, comportament anti-țânțari*

INTRODUCTION

Anti-bacterial textile products contribute to the health-care industrial sector. A diversity of textile products in the healthcare industry might be expected to give comfort and hygienic properties, such as bedding, surgical gowns, doctor coats, bedding, pillowcases, surgical masks, etc. However, the applications of anti-bacterial products are boundless rather than the healthcare industry, e.g., sports clothing and footwear. It was further extended to other applications like pet bedding, furniture, bath sheets, etc. After frequent washing, the significant aspect of anti-bacterial textiles products is to give long-lasting and continuous protection against detrimental bacteria (that might cause you ill and stains or odours) [1, 2].

For the time being, there is still a massive demand in the market to propose new techniques and advanced materials to exhibit antimicrobial properties to ensure satisfactory safety against microorganisms. Medical textiles are one of the most exciting areas in modern textiles to introduce products showing antimicrobial properties. Previously, the textile products were treated chemically; (phenols, iodine derivates, amines, formaldehyde derivatives, nitro compounds, inorganic salts, and antibiotics to restrain the bacteria attack. However, the chemical compounds are harmful due to their toxicity and poor degradability, which is not environmentally friendly and is against safety regulations. This is the reason why textile processing has been enforced to be concerned with the natural and non-toxic materials in the modern and technical processes, which are eco-friendly and not health hazards [3–7]. Natural fibres are attacked mainly by microorganisms rather than man-made ones due to the higher hygroscopic nature of natural fibres. Under certain conditions, the carbohydrates in cotton and proteins in keratinous fibres work as a source of nutrients. Furthermore, dust, soil, sweat, and textile finish can somehow contribute as a source of bacteria generation [8].

Compared with the other regenerated fibres, viscose fibre has a higher specific surface due to the high amorphous regions, thus having a higher specific surface. Using viscose fibres rather than the other regenerated fibres like modal and lyocell absorbed the highest amount of chitosan to act as an antimicrobial and antifungal activity [9–11]. Several studies showed that using antimicrobial fabrics or products increases the 60% of people to secure themselves from microorganisms. Thus, the demand has been increasing remarkably over recent years. The attention to hygienic products is increasing on the one hand, and the harmful effects of the chemicals on human health [12]. Microorganisms such as microbacteria, algae, and fungi, can grow and escalate on textile materials under appropriate conditions. The microorganisms produce the enzymes. Another concern is the production of undesirable odours when bacteria turn human sweat into compounds like carboxylic acid, aldehydes, and amines. Infestation of microbial textiles may also cause disease. Bacteria on underwear, such as *Staphylococcus*, can cause odours and purulence on the skin surface, and *Escherichia coli* can cause odours and ulcers [13–16]. The most recent studies focus on diverse ways to prevent bacterial infection by utilizing nanoparticles and assisting in manufacturing antimicrobial nanotherapeutics. Moreover, an innovative technique has been employed to overcome the bacterial resistance pattern to incorporate evolving nanomaterials (NMs) for anti-bacterial treatment. Nanomaterials may kill bacteria in various ways, making it difficult for bacteria to survive and build resistance to Nanomaterials. The surface chemistry, shape, core material, and size of Nanomaterials all influence the routes. Because of these factors, Nanomaterials-based products play an important role in improving treatment efficiency by interacting with bacteria biological systems and serving as an antibiotic replacement [17–18].

It's even better if the anti-bacterial materials are biodegradable, so cellulose research is important. Furthermore, as indicated by the findings of this research, the anti-bacterial potential of cellulose functionalized in wastewater treatment should not be overlooked, particularly in terms of water disinfection. We are resolved to view cellulose as a suitable support material used in many industries since its polyolic nature enables it to bind a series of molecules with chemical activities that may modify the hydrophilic/lipophilic balance and give enhanced qualities. One of the most promising advances in using cellulose derivatives in food preservation technology is the discovery of novel biomaterials with anti-bacterial capabilities [19].

MATERIALS AND METHODS

The functional viscose fibres have been obtained from Qingdao Baicao new materials co. Limited. Mint fibre is produced by mixing nano-grade menthone powders (derived from natural peppermint) into cellulose and then wet spinning the cellulose into mint fibres. Before the extrusion point, bactericidal agents are applied to the spinning solution. There is 8% mint menthone and 92% cellulose in this product. So, the mint fibre is cellulose-based.

Mechanical properties of simple viscose fibre and functional viscose fibre

The mechanical properties of functional viscose fibre compared to the standard viscose fibre have been given in table 1.

Table 1

MECHANICAL PROPERTIES OF SIMPLE VISCOSE FIBRE AND FUNCTIONAL VISCOSE FIBRE

Fibre type	Breaking tenacity (cN/tex)		Elongation at break (%)	
	Dry form	Wet form	Dry form	Wet form
Common	2.48	1.71	17.75	25.86
Functional	2.16	1.47	18.89	26.81

Yarn and fabric specifications

The yarns have been spun with different blend ratios, i.e., 100% cotton, 50/50 cotton/functional viscose, and 100% functional viscose, with a count of 24.6 tex (24Ne). These yarns are further knitted into 1×1 rib fabrics on a circular knitting machine.

Microorganisms and culture medium

Two microorganisms were used in the antimicrobial test: *Staphylococcus aureus* (gram-positive bacterium) and *Escherichia coli* (gram-negative bacterium). *Escherichia coli* was selected due to its prominence in daily life, while *Staphylococcus* was used because it causes significant cross-infection in hospitals. Nutrient Agar was used to sustain the strains (*Escherichia coli* and *Staphylococcus aureus*). The

incubation was performed at 37°C and stored at 4°C. The Luria Broth (LB) medium has been introduced to culture the *Escherichia coli* and *Staphylococcus aureus*. Which comprises of the ingredients; yeast extract 0.5%, peptone 1%, NaCl 1%, agar 2% & pH 7.4, The above mediums were sterilized at 121°C for 30 min.

Approach for evaluating the antimicrobial property of viscose fibres

This experiment measures the antimicrobial property by adding mint extract with the viscose fibre preparation for antimicrobial activity under the Shake flask method (GB/T 20944.3-2008). 0.75 g swatches of 100% cotton fabric (control sample) were mixed with 70 ml of phosphate buffer solution (PBS) in a 250 ml Erlen Meyer flask, respectively, then sterilized at 121°C for 30 min. For each fibre treatment, two replicates were used.

Escherichia coli and *Staphylococcus aureus* were incubated in Luria Broth (LB) liquid medium for 10 hours before each antimicrobial analysis. The density of cultures was diluted with sterile PBS to 1×105 CFU/ml to 5×105 CFU/ml by the Turbidimetric process at the end of the incubation. The turbidity was estimated at 500 nm using a SHIMADZU UV 1900i Spectrophotometer (China). Next, 5 ml of the distilled bacterial suspension and PBS with the fibre swatches were combined and rattled for 5 minutes to disperse them. After the dilution factor, 0.5 ml of the mixture was placed in Petri dishes and incubated for 24 hours at 37°C (*Escherichia coli* and *Staphylococcus aureus*). The remainder of the cross was shaken for 6 hours before being plated and incubated. Equation 1 expresses the results as a per cent reduction of bacteria (*R*), where *A* and *B* represent the colony numbers before and after shaking the culture for 6 hours.

$$R = \frac{A - B}{A} \times 100\ (\%) \qquad (1)$$

The colonies are counted with the inter-science (France), with the model Scan 500 as shown in figure 1.

Fig. 1. Colony counting machine by InterScience (Scan 500)

Mosquito repellent activity

Functional viscose fibre and ordinary viscose fibre are put in cavities A and C, respectively, as shown in figure 2. The gauze has been fixed on both sides of the box to keep it airy and keep mosquitos alive. In cavity B, 20 mosquitos were mounted. The partitions between A and B, as well as B and C, were then eliminated. We need to record the number of mosquitos in cavities A and C [4, 5].

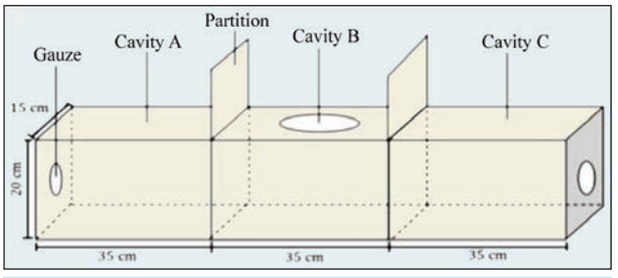

Fig. 2. Mosquito repellent testing setup

Then, the rate of mosquito repellency can be estimated using equation 2.

$$Q = \frac{N_C - N_A}{N_C - N_A} \times 100\% \qquad (2)$$

where *Q* represents the anti-mosquito rate. While N_A represents the number of mosquitoes in cavity 'A' and N_C represents the number of mosquitoes in cavity 'C'.

RESULTS AND DISCUSSIONS

Yarn mechanical property

The breaking strength of the functional viscose fibre has been decreased by about 12.9% in dry form and 14% in wet state, compared with standard viscose fibre. At the same time, the elongation of functional viscose fibre has been increased by 6.4% in dry form and 3.7% in the wet state, which helps the functional viscose fibre behave with a low modulus. That implies after applying plant extract to the viscose spinning solution, the binding composition of functional viscose fibres changes and the crystallinity decreases significantly. In addition, the presence of an enormous number of functional agent molecules between cellulose macromolecules prevents them from hydrogen bonding with several cellulose molecules, reducing fracture strength. However, when the cellulose molecules slip further, the elongation is increased.

Antimicrobial property

100% cotton has been used as a response material. Whereas, the number of colonies of 100% cotton is too high that the machine cannot count such no. of colonies. The number of colonies of bacteria has been counted for each sample. The number of colonies of *E. Coli* for 50/50% (cotton & mint added viscose fibre) with different concentrations has been shown in figure 3, *a–f*. While figure 3, *g–l* denotes the number

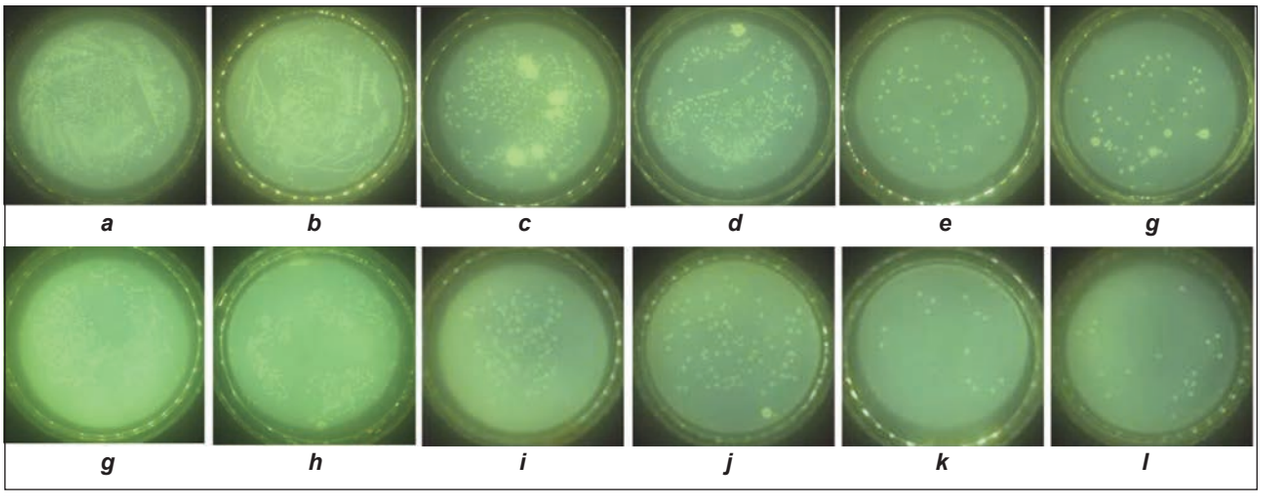

Fig. 3. *E.Coli* colonies: *a* – 50/50-3×10^5; *b* – 50/50-3×10^5; *c* – 50/50-4×10^5; *d* – 50/50-4×10^5; *e* – 50/50-5×10^5; *f* – 50/50-5×10^5; *g* – 100-3×10^5; *h* – 100-3×10^5; *i* – 100-4×10^5; *j* – 100-4×10^5; *k* – 100-5×10^5; *l* – 100-5×10^5

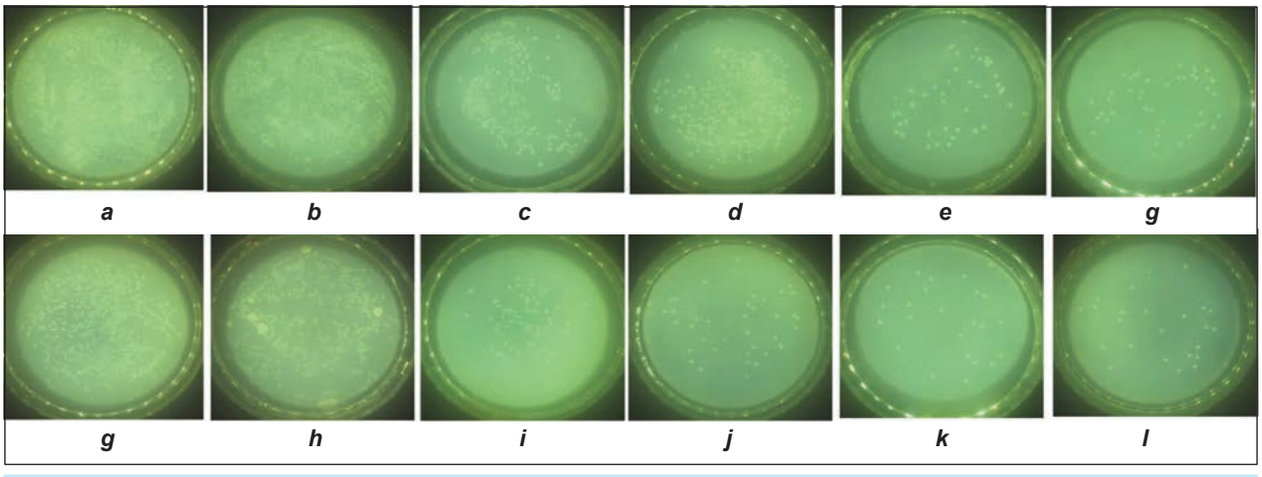

Fig. 4. *S. Aureus* colonies: *a* – 50/50-3×10^5; *b* – 50/50-3×10^5; *c* – 50/50-4×10^5; *d* – 50/50-4×10^5; *e* – 50/50-5×10^5; *f* – 50/50-5×10^5; *g* – 100-3×10^5; *h* – 100-3×10^5; *i* – 100-4×10^5; *j* – 100-4×10^5; *k* – 100-5×10^5; *l* – 100-5×10^5

of colonies of *E. Coli* against 100% viscose mint. Moreover, the number of colonies of *S. Aureus* for 50/50% (cotton & mint added viscose fibre) with different concentrations has been shown in figure 4, *a–f*. Whereas figure 4, *g–l* indicates the number of colonies of *S. Aureus* against 100% viscose mint. which signifies that the addition of mint extract results in fewer bacteria colonies for 50/50% (cotton & mint added viscose fibre) for the different concentrations. The number of bacteria colonies has been reduced for higher concentrations. The number of colonies for 100% viscose mint is deficient, indicating that the mint extract helps restrain bacteria. The antimicrobial property against the *E. Coli* and *S. Aureus* for 100% mint fabric is 97% and 94%, respectively. Whereas the bacteriostatic ratio against 50/50 cotton, viscose blend is proportionally lower, i.e., 85% and 81% against *E. Coli* and *S. Aureus* as shown in figure 5. It designates that the mint extract can help restrain bacteria.

Whereas, 50/50 = cotton/functional viscose fibre blend, 100 = 100% functional viscose fibre, 3×10^5, 4×10^5, 4×10^5 = different culture density.

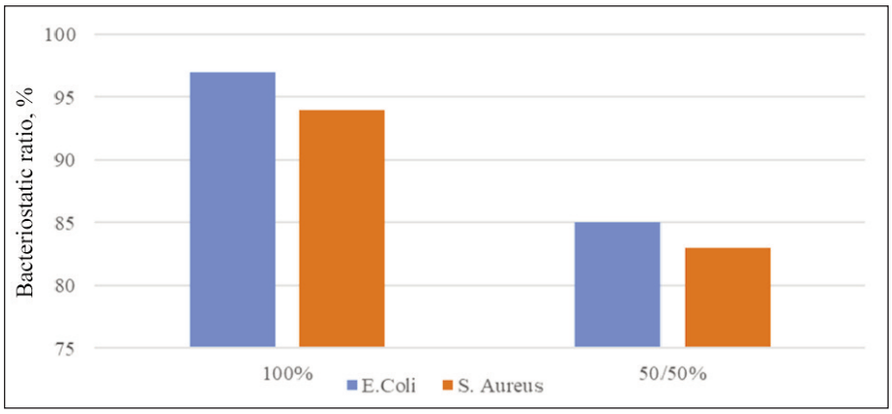

Fig. 5. Bacteriostatic ratio against *E. Coli* and *S. Aureus*

Whereas, 50/50 = cotton/functional viscose fibre blend, 100 = 100% functional viscose fibre, 3×10^5, 4×10^5, 4×10^5 = different culture density.

SEM of cotton and functional viscose fibres

The SEM of cotton and viscose with mint extract as well as simple viscose fibre have been shown in figure 6, *a* shows the structure of the cotton fibre, while figure 6, *b* which the adhesion of mint extract on the yarn's surface, whereas figure 6, *c* shows the structure of simple viscose yarn.

Effect of washing on antimicrobial property of the fabric

The results of bacteria reduction after the different number of washing are shown in figure 7. The fabric with 100% mint indicated a 14% reduction of bacteria by 14% for *E. Coli*. While the antimicrobial property decreased by 15% against *S. Aureus* after 5–20 washes compared to the fabric with the blend 50/50. Moreover, the bacteriostatic ratio decreased by 3–4% as compared with *E. Coli* and *S. Aureus* against fabric with a content of 100% functional viscose fibre as far as a 4–8% reduction ratio has been observed for *E. Coli* and *S. Aureus* against fabric with the content of 50/50 cotton/functional viscose fibre. Which still exhibits the property to resist bacteria. In contrast, *E.Coli* indicates the maximum resistance to bacteria.

Mosquito repellency test

The mosquito repellent test has been performed against the 100% functional viscose fabric and 50/50 cotton/ functional viscose fabric. The results given in figure 8 indicate that the mosquito repellency rate ranges from 70–90% for 5 to 20 washes against 100% functional viscose fabrics. The mosquito repellency rate lies between 60–80% for 5 to 20 washes against the fabric made up of a 50/50 blend. The overall results show acceptable behaviour against mosquito repellency.

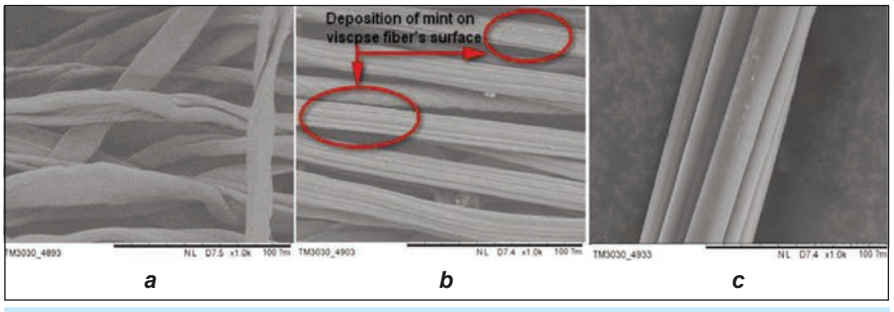

Fig. 6. Images of: *a* – the structure of the cotton fibre; *b* – the adhesion of mint extract on the yarn's surface; *c* – the structure of simple viscose yarn

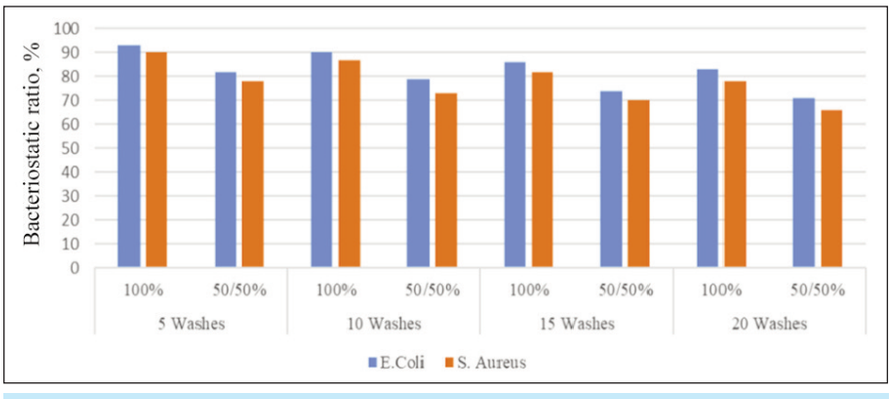

Fig. 7. Effect of the number of washing on Bacteriostatic ratio against *E. Coli* and *S. Aureus*

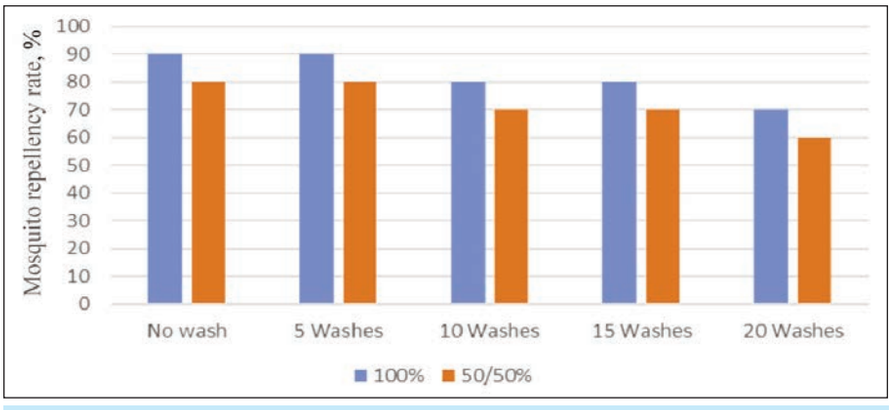

Fig. 8. Mosquito repellency rate against 100% functional viscose and 50/50 cotton/functional viscose fabric

CONCLUSIONS

From the above results, the conclusions can be drawn as follows:

1. The regenerated cellulose fibres can be used as a functional textile by adding natural additives. Which, in general, has no toxic effect, and no health hazard. The mint extract provides an antimicrobial product that can be applied to hospital beddings, masks, patient dresses, shoe pads, and skin problems like itches on allergies. Mint can provide comfort as well as aesthetic properties.
2. The addition of mint within cellulosic fibres can play a vital role in the fabrication, acting as a mosquito repellent.

Future work must be carried out for different microorganisms and also in a sense to

evaluate the comfort and anti-allergic properties. Further, the mint extract should be added to other cellulosic fibres such as cotton, Tencel, and modal to assess their antimicrobial, comfort, and aesthetic properties. Furthermore, mint extract might play a significant role in reducing inflammation. Moreover, the different natural extracts must be explored to reduce the usage of chemical finishes that cause a damaging impact on the skin and do not possess eco-friendly behaviour.

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Benefits of platelet rich plasma (PRP) treatment on skin autografts and allografts in a burned patient

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ABSTRACT – REZUMAT

Benefits of platelet rich plasma (PRP) treatment on skin autografts and allografts in a burned patient

Wound healing is promoted by a series of growth factors, secreted from the alpha granules of the platelets. Platelet rich plasma (PRP) emerged as a clinical strategy to increase the physiologic concentration of platelets and its clinical use for a large spectrum of disorders is reported, with good results. Extensive burns represent a promising field for PRP use, those patients confronting challenging wound healing and poor long-term results. We present our initial clinical experience represented by a case of a 51-year-old male patient, severely burned, who benefited from sequential surgical treatment of deep burn wound excisions and coverage using autologous and allogenic skin grafts. PRP was added to this patient's therapy in two stages, being injected and externally applied on the autografts in functional areas of the hands and the right upper arm region where both autografts and allografts were placed, with the exciting result of promoting allograft integration, long-term persistence and healing. Several literature data validate successful clinical applications of PRP in various therapies, including treatment of soft tissue injuries and chronic wounds, orthopedic surgery, burns, maxillo-facial surgery and elaboration of tissue-engineered products. Based on our preliminary experience and favourable reports in the literature, we encourage wider use of platelet rich plasma for immunomodulation and tissue-engineered constructs, due to its effects on local inflammatory response and role in enhancing the integration of various types of tissue grafts.

Keywords: *platelet rich plasma (PRP), burns, autograft, allograft, immunomodulation*

Beneficiile tratamentului cu plasmă îmbogățită cu trombocite (PRP) asupra autogrefelor și alogrefelor tegumentare la un pacient ars grav

Vindecarea plăgilor este promovată de o serie de factori de creștere, secretați de la nivelul granulelor alfa ale trombocitelor. Plasma îmbogățită cu trombocite (PRP) este o strategie terapeutică utilă pentru creșterea concentrației fiziologice de trombocite și utilizarea ei clinică a fost raportată pentru un spectru larg de afecțiuni, cu rezultate bune. Un domeniu promițător pentru folosirea PRP este reprezentat de arsurile extensive, pentru pacienții ce se confruntă cu o vindecare precară a plăgii și rezultate nefavorabile pe termen lung. Prezentăm experiența noastră clinică inițială, reprezentată de cazul unui pacient de 51 ani, ars sever, care a beneficiat de tratamentul chirurgical secvențial al arsurilor profunde prin excizia leziunilor și acoperire cu grefe tegumentare autologe și alogrefe. Terapia pacientului a fost suplimentată cu PRP în două etape, fiind atât injectat, cât și aplicat topic pe autogrefele din zonele funcționale ale mâinilor și membrului superior drept, unde au fost folosite atât alogrefe, cât și autogrefe, având un rezultat interesant de promovare a integrării alogrefelor, persistenței pe termen lung și vindecării. Multiple date din literatură validează aplicațiile clinice ale PRP cu succes în tratamentul diverselor patologii, inclusiv tratamentul leziunilor de părți moi și al plăgilor cronice, chirurgie ortopedică, arsuri, chirurgie maxilofacială și utilizarea în domeniul ingineriei tisulare. Pe baza experienței noastre preliminare și a rezultatelor favorabile din literatură, încurajăm folosirea mai largă a plasmei îmbogățite cu trombocite pentru imunomodulare și în asociere cu diverse matrici în ingineria tisulară, datorită efectelor sale asupra răspunsului inflamator local și a rolului în îmbunătățirea integrării grefelor tisulare de diverse tipuri.

Cuvinte-cheie*: plasmă îmbogățită cu trombocite (PRP), arsuri, autogrefă, alogrefă, imunomodulare*

INTRODUCTION

Platelet rich plasma (PRP) represents a fraction of the patient's blood that contains a high density of platelets (3–5 times higher) in comparison with the normal level. PRP is obtained through the centrifugation of the whole blood (harvested through a peripheral venous puncture and maintained in anticoagulant), then each blood component is separated according to its weight, resulting in a high platelet density [1].

In platelets, both cytokines and growth factors are deposited in their incomplete form in the alpha granules. In physiological conditions, activation of the platelets determines the bioactive modification of the growth factors and cytokines, which are actively secreted 10 minutes after the clot formation. This process can be reproduced by activating PRP using thrombin, which leads to the formation of a platelet gel. This gel acts just like a drug-delivery system due to its high platelet count, growth factors and cytokines density, which will stimulate the physiological processes. The result will be the appearance of a constantly repaired and regenerated tissue [2, 3].

The most important growth factors identified in the platelet rich plasma are PDGF (platelet derived growth factor), IL (platelet factor interleukin), TGF-beta1 (beta1 transforming growth factor), VEGF (vascular endothelial growth factor), PDAF (platelet-derived angiogenesis factor), EGF (endothelial growth factor), IGF (insulin-like growth factor) and fibronectin [3, 4].
Various successful clinical applications of PRP therapy were reported: treatment of soft tissue injuries or diseases, orthopedic surgery, burns, oral and maxillo-facial surgery, chronic wounds, tissue engineered products [2, 4, 5]. Burns represent a field where challenging wound healing and poor long-term results motivate researchers to address recently emerging techniques to improve clinical outcome and PRP seems to be a promising tool in this direction [6]. The association of PRP with various tissue grafts may be beneficial in their integration, which is the aim that we wanted to achieve in the case of the patient who is presented in this paper.

CLINICAL CASE PRESENTATION

We present the case of a 51-year-old male patient, a victim of an accidental 3-meter fall at the workplace, who suffered IIA, IIB and III-degree burns produced by steam and hot liquid (water), approximately 30% of total body surface area, involving the facial region, the right humeral region and the dorsal surface of the right upper limb, the dorsal surface of the left radio-carpal joint and hand, the right flank, the antero-postero-lateral right thigh, the antero-lateral right calf surface and foot. Additionally, the patient presented with cranio-cerebral injury, inhalation injury and thoraco-abdominal contusions.
At admission, the CT scan showed the following findings: a right temporal fracture line that extended to the petrous aspect of the temporal bone, a 5 mm right subdural hematoma, a 3 mm left subdural hematoma, bilateral hemorrhagic contusions of the temporal cortex, blood suffusions in the interhemispheric fissure, in the tentorium cerebelli and the peri-mesencephalic cisterns, as well as diffuse cerebral edema.
The initial period was characterized by a severe general status, with marked hemodynamic and respiratory instability, requiring ventilator and vasopressor support (0.2 mg/kg/min norepinephrine), continuous analgesia and sedation and nasogastric tube placement. Thus, the patient was admitted to the Intensive Care Unit, where fluid resuscitation was immediately initiated using the Parkland formula. The patient received blood derivatives as needed, loop diuretics, broad-spectrum antibiotic therapy, mixed enteral and parenteral nutrition and prophylaxis for stress ulcer.
Subsequently, the general status remained extremely severe, with hemodynamic and respiratory instability, the patient being intubated and receiving continuous analgesia and sedation. The lab results showed leukocytosis during the first few days, which then regressed, but the patient persistently presented with anemia and hypoproteinemia with hypoalbuminemia, hence developing systemic and septic complications. Local debridement and sterile dressing in the operating theater were performed daily and deep burns were sequentially excised and covered with antimicrobial dressings and allografts until the patient's general status improved, allowing definitive skin grafting.
The local lesions advanced and deepened. Sterile dressings with antiseptic and antimicrobial topical agents were constantly applied on the wounds, as well as special dressings and skin substituents, including allografts applied on the excised areas as temporary biological dressings. Figure 1 presents the dressings and skin substitutes used for the local treatment of this patient.

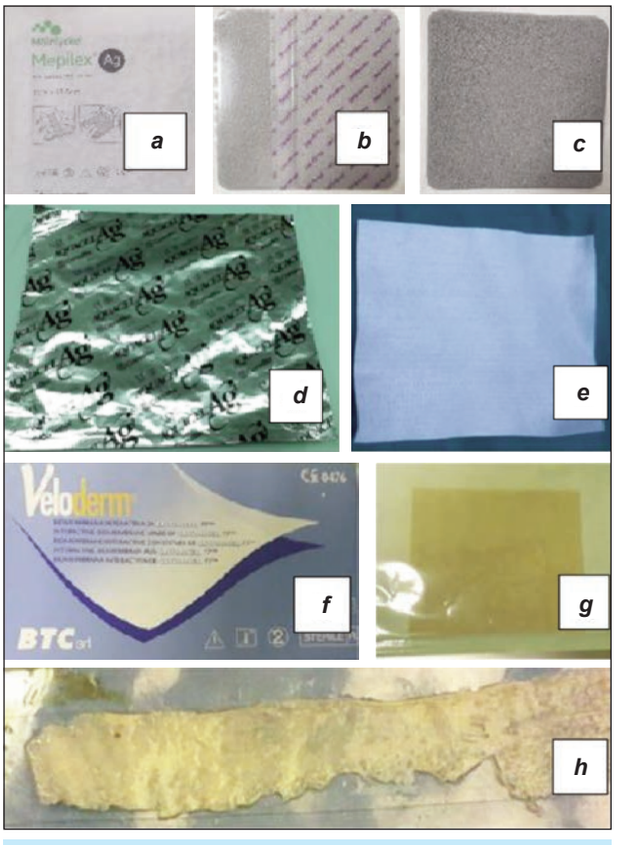

Fig. 1. Dressings and skin substitutes: *a, b* and *c* – Mepilex Ag; *d* and *e* – Aquacel Ag; *f* and *g* – Veloderm, *h* – Human skin allograft

After 2 weeks, the burn injuries stabilized and were completely delimited, allowing the excision of residual burn wounds and coverage with both autografts and allografts, since the wound bed was still not completely adequate for complete autografting.
On the 19th day following the injury, postburn lesions still partially persisted along with granulated wounds in the upper limbs and partially in the right lower limb (previously excised). Surgical intervention was decided and then performed, as follows: excision of the necrotic tissue in the right lower limb, covering the skin defects in the upper limbs with split-thickness autografts harvested from the calves bilaterally and

covering the skin defects of the posterior surface of the right arm and shoulder, right flank and right lower limb with cryopreserved allografts.

Local evolution at 3 weeks is presented in figure 2.

On the 23rd day, PRP treatment was initiated. Laboratory tests taken in the morning preceding the PRP procedure revealed a complete blood count with hemoglobin = 8.5 g/dl, leucocytes = 7700/mmc, and platelets = 294000/mmc.

PRP treatment was further performed for selected areas, as further described. Firstly, PRP was injected in the right arm and forearm and hand bilaterally, but PRP was additionally applied on the dorsal aspect of both hands, topically (figures 3, 4, 5 and 6).

Local evolution revealed almost completely integrated grafts in both upper limbs, with a tendency of lower limb allografts to graft failure. Figure 7 illustrates the dynamic aspect of the autologous and allogenic

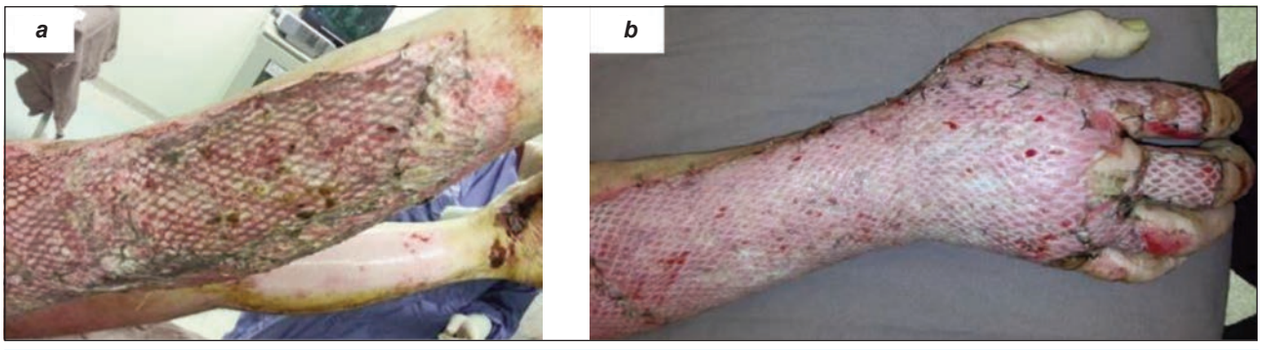

Fig. 2. The allografts: *a* – in the right lower limb, with partial graft failures; *b* – undergoing integration in the forearm and right hand, on the 22nd-day post-burn

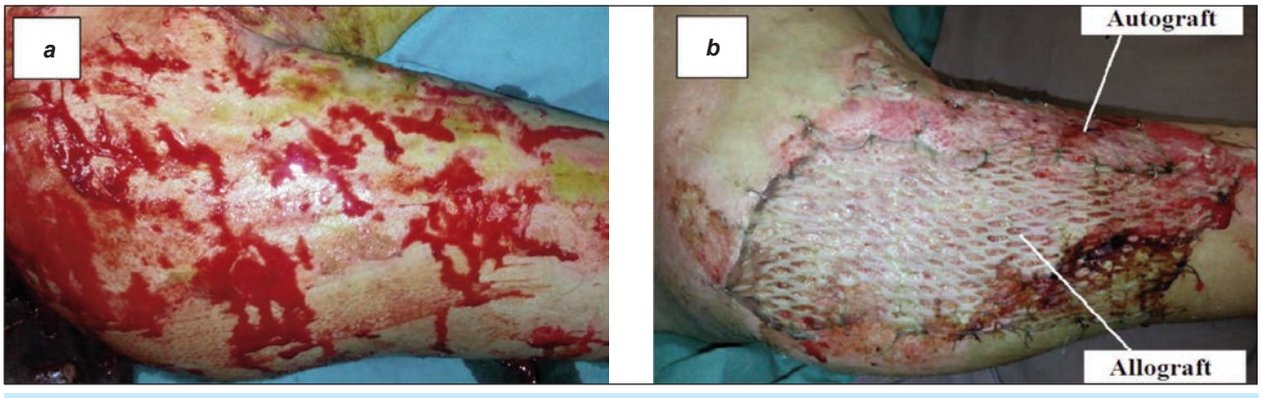

Fig. 3. The aspect of the right brachial region, where we placed both autografts and allografts to highlight their response to the platelet rich plasma therapy: *a* – the aspect of the studied region in the right arm, immediately after excision of the burn; *b* – the aspect of the skin grafts during the PRP treatment, on the 23rd-day post-burn, with the autograft on the antero-external arm and the allograft on the postero-external arm

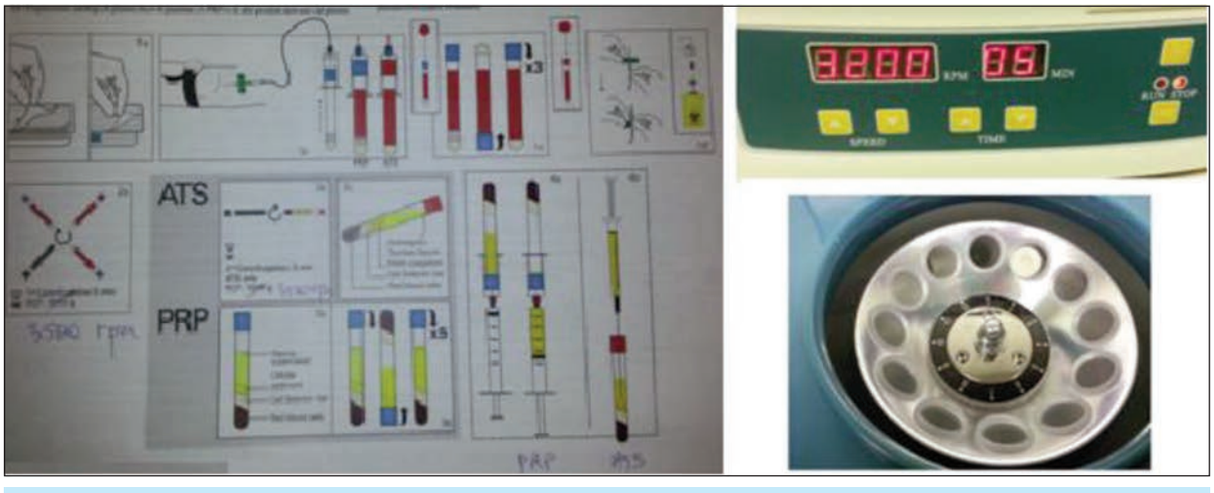

Fig. 4. The kit scheme and the centrifuge used for PRP therapy with 3200 RPM for 5 minutes

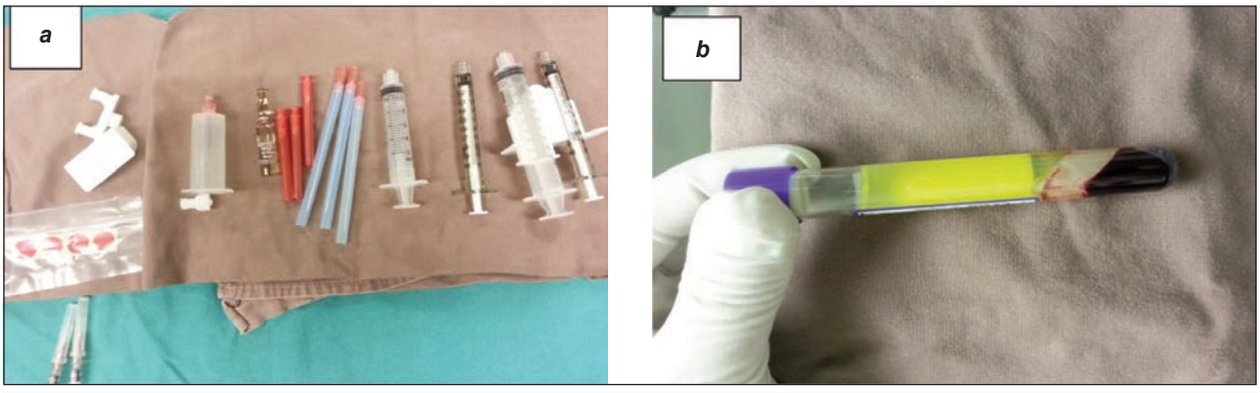

Fig. 5. Photos of: *a* – the devices used for PRP therapy; *b* – the aspect after centrifugation with separated components

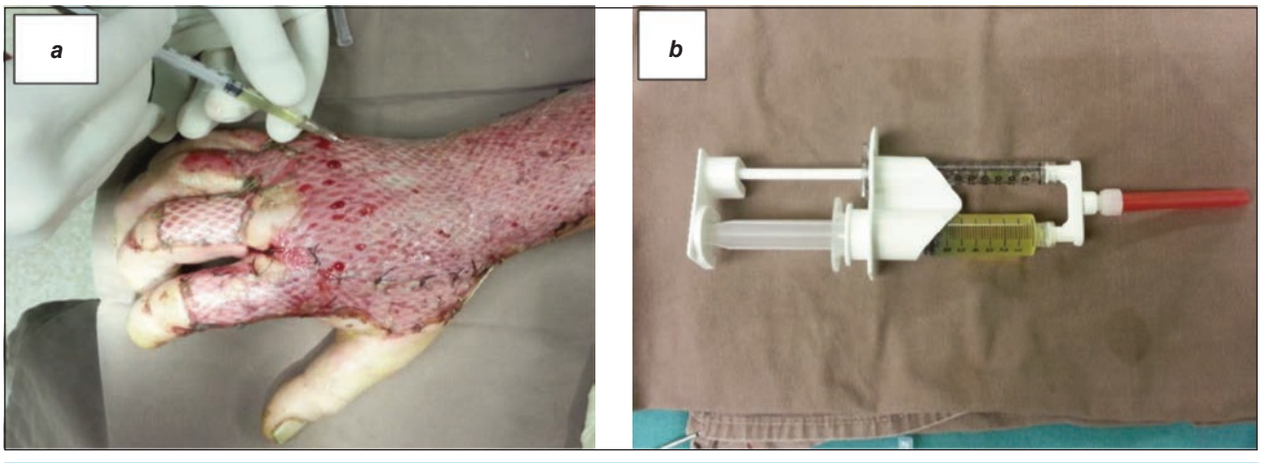

Fig. 6. Technique displayed in the dorsal aspect of the right hand: *a* – local PRP injected; *b* – external application performed with the device

split-thickness skin grafts applied on the right arm after PRP local treatment.

Even though the patient was extubated, the general status remained severe and he developed an embolic complication of the left lower limb, which showed incompletely delimited ischemic lesions of the left foot and areas of dry necrosis at this level.

On the 33rd day post-injury, autologous split-thickness skin grafts harvested from the antero-external region of the left thigh were used to cover the residual defects from the right flank and the right lower limb.

On day 35 of burn evolution, we decided to apply a second PRP treatment in the grafted areas of the upper limbs. Figure 8 displays the aspect of the graft in the right arm and the PRP kit that was used for the procedure.

The appearance of other areas can be observed in figure 9: on one hand, very well-integrated autografts in the right upper limb, with wounds surgically healed; on the other hand, still integrating autografts in the right calf (in the lower limb, the allografts have progressively deteriorated and have been previously removed).

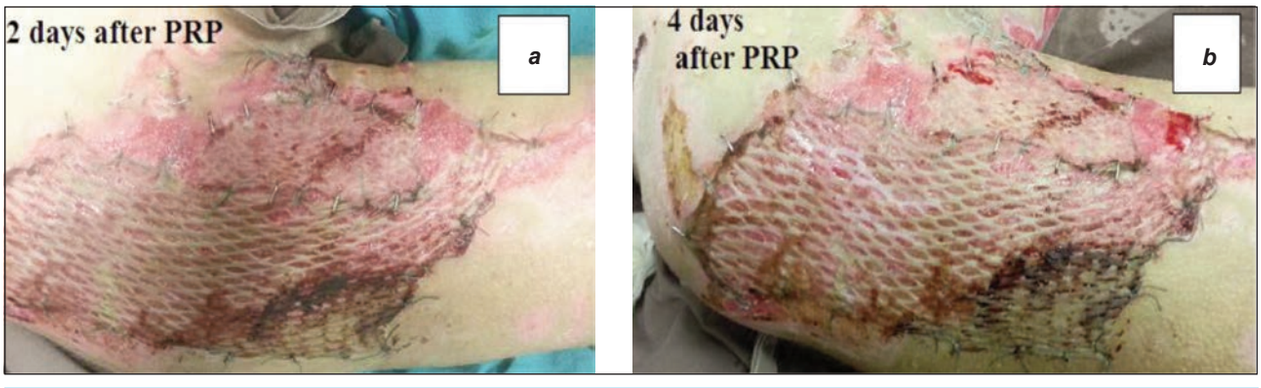

Fig. 7. Autologous and allogenic split-thickness skin grafts: *a* – 2 days; *b* – 4 days after the PRP therapy

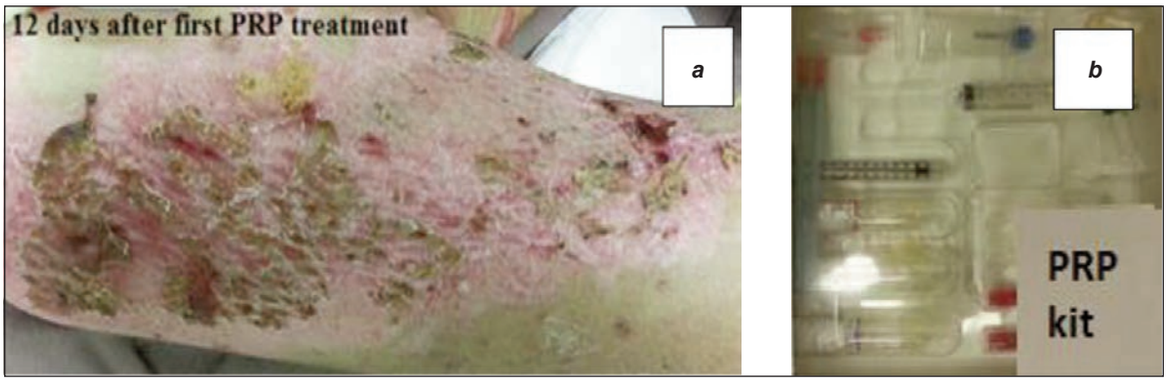

Fig. 8. Photos of: *a* – 12 days after the first PRP treatment on the grafts; *b* – another round of PRP injections

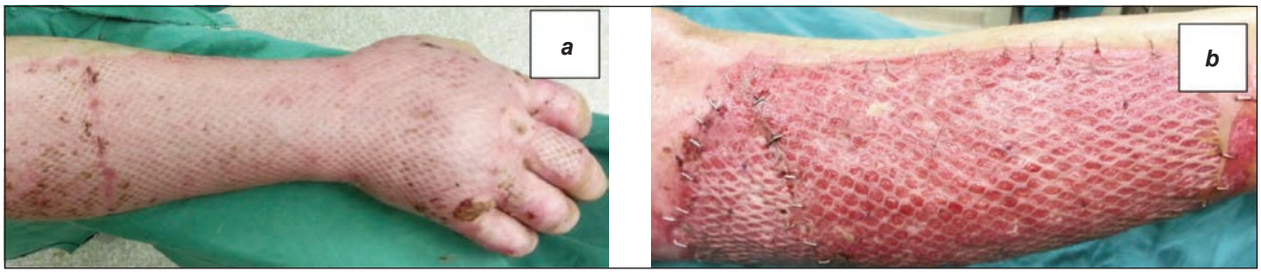

Fig. 9. Photos of: *a* – integrated autografts; *b* – autografts that are still integrating into other areas of the body, without PRP therapy

Figure 10 illustrates the aspect of the observed area in the right arm, 5 days after the second PRP treatment (on day 40 following injury) and we can observe complete integration of the autograft and also a satisfactory integration of the allograft.

However, the local evolution was unfavourable on the left lower limb, with delimited dry necrosis of the foot, requiring the amputation of this segment from the middle third of the left calf, which was performed on the 44th-day post-injury.

The patient then evolved favourably, not only from a general status point of view but also considering the local evolution, with integrated skin grafts, epithelisation of the burn injuries and a supple, surgically healing amputation stump.

Fig. 10. Autograft and allograft after 5 days from the second round of PRP therapy (the autograft was completely integrated and the allograft showed satisfactory integration in the right arm region)

The patient was discharged from the hospital on day 55 post-burn injury, in good general status, with completely healed burned wounds and he was transferred to the regional hospital for the initiation of the rehabilitation program.

On the day of discharge, the local exam showed healed cervical burn injuries, amputation of the right auricle following deep burned lesions, integrated skin grafts on the right deltoid region, right upper limb, dorsal aspect of the left hand, right flank and right lower limb, with very small areas that were still healing on the posterior side of the right thigh and a supple, surgically-healing amputation stump.

DISCUSSION

The application of platelet rich plasma treatment presented favourable results for various wound treatments. However, there is not a large panel of data regarding the effect of PRP therapy on burn lesions specifically [7].

The case that we presented above illustrates the integration and persistence of the right arm allografts, which received PRP treatment with their viable appearance (complete epithelization) at the time of patient discharge, almost 2 months post-injury. This result of allograft integration could be interpreted as an effect of the long-term immunosuppressive state which is characteristic of severely burned patients, but the particularity of this case is the fact that the rest of the allografts, applied in the other regions of the body and left untreated (without PRP), showed unfavourable evolution with progressive lysis, requiring their removal followed by autografting.

The association of PRP and skin grafts are described in the literature, with good results. The application of autologous platelet rich plasma to split-thickness skin recipient sites provide immediate adherence of the graft to the wound bed, reduces shearing forces, promotes inosculation and reduces healing time in a wound environment enriched in growth factors. [8, 9] PRP also has a benefic role, when applied locally, in reducing donor site pain after split-thickness graft harvesting, improving patient comfort, reducing analgesic usage postoperatively and it may even promote wound healing and angiogenesis in these areas [10–12].

Skin allografts are the best option to cover excised wounds in extensively burned patients when autografts are not available. Homografts represent a temporary solution for wound coverage, due to their high antigenicity, with the rejection process occurring in about two weeks post-grafting. Persistence of the skin allografts was reported in some patients, but the mechanism of those situations is not clear. An increased effort to study the factors influencing allograft longevity is encouraged because these results may improve the outcome of severely burned patients with scarce autologous sources for skin grafting 13, 14].

Adding PRP to burn lesions can, theoretically, stimulate angiogenesis, vascular proliferation, fibroblast proliferation and hemostasis, by facilitating fibrin clot formation. The studies undertaken on animals have revealed a decrease of the inflammatory infiltrate and a speed-up in the healing process for second-degree burns, with the reduction of cells with positive expression of CD31, CD68, CD163, TGF-beta, MPO and an increase of MMP2 cellular expression. However, studies that use PRP as an adjuvant treatment for burns are not standardized yet, which requires additional investigations to reach a complete and correct conclusion [6, 15–19].

PRP also proved to have a promising role in the regeneration of various types of lesions. PRP was used to improve the integration of bone grafts, promoting a faster radiologic maturation process and a higher bone density compared to the control group. An additional decrease in postoperative pain, number of infections, edemas and hematomas after PRP has been noticed. The involved mechanism seems to come from the quantitative expansion of the mesenchymal cells, stromal cells of the bone marrow and also chondrocytes. A key aspect of the integration of bone allografts is represented by early vascular invasion, therefore reducing complications such as delayed and incomplete bone integration. Therefore, PRP represents an important angiogenic inductor through the release of the vascular endothelial growth factor [3, 20–22].

PRP was also tested in association with autologous fat grafts used for contour reconstruction or scar remodelling and it was shown that PRP improves the tridimensional contour and volume maintenance, and speeds up wound healing processes, probably due to its growth factors which stimulate the proliferation of the adipose cells derived from progenitor cells [3, 23, 24].

PRP injection in acute or chronic pathology of the tendons has been followed by different clinical effects, especially regarding pain reduction. In the traumatized tendon, PRP can stimulate the proliferation and mitosis of fibroblasts, and increase TGF-P, followed by an increase in local synthesis of collagen I and II. Chondro-cutaneous grafts previously treated with PRP have benefited from accelerated epithelial and fibroblastic regeneration, inducing neovascularization and decreasing the apoptosis rate. In experimental models on rabbits, PRP administration on these types of autografts resulted in a higher expression of CD31 in blood vessels and also of vascular endothelial growth factor, in comparison with the control group [25–28].

The association of neurorrhaphy techniques with PRP and human mesenchymal stem cells has proven to be more efficient in nervous regeneration, compared to using each technique separately, by increasing angiogenesis and production of neuronal growth factors [1].

All these reports illustrating a wide variety of applications of PRP for wound healing attest to the potential benefits of this therapeutic strategy, but further studies are necessary to elaborate standardized indications and clinical protocols, all while having in mind the safety of the patient and the potential functional benefit [2].

Perspective: PRP and tissue engineering constructs

Tissue engineering is one of the main directions of study in the biomedical field, because of its variety of potential applications, ranging from tissue regeneration to entire organ replacements. To achieve cell proliferation, three components need to be incorporated into the process: stem cells (including various types of adult stem cells), a three-dimensional scaffold that serves as the extracellular matrix and also growth factors and other stimulating molecules [29, 30]. Platelets represent one of the main contributors in the inflammatory reaction, as well as the regeneration processes that arise in the human body, due to the variety of cytokines and growth factors that they release: vascular endothelial growth factor (VEGF), epidermal growth factor (EGF), platelet derived growth factor (PDGF), transforming growth factor (TGF), insulin-like growth factor (IGF), basic fibroblast growth factor (bFGF), to name but a few [31]. These growth factors play important roles not only in processes such as cell proliferation, differentiation or recruitment but also in cell regeneration [32]. Hence, platelet-rich plasma (PRP) has been used as an easily accessible, autologous source of growth factors, providing an alternative to the use of recombinant growth factors, which are not as safe as PRP from an immunological standpoint [33]. Moreover, the fibroblasts in the dermis have an increased expression of type I collagen and matrix metalloproteinase-1 after PRP stimulation [29]. It is regarded to be a type of

advanced therapy for both acute and chronic wounds: chronic ulcers, surgical wounds, and diabetic ulcers [34].

PRP electrospinning is used to obtain scaffolds through which cell proliferation can be promoted. Moreover, it has the capacity to bioactivate scaffolds obtained from other biodegradable polymers, such as poly(ε-caprolactone) (PCL) [33]. The advantages of PRP use in cell regeneration and proliferation are not only related to its safety and abundance of growth factors but also its simplicity and cost-effectiveness as a technique [35]. The activation of PRP is done through freeze-drying, during which the proliferative and adhesive properties of the PRP are conserved since lyophilization does not affect the viability of the growth factors. This contrasts with activating the PRP with thrombin or calcium chloride, forming a PRP gel, which, despite its hemostatic role, has the disadvantage of diminishing these properties [36–38]. However, it has been shown that PRP concentration can influence its effects on mesenchymal stem cell (MSC) proliferation: whilst a low concentration of PRP has a positive effect, with more abundant extracellular matrix production, higher concentrations can suppress cell viability and, thus, proliferation [33, 39]. When it comes to PRP adsorption on biodegradable polymer scaffolds, the same principles apply. According to Diaz-Gomez et. al, freeze-drying not only protects the benefic properties of the PRP, but it also does not affect the PCL scaffolds, preventing the alteration of their nanofibrous structure. The PRP coating can have different densities, depending on both the timespan of scaffold immersion in PRP in advance to freeze-drying and the growth factor concentration. PRP also aids in MSC proliferation through a biodegradable scaffold, which is more efficient than through a non-coated biodegradable scaffold [33]. Animal studies on rodents highlight that hydrogel scaffolds consisting of type I collagen and PRP accelerate wound healing compared to non-PRP coated scaffolds and secondary wound healing, by promoting stem cell recruitment from the dermis. [40] Similar results were seen in studies performed on porcine models [41].

The release pattern of the growth factors from PRP-treated surfaces has been of interest to scientists and clinicians alike. A 2013 study on PRP-coated titanium discs found that VEGF and TGF release is not as sustained as that of PDGF [42]. This finding was seconded by Diaz-Gomez et al., who studied the same patterns of growth factors released on PRP-coated biodegradable scaffolds. They proved that VEGF release showed a burst in the first few hours, reaching nearly complete release after 7 days, as opposed to the PDGF release that had a sustained pattern of release from the coated scaffold. TGF release, on the other hand, showed a progressive pattern, reaching a peak on day 3 [33]. Compared to previous studies using thrombin and calcium chloride for PRP activation, the released growth factor amounts were greater when freeze-thaw cycles were used for this purpose. [36] Recent studies reveal that nanofibrous dressings containing platelet rich fibrin have the same release patterns, with growth factors such as VEGF or PDGF being available for 7 days [43].

The effects of the aforementioned growth factors have been widely studied in the literature. For example, VEGF is known to activate and signal PDGF receptors, leading to cell proliferation. Additionally, PDGF has mitogenic activity and TGF increases MSC proliferation. All these growth factors are released from activated PRP and play important roles in the regeneration process [44].

This combination has been proven to have angiogenic properties, as well, with an increase in the allantoic vessel density of the chicken chorioallantoic membrane (CAM) after PRP-coated scaffold treatment. Moreover, the PRP-coated scaffolds were incorporated in the CAM, which grew around the scaffold, displaying the tissue proliferation properties, as opposed to non-PRP-coated biodegradable scaffolds, which remained as an overlayer on the CAM [33].

Future research is required for developing tissue-engineered constructs able to restore, conserve or improve various affected structures to promote optimal functional recovery and restore the adequate quality of life for patients with various tissular defects.

CONCLUSION

Platelet rich plasma, containing an important amount of growth factors, seems to represent a viable immunomodulatory strategy with effects on local inflammatory response and the ability to improve the success rate of various types of autologous and allogenic tissue grafts. Our clinical case of using PRP in association with skin grafting in a burned patient showed favourable effects of PRP on autologous skin grafts and homografts from the treated anatomical areas, favouring their integration. Future studies should consider PRP as a promising clinical strategy to address a wide range of inflammatory phenomena, including allograft rejection. Through its growth factors, PRP shows also importance in the development of complex tissue engineering constructs in association with recently developed scaffolds and stem cells population.

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Study of physical, moisture-management and stretch properties of underwear fabrics

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ABSTRACT – REZUMAT

Study of physical, moisture-management and stretch properties of underwear fabrics

This study investigated and characterized the physical properties and their influence on moisture management and stretch properties of underwear fabric made of different compositions of fibres. It is found that fabric made of finer filament yarn, having an open and porous structure, smaller stich length, and smaller thickness has higher air permeability, water vapour permeability, better moisture transport and overall moisture management capacity. It is also found that elastic recovery is higher in the wale direction in the case of weft-knitted fabrics. Furthermore, a fabric with longer stich length has higher stretch in both directions and more recovery in the wale direction. In addition, it is found that warp-knitted fabric has better moisture transport.

Keywords: *fabric composition, humid, water vapour transmission, elastic recovery, weft knitted fabrics, warp knitted fabrics*

Studiul proprietăților fizice, de gestionare a umidității și de întindere ale materialelor pentru lenjeria de corp

Acest studiu a investigat și caracterizat proprietățile fizice și influența lor asupra gestionării umidității și proprietăților de întindere ale materialelor pentru lenjeria de corp din diferite compoziții de fibre. Se constată că materialul textil din fire filamentare mai fine, având structură deschisă și poroasă, lungime mai mică a ochiurilor și grosime mai mică are permeabilitate mai mare la aer, permeabilitate la vapori de apă, transport mai bun al umidității și capacitate generală de gestionare a umidității. De asemenea, se constată că revenirea din întindere este mai mare în direcția şirului de ochiuri de tricot în cazul tricoturilor din bătătură. În plus, un tricot cu o lungime mai mare a ochiurilor are o întindere mai mare în ambele direcții și o capacitate de revenire mai mare în direcția şirului de ochiuri de tricot. În plus, s-a constatat că tricotul din urzeală are un transport mai bun al umidității.

Cuvinte-cheie*: compoziția tricotului, umed, transmisia vaporilor de apă, revenire din întindere, tricoturi din bătătură, tricoturi din urzeală*

INTRODUCTION

Comfort is a vital consideration in selecting underwear as it has direct contact with human skin and sensitive body parts [1]. Thermal comfort is related to moisture management (MMT) and thermal regulation properties of a fabric. MMT is the ability of a fabric to wick or diffuse the moisture from perspiration through the fabric as quickly and efficiently as possible. It is reported that the fibre type of the underwear affects MMT properties [2] and hydrophobic fibres provide higher breathability to the fabrics [3]. Heat transfer through fabric layers by conduction also influences the comfort of underwear [4]. In addition, stretch and recovery properties are critical for the ergonomic comfort of underwear [5]. Most recently, it is reported that fabric with good air permeability (AP) (485 mm/s), overall moisture management capacity (OMMC) of (0.61), and short drying time (16 min) is more suitable for summer sportswear [6].

To date, several materials have been investigated to study the influence of material on the thermos-physiological response of fabric and clothing-skin microclimate. For example, it is reported that polypropylene underwear gives a higher degree of skin and clothing dampness sensation [7]. It has also been reported that fabric made of 56% polyamide, 39% polypropylene, and 5% elastane gives the best performance in terms of wet comfort index (WCI) [8]. Another study revealed that fabric made of 98% modal and 2% elastane, and another made of 47% cotton, 47% modal and 6% elastane give better performance. Because of the balance of the content between modal and elastane, softness and stiffness can be retained with additional breathability, moisture absorption and extensibility characteristics [9]. Prakash et al. reported that fabric made of Bamboo possesses high AP with relative water vapour permeability (Wvp) of 40–50% and absorbs more water compared to cotton and polyester [10]. Likewise, in a study of sweat accumulation by the underwear fabric, it is reported that wool has slightly more sweat accumulation than polypropylene because of its non-absorbent and high-wicking properties [11]. Recently, Phase Changing Materials (PCM) that can liberate

latent heat from transformation between liquid-solid, has been utilized in underwear for improving thermo-regulating effects to the underwear. It is revealed that because cotton has large porosity, therefore PCM can be integrated through encapsulation to increase latent heat-storing capacity. Furthermore, shape-stabilized PCM can prevent polyester from reaching above the melting point and act as a supporting material to give a cooling effect [12]. The relationship between fabric structures and MMT properties has also been investigated. It is reported that the fabric structure and stitch density (SD) influence the fabric's physical characteristics like thickness and porosity, which ultimately influence the fabric comfort or MMT properties [13]. It is also found that the interlock knitting of fabric at a lower gauge and higher stitch length (SL) results in a loose structure with larger air gaps as compared to the tighter fabric structure [14]. Oğlakcioğlu and Marmarali reported that single jersey fabrics have higher Wvp [15]. In another study, single pique and honeycomb fabrics made of silk yarns have been investigated. Another study reported that the OMMC capacity of the fabric is 'very good' to 'excellent'. They concluded that the vertical wicking ability of single pique silk fabrics is influenced by tuck stitches and slick structures to increase moisture absorption rates [16]. It has also been reported that double face polypropylene-cotton blended knitted fabric has better MMT because the hydrophobic polypropylene in the base layer creates a capillary effect to transfer sweat to the hydrophilic, absorbent cotton surface layer. Therefore, moisture is wicked by the base layer followed by absorbency and quick drying by the surface layer [17]. It is concluded that warp-knit Raschel fabric has better AP, MMT, and low thermal and water vapour resistance. It is reported that fabrics with a fleecy structure have a higher initial water absorption rate and one-way transport capacity [18].

The studies mentioned, provided an understanding of the physio-thermal and MMT properties of materials including bamboo, cotton, polyester, modal, and polypropylene with spandex. However, very few studies focused on the relationship between material combination, structure, and physical and mechanical properties of the fabric. The structural properties of fabric including SD, SL, areal density (AD), thickness, fabric structure, and fibre combination are parameters that affect the MMT properties of underwear fabric and their comfort characteristics in real-life applications. Therefore, this study aims to investigate and compare MMT, and mechanical properties of underwear fabric having different structural parameters and fibre combinations. Underwear fabrics made of cotton, polyester cotton blend, nylon, viscose, bamboo, and modal are tested to obtain their real characteristics including tensile properties, MMT properties, breathability, absorbency, and wicking. This study, it is aimed to find a certain structure, fibre or combination of fibres that gives better performance in terms of MMT and mechanical properties. These findings will also help to explore further the factors that will affect the performance of underwear.

MATERIAL AND METHOD

Fabric compositions, types, structures, physical properties, water vapour permeability (Wvp) and air permeability (AP) of underwear fabrics used in this study are given in table 1. Fabric structure and physical properties were evaluated in standard atmospheric conditions (65±5 % RH and 20±5 °C). The areal densities (AD) of fabrics were calculated according to ASTM D3776. The thicknesses of the fabrics were measured according to ASTM D1777 using a digital fabric thickness tester by AMES. Course/cm (CPc) and wale/cm (WPc) were measured according to standards ASTM D8007. The yarn linear density was measured according to the standard ASTM D1059. SD of the fabrics was calculated as the product of CPc and WPc. The SL is measured according to the standard EN 14970. The structure of each fabric is photographed by Leica Microsystems GmbH. The AP of fabrics was measured according to the standard ASTMD737 at a pressure drop of 100 Pa using an SDL Atlas AP tester. The Wvp was tested according to standard BS 7209. The MMT properties of fabrics were evaluated by using the SDL Atlas MMT tester, according to the standard AATCC 195-2009. The stretch-recovery and growth properties of fabrics in both course direction (CD) and wale direction (WD) were measured on an electronically controlled INSTRON tensile testing machine according to standard ASTMD 6614. Three replicates of each fabric were tested, and the results were averaged. In addition, to study the association between all indicators obtained from the MMT test, correlation analysis was performed using Minitab® [19] and correlation coefficients were calculated [20]. Moreover, the *p* value less than 0.05 shows a significant correlation.

RESULTS AND DISCUSSIONS

Physical properties and breathability of underwear fabrics

Table 1 just shows the physical properties of studied underwear fabrics. It can be seen that fabrics K1A K1B and K3 with higher thickness or SD have lower AP. This is because higher thickness or SD resulted in compact fabric structure, higher fibre content and decreased fabric porosity. On the other hand, fabric K2 and K4 has higher AP because they have lower thickness even with higher SD. It was also reported that the AP of bi-stretch woven fabric decreases by using a higher elastane yarn ratio [21].

However, this might not apply to all kinds of knitted fabrics. It can also be seen from table 1 that fabrics K4, K5 and fabric K6 have higher elastane ratios. In the case of fabric K5, a higher elastane ratio along with higher SD and smaller SL make the fabric structure more compact which resulted in lower AP. However, in the case of fabrics K4 and K6, a higher elastane ratio did not decrease the AP. In the case of fabric K4 the least thickness and use of ultra-thin

Table 1

PHYSICAL PROPERTIES, COMPOSITION, WVP AND AP OF UNDERWEAR FABRICS AND STANDARD TEST METHODS USED

Fabric	Yarn (Tex)	Course/cm (CPC) & Wales/cm (WPC)	Stitch density (SD) /cm^2	Stitch length (mm)	Fabric areal density (g/m^2)	Fabric thickness (mm)	Fabric structure/ Composition	Water vapour permeability (g/m^2/24h)	Air permeability (ml/s/cm^2) at 100Pa
K1A	28	29±01.00 18±02.00	522±69.00	1.4±0.2	203±2.00	00.90±0.02	SJ 97%C:3%S	625.00±4.00	33.00±3.50
K1B	29	25±01.00 16±00.00	400±07.00	1.6±0.1	173±10.50	00.78±0.02	SJ 97%C:3%S	632.00±2.18	54.50±3.50
K2	24.5	28±00.00 20±00.00	560±00.00	1.4±0.1	206±02.00	00.33±0.02	SJ 94%V:4%S	654.00±8.00	54.00±4 .00
K3	24.5	29±01.00 21±01.00	609±29.00	1.3±0.2	194±01.50	00.54±0.02	SJ 95%M:3%S	657.00±2.00	57.00±4.50
K4	16.5	30±02.00 20±00.00	600±33.00	1.1±0.2	104±00.50	00.31±0.01	SJ 89%P:11%S	660.00±0.50	77.00±3.60
K5	16.5	44±02.00 25±01.00	1100±77.00	1.00±0.2	192±02.00	00.40±0.03	I 89%N:11%S	636.00±1.50	34.00±2.90
K6	16.5	36±02.00 21±01.00	756±64.00	0.92± 0.6	178±01.00	00.60±0.02	WK 88%P:12%S	714.00±5.50	72.00±3.50

Note: * Fabric structure/Composition: SJ = Single Jersey, I = Interlock, WK = Warp Knitted, W = Woven, C = Cotton, V = Viscose, M = Modal, N = Nylon, P = Polyester, S = Spandex.

yarn (AIRism) [22], resulted in higher AP. Therefore, thickness, SD, or both and elastane ratio are not the only parameters which influence AP. For example, in the case of fabric K6, both SD and thickness are higher, but this fabric has a higher AP. The reason for this is its porous structure with many capillaries. Therefore, more air can pass through this fabric resulting in higher AP.

Figure 1 presents the results of AP and Wvp or breathability of fabrics. Fabric K4 and K6 have higher Wvp and those fabrics with lower AP like fabrics K1A, K1B, K2, K3 and K5 have lower Wvp. Moreover, the most breathable fabric is K6. Because of the open structure of this fabric and higher AP, more water is evaporated through this fabric resulting in higher Wvp.

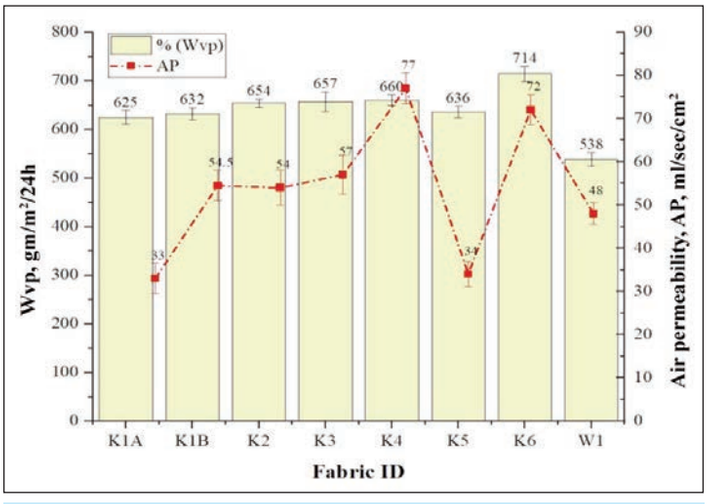

Fig. 1. Comparison of air permeability (AP) and breathability (Wvp) of underwear fabrics

MMT properties of underwear fabrics

The results of MMT indices obtained by the moisture management test are given in table 2. The wetting time at the top (WTt) and bottom surface (WTb) demonstrates the phenomenon during the initial contact with water. Generally, WTt is shorter. However, it can be seen that fabrics K1B, K2 and K4 have shorter WTb. This is because the thickness (as listed in table 1) of these fabrics is smaller. Therefore, the water passed through the fabric layer in a shorter time to the sensors at the bottom. Conversely, fabrics K1A, K1B, K3 and K5 have higher thickness and more fibre mass is required to be wetted resulting in higher wetting time. Additionally, fabrics K4 and K6 have shorter wetting times, because of their structure. Both of these fabrics have more capillaries as compared to other fabrics which is why water can pass through these fabrics more quickly resulting in shorter wetting time. Likewise, comparing the results of water absorption rate at the top (ARt) and bottom surface (Arb), it can be seen that fabric K6 has higher water absorption rates because the structure of fabric K6 is open and porous and has many capillaries like pores therefore, this fabric absorbed more water in less time. Furthermore, comparing the results of maximum wetted radius at the top (MWRt), at the bottom (MWRb), water spreading speed at the top (SSt) and bottom surfaces (SSb), the indices show how quickly fabric can spread moisture to a larger area.

It can be seen from table 2 that fabrics K1B, K2, K4 and K5 have larger MWRt. All fabrics have similar MWRb (10 mm) except fabric

Table 2

INDICES OF MMT PROPERTIES OF UNDERWEAR FABRICS

MMT indices	Wetting time (s) Mean±SD		Absorption rate (%) Mean±SD		Max. Wetted Radius (mm) Mean±SD		Spreading speed (mm/s) Mean±SD		AOTI (R%) Mean±SD	OMMC Mean±SD
	WTt	WTt	ARt	ARb	MWRt	MWRb	SSt	SSb		
K1A	13.05±2.76	57.55±3.82	75.31±46.24	3.58±0.42	5.00±0.00	10.00±0.00	0.40±0.09	0.31±0.09	1304±67.96	0.50±0.01
K1B	12.14±9.05	5.87±1.56	35.29±19.54	49.04±39.68	13.33±6.24	10.00±0.00	1.73±1.40	2.23±1.11	1452±78.00	0.72±0.02
K2	6.4±0.2	5.8±1.2	35.49±1.42	8.3±4.52	15.00±0.00	10.00±0.00	2.43±0.09	2.61±0.08	1306±27.30	0.64±0.03
K3	12.06±2.95	25.94±6.9	69.71±32.63	37.02±26.00	7.50±2.50	10.00±0.00	0.63±0.13	1.37±0.85	1594±103.00	0.61±0.05
K4	3.40±0.23	2.64±0.52	46.89±15.47	12.32±8.16	27.5±2.5	12.5±2.50	6.61±1.02	3.6±0.08	1780±157.00	0.73±0.02
K5	11.92±3.55	26.07±9.6	59.07±13.48	5.07±0.63	15.00±0.00	10.00±0.00	0.503±0.08	0.702±0.26	1733±132.00	0.50±0.02
K6	6.62±1.26	9.94±1.05	168.79±10.57	18.00±1.41	5.00±0.00	10.00±0.00	0.79±0.17	2.96±0.69	2156±47.95	0.64±0.01

K4. This is because the MMT tester cannot accurately show MWRb. This problem has also been reported previously [23]. A larger wetted radius means that the fabric is a quick dry fabric with a higher drying rate. It can also be seen that fabric K4 has the largest value of MWRt and SSt. This is because of smaller fabric thickness, smaller AD, and the use of ultra-thin polyester fibres (AIRism) [22]. This fabric has higher permeability and prevents the build-up of moisture, making it more breathable and water can spread quickly to a larger area. On the other hand, fabrics K1A, K1B and K3 have higher thickness and fibre mass per unit area and more water can be absorbed in a smaller area resulting in smaller MWRt. Likewise, because of their open and more breathable structure as explained earlier (higher Wvp), fabric K4 and K6 showed higher accumulated one-way transport index (AOTI) values. Considering the results of OMMC of fabrics, it can be seen that most of the fabrics have very good OMMC except fabrics K1A and K5. It can also be seen that OMMC is inversely related to wetting time while directly related to the maximum wetted radius and spreading speed. From the above discussion, it is also evident that AOTI and OMMC have no relationship with other indices within tested samples.

The correlation coefficient between indexes of the MMT test and physical properties is given in table 3. AOTI has a strong positive correlation with Wvp confirming that fabrics with higher Wvp have good moisture transport ability. This is also evident from the results of AOTI (table 2) and Wvp (table 1).

Besides, AOTI and Wvp have a strong negative correlation with SL. Because a fabric with longer SL has a loose fabric structure with a larger exposed surface area of yarn and moisture takes longer to be

Table 3

CORRELATION COEFFICIENT BETWEEN INDEXES OF MMT, STRETCH AND PHYSICAL PROPERTIES

Indices		N	Correlation	P-value	Indices		N	Correlation	P-value
Wvp	AOTI	7	0.875	0.004**	WTb	SSb	7	–0.705	0.051**
SL	AOTI	7	–0.921	0.003**	AP	SSb	7	0.913	0.002**
SSt	OMMC	7	0.702	0.050**	MWRb	MWRt	7	0.820	0.013**
SSb	OMMC	7	0.893	0.003**	ARt	MWRt	7	–0.640	0.044*
AP	OMMC	7	0.824	0.012**	WTt	MWRb	7	–0.677	0.032*
SSb	SSt	7	0.746	0.034**	WTb	WTt	7	0.820	0.013**
MWRt	SSt	7	0.894	0.003**	AP	WTt	7	–0.779	0.023**
MWRb	SSt	7	0.942	0.000**	T	WTt	7	0.638	0.045*
WTt	SSt	7	–0.754	0.031**	AP	WTb	7	–0.677	0.033*
AP	SSt	7	0.651	0.040*	T	WTb	7	0.820	0.013**
WTt	SSb	7	–0.818	0.013**	SL	Wvp	7	–0.672	0.034*
Indices		**N**	**Correlation (CD)**		**P-value**		**Correlation (WD)**		**P-value**
Stretch%	SL	7	0.823		0.011*		0.515		0.119
Recovery%	AD	7	0.247		0.297		**0.891**		**0.004***
Recovery%	Growth%	7	**–0.910**		0.002*		**–0.766**		**0.022***
SD	SL	7	**–0.816, 0.013***						

Note: ** Correlation is significant at 0.05 level (2-tailed), * Correlation is significant at 0.05 level (1-tailed).

transported resulting in smaller Wvp and AOTI. Likewise, OMMC has a strong positive correlation with SSb, SSt and AP. In addition, AP also has a strong positive correlation with SSt and SSb and a negative correlation with WTt and WTb. This shows that a fabric with higher AP has a faster spreading speed and at the same time can be wetted quickly. Because of higher AP, water spreads quickly on top, leading to quick transport of water to the bottom surface, resulting in shorter wetting time and higher OMMC. Moreover, SSt also showed a significant positive correlation with SSb, MWRt and MWRb. The correlation with MWRb was found to be very strong. The correlation analysis also showed that MWRt and MWRb have a positive correlation. MWRt has a negative correlation with ARt while MWRb has a negative correlation with WTt. These correlations indicate that a fabric with smaller ARt, faster SSt and shorter WTt has faster SSb, and larger MWRt and MWRb. This is also evident from MMT test results (table 2). Fabric K4 has the highest SSt, SSb and correspondingly larger MWRt and MWRb. On the other hand, SSt has a significant negative correlation with WTt, while SSb has a significant negative correlation with WTt and WTb. Furthermore, thickness (T) has a positive correlation with WTt and WTb. These correlations indicate that a fabric with a smaller thickness has shorter WTt, and WTb has a larger SSb. This is also evident from MMT test results (table 2). Fabric K4 has the least thickness, smallest WTt and WTb and fastest SSt and SSb. Additionally, WTt and WTb have a strong positive correlation with each other indicating that a fabric that can be wetted faster on the top surface can also be wetted quickly on the bottom surface.

Stretch properties of underwear fabrics

To identify physical parameters that influence the stretch and recovery properties of underwear fabrics, Pearson's correlation analysis was performed and the parameters with strong and significant correlation with stretch properties in CD and WD were plotted for comparison as shown in table 3 and figures 2 and 3. It is evident from the results that the direction with elastane induction (CD in case of weft knitted fabrics and WD in case of warp knitted fabric) has higher stretch. Stretch % has a significant positive correlation with Stich Length (SL) in CD indicating that a fabric with longer SL has higher stretch. This is also supported by the results in figure 2, Fabric K1A and K1B with longer SL showed the highest stretch% in CD. This is because SL is the length of yarn along CD and longer SL makes the fabric structure looser and easier to stretch. Furthermore, SL and SD have a significant negative correlation with each other confirming that a fabric with a smaller SL has a higher SD. This is because smaller SL makes fabric structure compact and tight resulting in increased SD and difficulty to stretch. In addition, it is evident from figures 2 and 3 that the fabrics with smaller SD and longer SL have higher stretch% and lower recovery%. Additionally, the recovery % is even higher in WD for these fabrics. One possible reason for this might be the fact that yarns run in CD in weft-knitted fabrics, therefore stretching in this direction stretches the yarns in their longitudinal direction that is parallel to the yarn axis and upon higher stretching there is a permanent deformation set in within the yarn structure because of fibre-to-fibre displacement as well as due to the extension of polymer chains in elastane filament. Therefore, the fabric cannot recover fully from stretch resulting in increased growth and smaller recovery. However, in WD there is no elastane filament, and elasticity comes from the interlooping of yarns in the fabric structure. Hence, upon stretching not only the stretch% is smaller but also the yarns are not stretched along their axis resulting in higher recovery% as shown in figure 3.

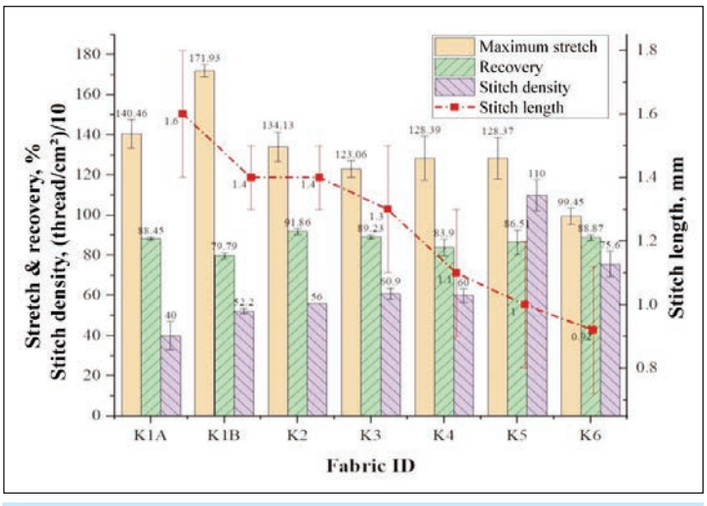

Fig. 2. Comparison of stretch and physical properties of different fabrics in course direction

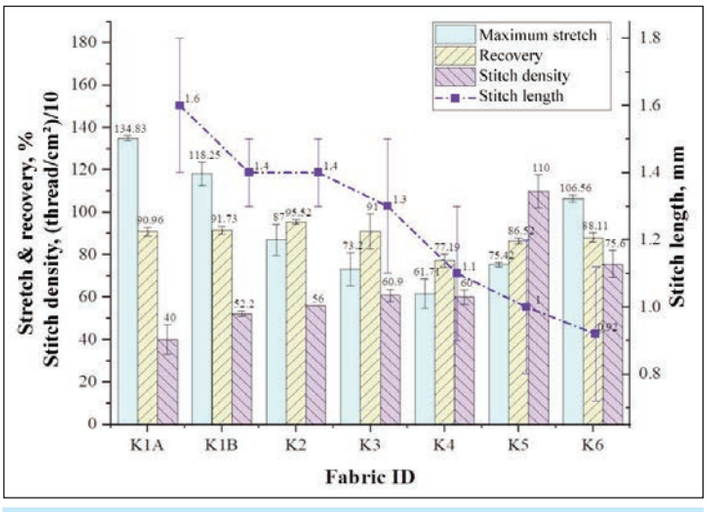

Fig. 3. Comparison of stretch and physical properties of different fabrics in the wale direction

Furthermore, the recovery% is also influenced by SD. Because of higher SD, the fabric becomes tight and difficult to deform resulting in lower stretch% and higher recovery%. The warp knitted fabric K6 also showed higher stretch% along the direction with elastane filament that is WD. Because of higher SD and tight warp knitted structure, this fabric has similar recovery% in both directions.

Additionally, the recovery% in WD has a strong positive correlation with AD. This is because fabric with higher AD has longer SL and upon stretching in WD, the yarns are stretched in a direction that is at 90° to their axis because of longer SL, the loops do just slide over each other and the yarns are not stretched up to the point of permanent deformation build up. This resulted in a higher recovery % in this direction. This is also evident from figure 2, Fabrics K1A, K1B, K2 and K3 have higher AD and showed higher recovery% in WD.

CONCLUSIONS

In this study physical, moisture management and stretch properties of underwear fabrics made of cotton, polyester cotton blend, nylon, viscose, bamboo, and modal are tested and characterized. Following conclusions can be drawn from this study.

- A fabric made of finer filament yarn, having a smaller thickness and higher AP has shorter WTt, WTb, faster SSt, SSb, larger MWR and better OMMC.
- A fabric with a smaller thickness shorter WTt and WTb has higher SSb.
- A fabric with higher WVp and smaller SL has higher AOTI.
- A fabric with Smaller ARt, faster SSt and shorter WTt has faster SSb and larger MWR.
- A fabric with shorter WTt also has shorter WTb.
- Stretch is higher in the direction of elastane filament induction while recovery is higher in WD in the case of weft-knitted fabrics but in the case of warp-knitted fabrics recovery is the same in both directions.
- A fabric with longer SL has higher stretch% in both directions and more recovery % in WD.
- A fabric made of finer filament yarn with a more porous and tighter structure, smaller thickness and AD, higher SD, and smaller SL has better OMMC and recovery%.
- A fabric with longer SL has better stretch%.

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Relevance of trust and satisfaction as mediators to behavioural intention of consumers towards online apparel shopping

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ABSTRACT – REZUMAT

Relevance of trust and satisfaction as mediators to behavioural intention of consumers towards online apparel shopping

The Internet is an integral part of every individual and is a means of business transaction, leading to the immense growth of e-commerce in all sectors. This research study evaluates the significance of attitude as a mediating variable between behavioural intention and overall satisfaction in apparel shopping using Partial Least Square – Structural Equation Modelling with a bootstrapping approach for evaluating the hypothesis. A total of 227 consumers were surveyed using a structured questionnaire and convenient sampling method with a cross-sectional method for collecting data. The hypothesis states that there is a significant relationship between overall satisfaction effect & attitude, reputation & trust, attitude & behavioural intention and trust & behavioural intention. Evidence of the partial mediation effect of attitude between overall satisfaction and behavioural intention is also identified. The findings indicate that the model is valid and has a good fit. Therefore, improved customer service and delivery service will help the corporate to uplift the endogenous latent variable of Behavioural Intention.

***Keywords**: e-commerce, online shopping attitude, behavioural intention, overall satisfaction, consumers, apparel, textile industry, artificial intelligence*

Relevanța încrederii și a satisfacției ca mediatori asupra intenției comportamentale a consumatorilor față de achiziția online de îmbrăcăminte

Internetul reprezintă o parte integrantă a fiecărui individ și este un mijloc de tranzacție comercială, ceea ce conduce la creșterea semnificativă a comerțului electronic în toate sectoarele de activitate. Acest studiu de cercetare evaluează semnificația atitudinii ca variabilă de mediere între intenția comportamentală și satisfacția generală în cumpărăturile de îmbrăcăminte folosind metodologia Partial Least Square – Structural Equation Modelling cu o abordare bootstrapping pentru evaluarea ipotezei. Un total de 227 de consumatori au fost chestionați folosind un chestionar structurat și o metodă convenabilă de eșantionare bazată pe o metodă de tipul cross-sectional pentru colectarea datelor. Ipoteza presupune că există o relație semnificativă între efectul de satisfacție generală și atitudine, reputație și încredere, atitudine și intenție comportamentală, precum și încredere și intenție comportamentală. De asemenea, sunt identificate dovezi empirice ale efectului de mediere parțială a atitudinii între satisfacția generală și intenția comportamentală. Constatările indică faptul că modelul este valid și se potrivește bine. Prin urmare, serviciul îmbunătățit pentru clienți și serviciul de livrare vor ajuta compania să ajusteze ascendent variabila latentă endogenă a intenției comportamentale.

***Cuvinte cheie:** comerț electronic, atitudinea privind cumpărăturile online, intenție comportamentală, satisfacție generală, consumatori, îmbrăcăminte, industria textilă, inteligență artificială*

INTRODUCTION

Extensive growth in e-commerce and the adoption of new technologies like quick response code, Blockchain, artificial intelligence, and reverse logistics help the consumer to be well-informed and are most likely to be more of a B2C business. The imperative factor to the business is to have a wide range of products in addition to factors like competitive prices and services. The apparel industry has gained huge popularity among other industries and e-commerce makes the consumer's life easier by providing them with the liberty to choose the time and place to shop and saves their time. The retail industry in India has grown considerably due to the surge in internet facilities which in turn had encouraged digital payment technologies. The requirement of e-commerce retailers in the logistics sector is getting reformed by the increase in demand which is expected to unceasingly adapt to the changes, trends, and developments. E-commerce is a transition influencer for both marketers and customers where it enhances the existing business practices [1] with the aid of the internet. The steady growth of e-commerce has taken the business up to the next level and has endorsed customers to decide on and research, the product, and the seller,

and indicate the probable delivery time of the product. It also provides an information-based business process wherein the customer can interact directly with the vendor for online advertisement, marketing, and customer services giving their specification for the product in case of customization. Technological advancement is an important driving force in logistics and e-commerce and has transformed and improved the way of living. One of the foremost apprehensions of logistics is the fulfilment of the end-user requirements that is the customer. The supply chain lets business build their online presence enabling them to reach a global market by collaborating with a wide arena of allied services like transportation, warehouse management, and marketing around the globe. This transformation has enabled positive growth and consumers have accepted e-commerce stores which are expected to gain prominence due to the ease and flexibility it provides.

Apparel shopping is gaining popularity on social media platforms like Facebook and Instagram which is helping a lot of new entrepreneurs. Anthropologists have dated the prominence of wearing back to 70,000–100,000 years according to an article (published by thoughtco.com) primarily to protect their bodies from harsh weather and unpredictable climate. Before the industrial revolution, most of the garments and textiles were limited to home production and predominantly from the cottage industry. Post-industrial revolution, materials of different fabrics were mass-produced and the development of the apparel industry thus began. Import and export of clothing spread globally, and it became a huge success. Apparel reached the status symbol of fashion, class, and culture. Clothing trends and fashion changed in the twentieth century allowing various brands to open up and occupy the market. According to the statistics provided by bigcommerce.com, 59% of US shoppers purchased clothing online, between 2018–2019. Online apparel shopping has gained tremendous popularity as compared to other products which are sold online. Numerous sites are offering a wide range of international brand clothing which was difficult to access before. With huge discounts and with a wide range of options to choose from, online shopping for apparel has come a long way. New marketing strategies and improved technologies have given customers a whole new shopping experience.

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Online shoppers are sensitive to net factors that offer pricing information [2] and notably, the degree of sensitivity varies depending on price and product categories. The success of E-Bay and Amazon depends on the extensive advertisement of competitive lower price for products which is potentially sold at a higher price by local businesses. This demonstrates the importance of pricing as consumers like to shop around for the best deal [3]. The Internet allows consumers to explore alternates and comparison matrices with in-depth evaluation [4] facilitating a quick price, quality, and technological comparison [5]. The constructs pertaining to the research are presented below in the form of a conceptual framework (figure 1).

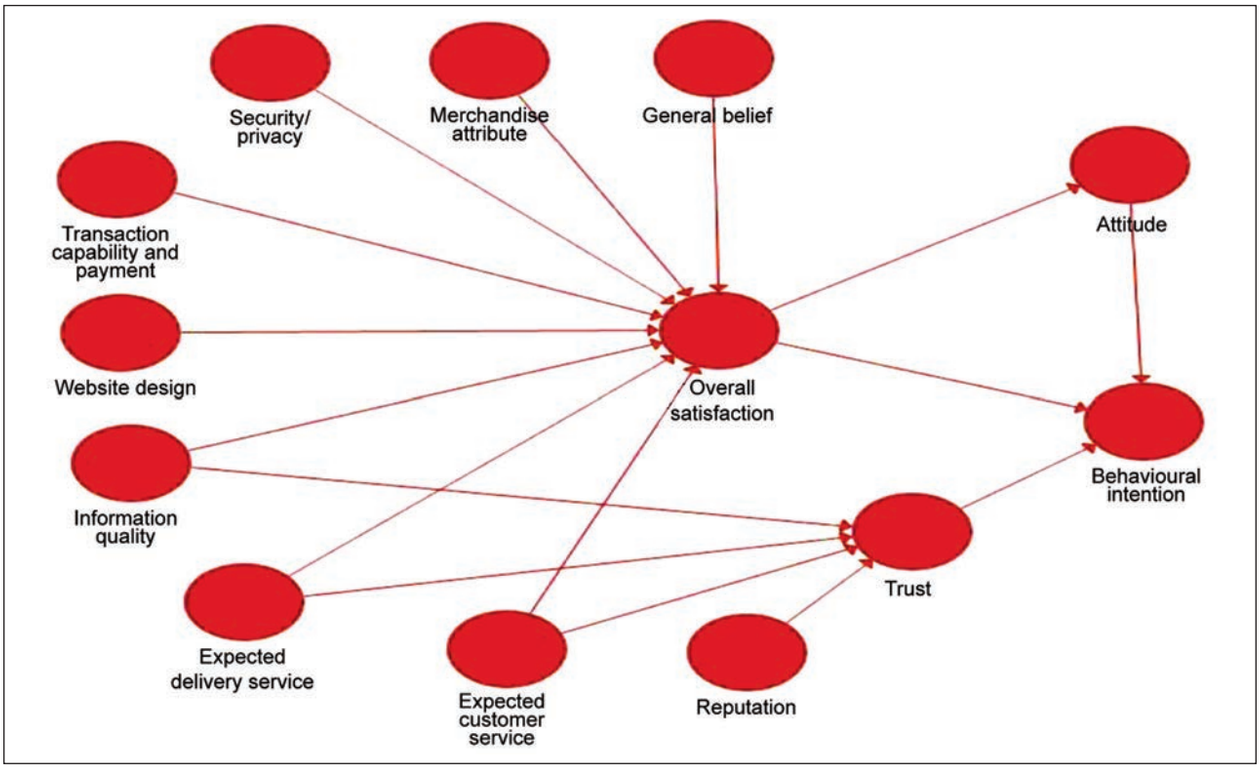

Fig. 1. Association of attitude, overall satisfaction and behavioural intention in apparel shopping

General belief

Belief is an attitude associated with a consumer's favourable or unfavourable assessment of an object [6]. A person, an institution, a group of individuals or an event can be the object of belief, and the associated attribute can be any object, quality, property, characteristic, or event. It is the perception of a given component that is related to their self-awareness and situation which influences attitude, intention, and behaviour [7]. Perceived efficacy and simplicity are two perceptions that influence the likelihood of online purchases. Individuals' subjective evaluations of a given e-store or online shopping experience are well-defined as beliefs about an e-store or online shopping experience [8, 9].

Merchandise attribute

The generally held belief is that a consumer's estimate of product utility is based on a set of benefits purchased by each product attribute [10, 11] as a product is a collection of components and characteristics. Customers' shopping preferences are based on nine labels: appearance/fashion-conscious, brand-conscious, convenience and time-conscious, local store-oriented, shopping mall-oriented, impartial, and credit-oriented, and economy/price-conscious [12, 13]. Further, consumers most frequently utilise cost and brand in evaluating clothes [14].

Security and privacy

Security and privacy concerns such as data theft, hacking, and malware have made security and privacy a major problem for electronic commerce. Privacy is considered a commercial commodity, while it is a fundamental right. Potential hazards, such as targeted attacks, network vulnerability, unintended content modification, unnecessary infrastructure and maintenance costs, and productivity loss [15, 16].

The e-commerce websites can easily provide vast amounts of personal data such as customer preferences, search patterns, shopping patterns and other data in real-time through data mining. This might be used to provide a better quality of services but it can also be used to send unwanted e-mails, selling customer's information to others, that the customers would not like to share [17].

Transaction capability and payment

India's use of smartphones and the internet has surged and payments via cell phones have become the most popular method of payment [18] due to the impacts of social [19] and cultural factors. Government initiatives such as Digital India are having a positive impact on the expansion of digital payments. India is on the verge of a tremendous digital transformation and m-Payment could be the best option for cashless transactions because of its high wireless density [20]. Cashless transactions will drive the future economy, which will be feasible only through the digitization of payment.

Website design

A good website design is linked to increased e-commerce response [21]. Consumers identify websites not only as a source of information but also as a virtual store that facilitates the complete purchasing experience [22]. The website has to be attractive and vivid in terms of descriptive images and graphics to give a real shopping experience to consumers, save time and provide convenience to the consumers thus gaining customer satisfaction comfort and trust [23]. Further, extensive use of business intelligence enables businesses to recognise the behaviour of the customer and predict their purchase pattern for business improvement and environmental sustainability [24].

Information quality

Information quality is significant to online sales as inaccurate information leads to a loss of brand equity [25]. Consumers focus more on product information for merchandising features and tend to concentrate on information quality rather than other attributes [26, 27]. Reliable information leads to a positive impact on customer satisfaction with the online retail experience and results in purchases [28]. Superfluous information about the product may not impact purchase decisions but will burden the consumer. Shoppers use the brand name as the source of information for evaluating the product, which reduces the perceived risk and helps in purchase decisions [29].

Expected Service Delivery (ESD)&Expected Customer Service (ECS)

In our research, ESD and ECS differ from SD and CS in the post-purchase phase which implies that these constituents have different roles at different stages. When consumers place orders, the EDS and predicted ECS are calculated. On the other hand, SD and CS occur post the purchase stage, which is after consumers have received their products. At the ESD stage, the researcher believes that if consumers are offered a variety of SD approaches to try, they will be satisfied. Based on the choices of consumers for how the product should be delivered, the e-retailer can offer express delivery. In addition, the sum mentioned for delivery charges must be reasonable and free of any hidden fees[30]. The most important factor that satisfied consumers was fast delivery at a reasonable price with no hidden fees.

Reputation

Reputation determines if a company is "good" or "bad" [31]. Reputation is highly important especially for service companies because it contributes to performance as a valuable intangible asset [32]. The impact of identification fit may be decreased when customers perceive a negative reputation [33]. An organization's ability to sustain a strong reputation over time builds 'reputational capital' that can protect the organization from failure in times of crisis or

threat [34] and thereby administer a directional framework, and contribute to task control [35].

Trust

Trust is the most relevant factor among the young generation towards online shopping. Creating trust among the consumers is a primary benefit that connects to technical attributes towards the website's usefulness [36]. Consumers feel more confident about online purchasing when they buy from a company they trust [37]. While consumer trust may not have a direct impact on consumer behavioural intentions, it is indirectly influenced by product information searches and perceived internet confidence [38]. Trust influences consumer perception such as perceived risk and perceived ease in purchase intention [39]. Brand experience significantly affects brand trust and businesses should aim at increasing brand trust, which improves brand loyalty [40]. Trusting a customer is a high level of brand preference, which ultimately leads to converting a trusting customer into a loyal customer [41].

Overall satisfaction

Overall satisfaction builds long-term consumer relationships [42], and it is the result of experiences throughout the purchasing process; needing something, gathering information, evaluating alternatives, making a purchase decision, and post-purchase behaviour [43]. Satisfaction is achieved when the expectation of the consumer is met. Ease of website handling, convenience in ordering, variety and cost help in deciding the satisfaction level. Customer satisfaction is the result of merchandising (product factor), privacy (technology factor) and convenience (shopping factor) as the primary factors followed by trust, delivery, usability, product quality and customization [44]. Once the consumer is satisfied they will repeat the purchase if the service has been to their expectation [22].

Behavioural intention

Behavioural Intention is the customer's desire to return or repurchase the same item or items within the same brand, resulting in increased brand loyalty and, as a result, helping the business expand its market and save costs [45]. The amount of satisfaction or dissatisfaction is a direct effect of consumer experience [46]. In apparel shopping, prior experience of shopping is an important type of internal information that will increase purchase intention and condenses the perceived risk [47]. Behavioural intention helps managers point out if a consumer will remain with or hop to an alternate brand [37, 46].

Attitude

Consumer attitude towards online shopping is a prominent factor affecting actual buying behaviour. Consumers' attitude towards online shopping is a prominent factor affecting actual buying behaviour [48]. Attitude towards specific web base stores, in which perceptions of the store's reputation and size affect consumer trust in the retailer [49]. On the web, shopping enjoyment is positively and significantly related both to attitudes and intentions toward shopping on the web [50] and satisfaction significantly affected customers' attitudes and their intention to purchase. A high level of trust by buyers has been found to stimulate favourable attitudes and behaviour [51, 52].

EMPIRICAL SETTING AND TESTING PROCEDURES

Sample and data collection

This research is focused on evaluating the relevance of attitude as a mediating variable between overall satisfaction and behavioural intention in apparel shopping. The data is gathered using a questionnaire which is formed according to the constructs using a "Seven-point Likert scale" with options varying from "Strongly disagree" to "Strongly agree". The responses collected were analysed using SMART PLS 3 software. The population is a collection of totals of all the subjects, objects, or members that conform to a set of terms [53]. The study is confined to people who are involved in buying apparel online. The sampling element for the current research endeavour consists of people who are buying apparel online and sampling units consist of people who are purchasing apparel online from one year and above in the Karnataka state of India.

Scales used

The general belief construct scale is developed by Hirst and Ashwin [54], Rajamma &Neeley [55] and Swinyard and Smith [56]. Information quality questions are based on the scale propounded by Muyllea et al. [57] and Jeong et al. [58]. Web design construct is developed by using the scale suggested by section Kim and Stoel [59], Jeong et al. [58] and Muyllea et al. [57]. The merchandise attributes scale of Liu et al. [60] and Szymanski and Hise [61] are taken for this research survey. Kim and Stoel [59] and Liu et al. [60] scale used to measure Transaction capability & payment. Similarly, Security/privacy is measured by using a scale of Wolfinbarger and Gilly [62]. Furthermore, expected delivery service is measured by using the Rossiter scale. The expected customer service construct is measured by Wolfinbarger and Gilly [62]. Reputation has four questions measured by Kim and Park's [63] scale. Three more questions on Overall Satisfaction are based on Liu et al. [60] scale. All four questions of trust are measured with Kim and Park's [63] scale. Attitude is measured by using a scale propounded by Jarvenpaa et al. [49] and Chen et al. [64]. Finally, the behavioural intention constructs are measured by a scale initiated by Parasuramanet et al. [65].

Determining sampling size

The Partial Least Square-Structural Equation Modelling (PLS-SEM) has two ways of determining sampling size.

(1) The use of the rule of thumb [66], where the sample size should be the number which is highest amongst the 'structural paths' that point towards only one construct in the 'structural model', multiplied by 10. So the sample size is 3×10 = 30.
(2) The statistical power analysis [67], where, the sample size is also determined by considering the desired R^2level.

Accordingly, the number of arrows that point towards a construct, significance level, and minimum desired R^2level are considered for obtaining a statistical power of 80% while determining the sample size. The current study has three maximum arrows that point towards the dependent construct of the model of the study. The minimum desired R^2level would be 0.25 at a 5% level of significance. Considering these requirements, the sample size would be 59. The maximum number of arrows directing at a construct is 3 with a 5% level of significance, making the minimum number of samples to be 59. In this research endeavour, the total sample size is 227. The formula used to derive sample size is as follows:

$$n = \frac{Z_\alpha^2 \times pq}{E^2} = \quad (1)$$

$$= \frac{(1.96)^2 \times (0.5)(0.5)}{\frac{0.5 \times 13}{100}} = 227$$

where Z_α is 95% confidence level with its value as 1.96, p – proportion to online apparels buyer, q = 1–p, E – 10 percent of error (90% power) with 10% non-response. So the total sample size is 227.

EMPIRICAL RESULTS

Measurement model assessment

The measurement model involves path coefficient values, outer loadings, R square, construct reliability, construct validity through Average Variance Extracted (AVE), discriminant validity, collinearity and model fit (figure 2).

According to previous research [68], R^2 cut-off values of 0.25, 0.50, and 0.75 for endogenous constructs are considered as weak, moderate, and high in other investigations. All five exogenous constructs namely, General Belief (GB), Merchandise Attribute (MA), Security and Privacy (SP), Transaction Capability and Payment (TCP), Website Design (WD), Information Quality (IQ), Expected Delivery Service (EDS), Expected Customer Service (ECS) and Reputation (REP) explain 60.4% of Overall Satisfaction (OS) (R^2 = 0.604), 68.6 of Trust (TR) (R^2 = 0.686), 62.1% of Attitude (ATT) ((R^2 = 0.621), and 54.1% of Behavioural Intention (BI) (R^2 = 0.541). The SRMR criteria fit is used to assess model fitness [69]. When the SRMR value is zero, the best fit occurs. Less than 0.08 is a decent fitness threshold value [70]. The SRMR score of 0.071 in this study indicates that the

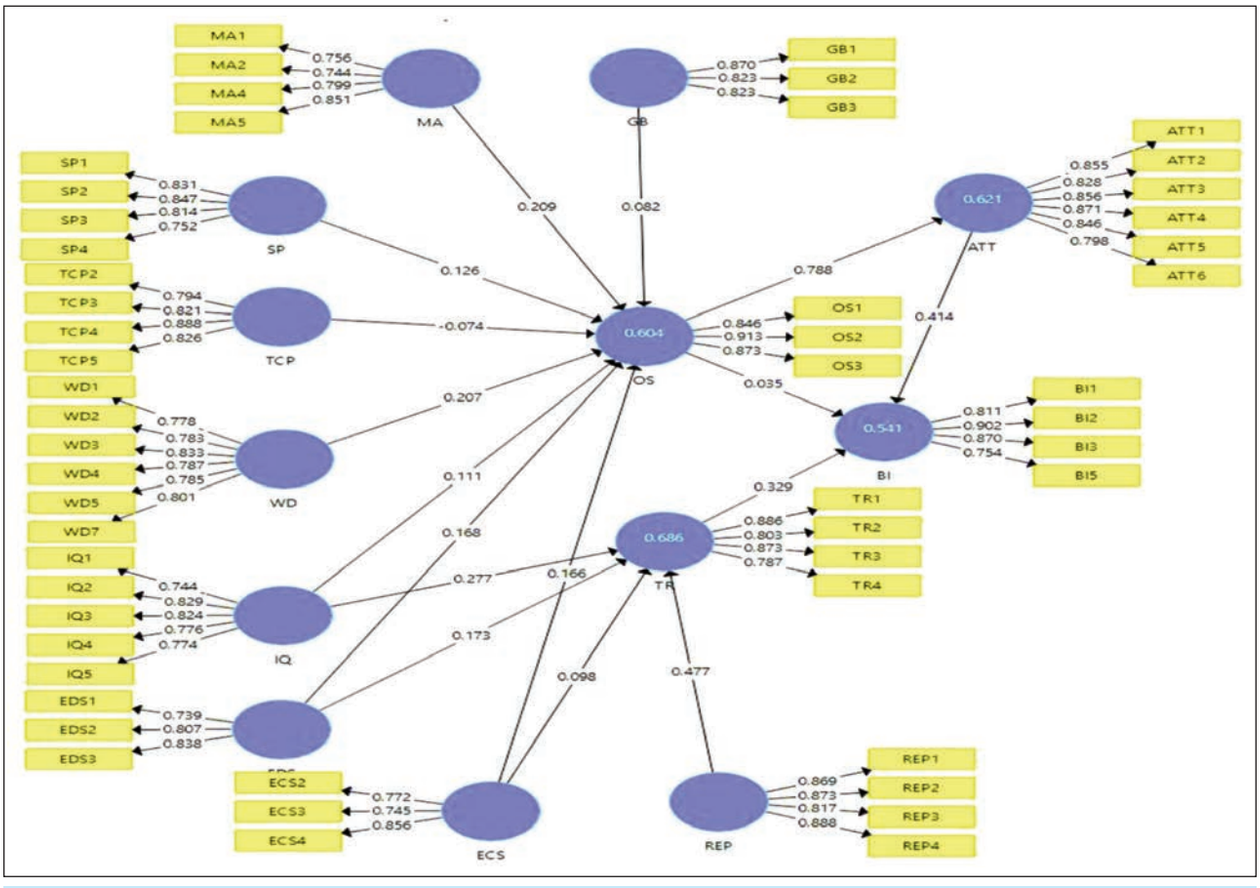

Fig. 2. Measurement model assessment

model is fit. From the reflective model, it is very clear that the value for the construct is 0.541 indicating the model is moderate in nature.

Structural model assessment

The study explored the impact of exogenous constructs Merchandise Attribute (MA), Website Design (WD), Expected Delivery Service (EDS) and Expected Customer Service (ECS) on Overall Satisfaction (OS) and our investigation indicate a significant effect the path-coefficient level (figure 2) and the empirical t value (figure 3) was also found to be more than 1.96 at 5% level of significance. Therefore hypotheses 2, hypotheses 5, hypotheses 7 and hypotheses 8 **justify the positive direct effect** on Overall Satisfaction (OS). In the case of hypotheses 1, hypotheses 3, hypotheses 4 and hypotheses 6 i.e., the direct effect of General Belief (GB), Security and Privacy (SP), Transaction Capability and Payment (TCP) and Information Quality (IQ), the path-coefficient level and the empirical t value were below the threshold value and therefore cannot be validated to have had a direct effect on Overall Satisfaction (OS). The direct effect of Information Quality (IQ), Expected Delivery Service (EDS) and Reputation (REP) on Trust (TR) was investigated and found to be significant ($p<0.05$) at the path-coefficient value (figure 2) and the empirical t value (figure 3) was more than 1.96 at 5% level of significance. Therefore, these values prove that hypotheses 9, hypotheses 10, and hypotheses 12 justify the positive direct effect on Trust (TR). But in the case of Expected Customer Service (ECS), the direct effect on Trust (TR) is not significant ($p<0.05$) at the path-coefficient value of 0.098 (figure 2) and the empirical t value is 1.443 (figure 3) which is lesser than 1.96. Therefore, these values do not verify the hypotheses 11.

The direct effect of endogenous latent variable Overall Satisfaction (OS) on Attitude (ATT) was investigated at the path-coefficient value of 0.788 (figure 2) and the empirical t value of 19.580 (figure 3) and these values verify the hypotheses 13 and justify the direct effect of Overall Satisfaction (OS) on Attitude (ATT). Further, the direct effect of Attitude (ATT) and Trust (TR) on Behavioural Intention (BI) was investigated and it was found that the path-coefficient value and the empirical t value verify hypotheses 15 and hypotheses 16 thus justifying the positive direct effect on Behavioural Intention (BI). However, hypothesis 14 does not justify and therefore it is clear that there is no positive direct effect of Overall Satisfaction (OS) on Behavioural Intention (BI).

Mediator analysis

There is no mediating impact if the Variance Average For (VAF) values are less than 0.20. If the value is between 0.2 and 0.8, we conclude that partial mediation exists. For a complete mediating effect, the

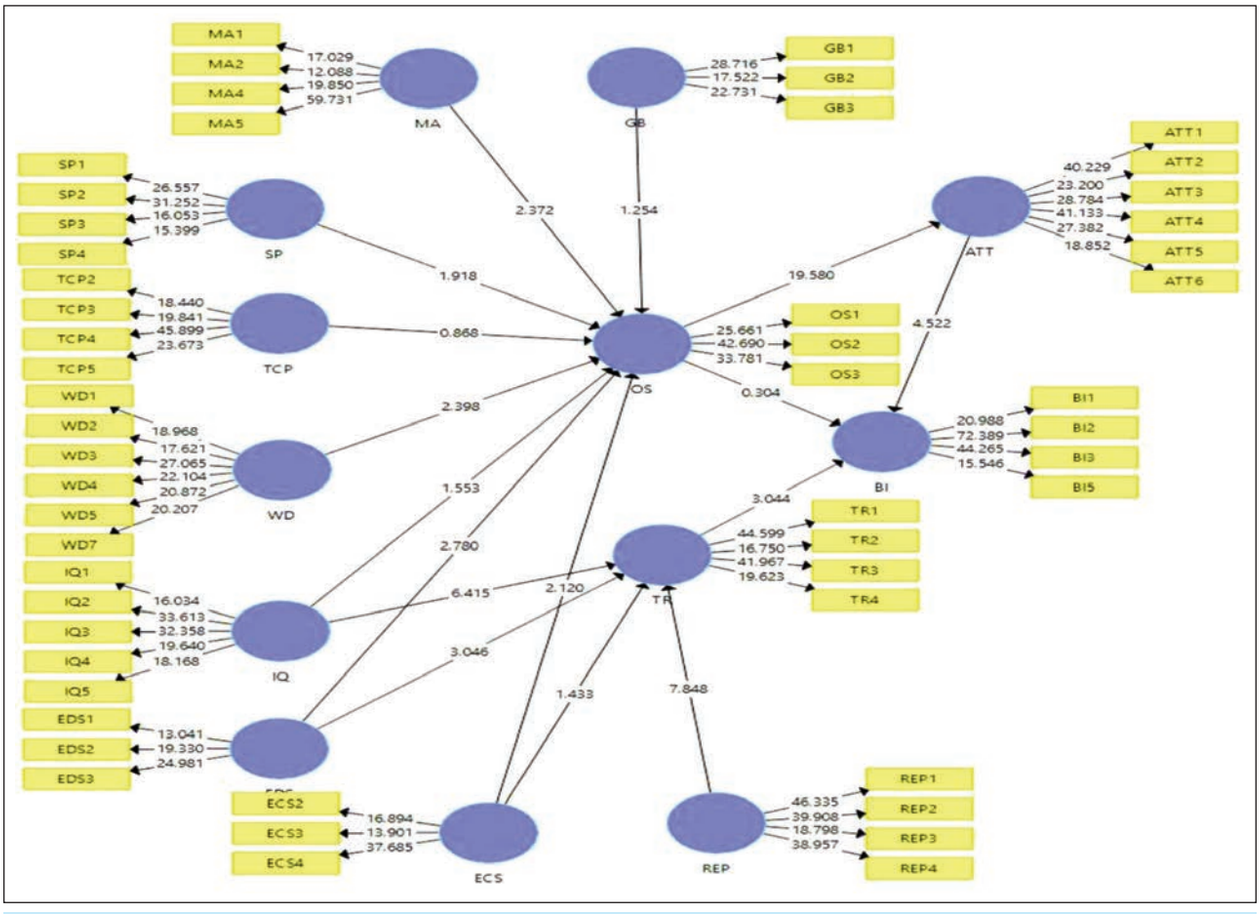

Fig. 3. Structural model assessment

value should be more than 0.8. The following formula is used to calculate the mediating effect:

$$VAF = \frac{IndirectEffect}{IndirectEffect + DirectEffect} = \quad (2)$$

$$= \frac{0.788 \times 0.557}{(0.788 \times 0.557) + 0.190} = \frac{0.4389}{0.6289} = 0.6978$$

The VAF is greater than 0.20 but less than 0.80. As a result, it's reasonable to argue that the Attitude (ATT) construct has a partly mediating influence in the relationship between Overall Satisfaction (OS) and Behavioural Intention (BI). The Bootstrap values of paths between OS and BI are 2.258, OS and ATT are 19.925 and ATT and BI are 7.876 which is above 1.96 substantiates hypothesis 17 states that attitude mediates between OS and BI (figure 4).

Construct reliability and validity

The ideal composite reliability value is equal to or greater than 0.80 [71]. The exogenous latent variables of the measurement models, in the present study, demonstrate high levels of internal consistency reliability. This is illustrated by the values of composite reliability of exogenous latent variables constructs value which are higher than 0.80 (table 1). To measure the convergent validity the average variance extracted (AVE) is a strongly recommended test [72]. Convergent validity is measured with an AVE threshold value that should be more than 0.50 [73, 74]. AVE values of all exogenous and endogenous latent variables constructs are above the threshold value of 0.50 (table 1). Therefore, there exists convergent validity in all exogenous and endogenous latent variables constructs of all measurement models.

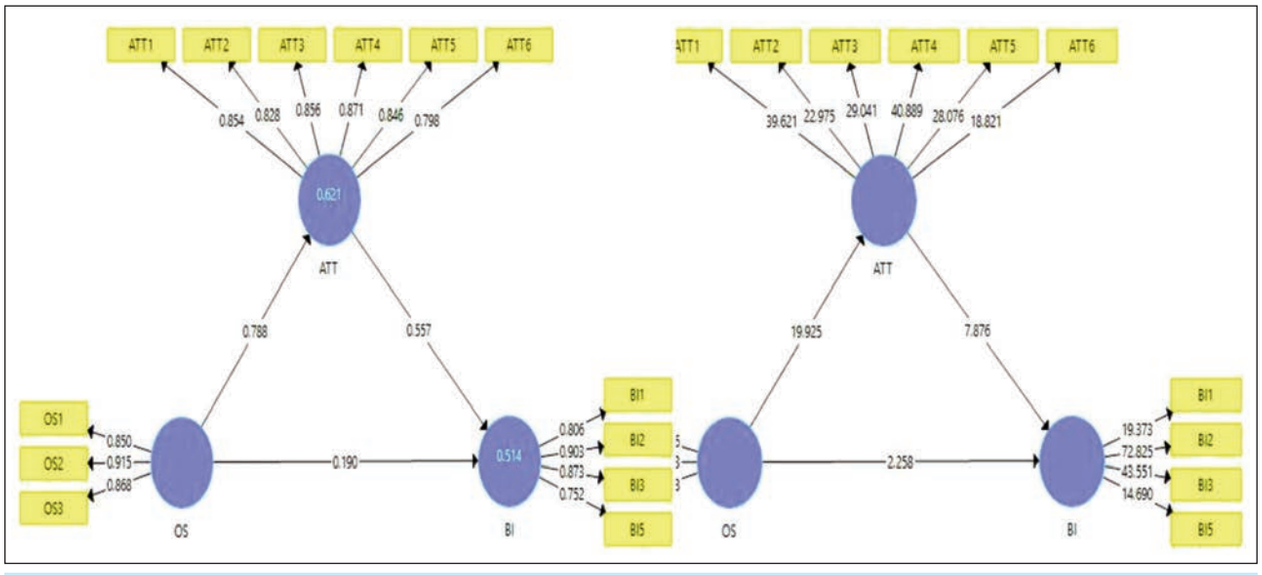

Fig. 4. Mediating effect of attitude between overall satisfaction and behavioural intention

Table 1

COMPOSITE RELIABILITY AND AVERAGE VARIANCE EXTRACTED

Variables	Cronbach's Alpha	rho_A	Composite reliability	Average Variance Extracted (AVE)
ATT	0.918	0.920	0.936	0.710
BI	0.857	0.883	0.902	0.699
ECS	0.708	0.740	0.835	0.628
EDS	0.709	0.717	0.838	0.633
GB	0.790	0.795	0.877	0.704
IQ	0.851	0.868	0.892	0.624
MA	0.803	0.856	0.868	0.622
OS	0.851	0.858	0.910	0.771
REP	0.885	0.886	0.920	0.743
SP	0.828	0.840	0.885	0.659
TCP	0.853	0.863	0.901	0.694
TR	0.858	0.862	0.904	0.703
WD	0.883	0.885	0.911	0.632

Discriminant validity

PLS is a better way to assure the degree to which a given construct of the model is distinct from other constructs for measuring the discriminant validity [73]. Discriminant validity can be assessed using the Fornell-Lacker (1981) criterion [75, 76] which is a comparison between the square root of AVE and other latent variables. Therefore, discriminant validity is a measure of the uniqueness of a given construct. Table 2 demonstrates how the square root of AVE of every latent variable exceeds its correlation with other latent variables which indicates that this model has established discriminant validity.

Importance-Performance Matrix Analysis (IPMA)

The IPMA contrasts the overall effects, which show the importance of the previous constructs in forming a given target construct (figure 5), with their average latent variable scores, which indicate their performance [77, 78].

A one-unit increase in construct General Belief from 68.804 to 69.804 will raise the performance of Behavioural Intention by 0.030 points from 72.191 to 72.221. A one-unit increase in construct Merchandise Attitude from 68.508 to 69.508 will raise the performance of Behavioural Intention by 0.076 points from 72.191 to 72.267. A one-unit increase in construct Security and Payment from 69.558 to 70.558 will increase the performance of Behavioural Intention by 0.046 points from 72.191 to 72.237. A one-unit increase in construct Transaction Capability and Payment from 74.779 to 75.779 will raise the performance of Behavioural Intention by –0.027 points from 72.191 to 72.164. A one-unit increase in construct

Table 5

DISCRIMINANT VALIDITY THROUGH FORNELL-LARCKER CRITERION

Variables	ATT	BI	ECS	EDS	GB	IQ	MA	OS	REP	SP	TCP	TR	WD
ATT	0.843												
BI	0.705	0.836											
ECS	0.589	0.581	0.793										
EDS	0.618	0.519	0.629	0.796									
GB	0.542	0.447	0.404	0.400	0.839								
IQ	0.503	0.467	0.404	0.300	0.503	0.790							
MA	0.670	0.532	0.558	0.518	0.612	0.504	0.789						
OS	0.788	0.629	0.613	0.588	0.518	0.507	0.659	0.878					
REP	0.720	0.599	0.673	0.620	0.506	0.394	0.593	0.817	0.862				
SP	0.624	0.617	0.630	0.615	0.379	0.455	0.518	0.591	0.621	0.812			
TCP	0.621	0.605	0.683	0.638	0.504	0.423	0.668	0.599	0.689	0.652	0.833		
TR	0.798	0.689	0.640	0.614	0.461	0.557	0.614	0.811	0.760	0.665	0.673	0.838	
WD	0.624	0.513	0.572	0.537	0.523	0.512	0.718	0.661	0.638	0.562	0.691	0.668	0.795

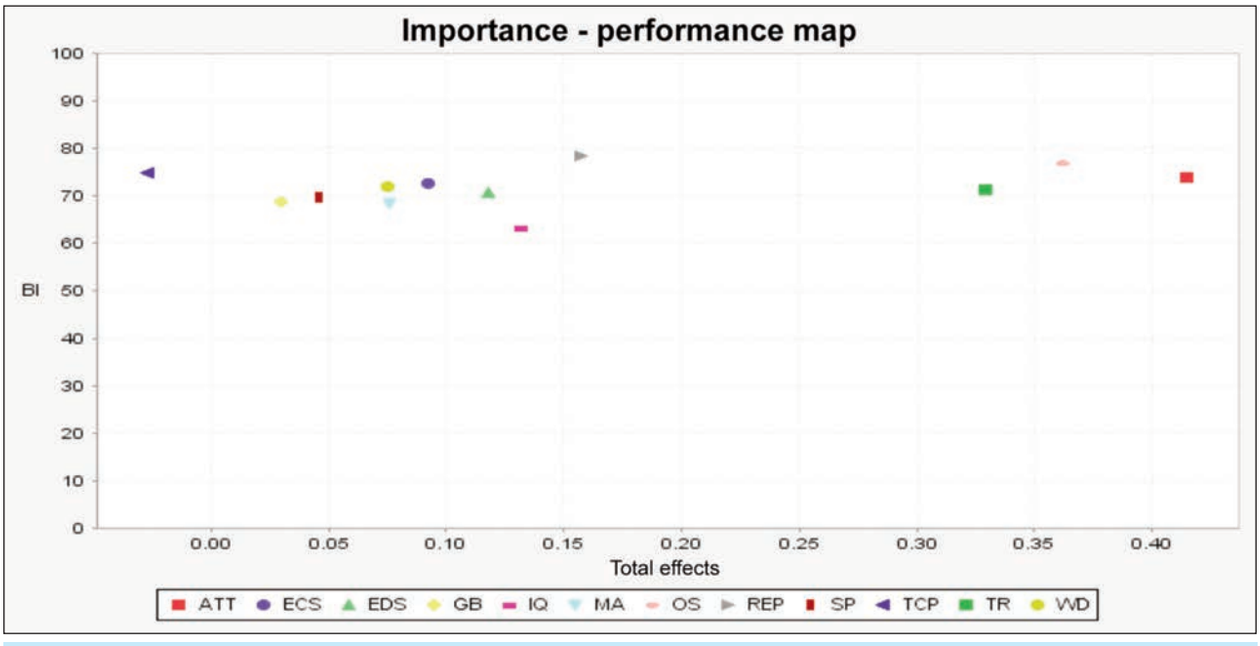

Fig. 5. Importance Performance Matrix Analysis (Chart)

Website Design from 71.954 to 72.954 will raise the performance of Behavioural Intention by 0.075 points from 72.191 to 72.266. A one-unit increase in construct Information Quality from 63.019 to 64.019 will raise the performance of Behavioural Intention by 0.131 points from 72.191 to 72.322. A one-unit increase in construct Expected Delivery Service from 70.803 to 71.803 will raise the performance of Behavioural Intention by 0.118 points from 72.191 to 72.309. A one-unit increase in construct Expected Customer Service from 72.731 to 73.731 will raise the performance of Behavioural Intention by 0.092 points from 72.191 to 72.283. A one-unit increase in construct Reputation from 78.421 to 79.421 will raise the performance of Behavioural Intention by 0.157 points from 72.191 to 72.348. A one-unit increase in construct Overall Satisfaction from 76.806 to 77.806 will raise the performance of Behavioural Intention by 0.362 points from 72.191 to 72.553. A one-unit increase in construct Attitude from 73.906 to 74.906 will raise the performance of Behavioural Intention by 0.414 points from 72.191 to 72.605. A one-unit increase in construct Trust from 71.430 to 72.430 will raise the performance of Behavioural Intention by 0.329 points from 72.191 to 72.52.

CONCLUSION

This research has empirically shown from the measurement model that the exogenous latent variable attitude has a high level of influence on behavioural intention followed by trust. The growing importance of Artificial Intelligence in services industry in India [79] represents a major challenge and a research topic of great current interest. Furthermore, this result is supported by the empirical t value. Since attitude and behavioural intentions as well as trust and behavioural intentions are complimentary to each other, it calls for the need to pay attention towards improving indicators of attitude and trust. This can be done by paying attention to manifest indicators of attitude, (i) “I have a positive attitude towards the website” and (ii) “This is a nice website”. There is a need for improving trust constructs indicators like (i) “This website would like to be known as a website which will keep the promises and commitments made by them” and (ii) “The website is trustworthy for apparel shopping”.

The importance-performance matrix analysis showed that construct attitude has the highest performance and construct general belief has the lowest performance compared to other constructs. Therefore, there is no need to improve the construct attitude because it’s already performing better compared to all other constructs. With regards to the construct general belief the performance is very low and improving this construct will not make much difference for the construct's Behavioural Intention. The construct which is average and stands between all constructs ECS and EDS with average performance of 72.283 and 72.309 respectively. Therefore, the constructs ECS and EDS manifest indicators need improvement which will improve endogenous latent variable Behavioural Intention. Therefore, the corporate need to concentrate on the following indicators of expected customer service constructs: (i) “Sales staff are willing to respond to customer needs”; (ii) “If I am not satisfied with my purchases, this website guarantees me a refund” and (iii) “The website provides online tracking for products”. There is also a need for corporates to concentrate on the following indicators of expected delivery service constructs i.e., (i) “This particular website offers a common fee for the delivery service”; (ii) “The website provides clear T&C for delivery service”; (iii) “This particular website offers various options for the delivery service such as standard post, express shipment and home delivery”.

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