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A promising perspective to upgrade cotton dyeing performances when dyed with a red fluorescent pigment

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HIND ALGAMDY

ABSTRACT – REZUMAT

A promising perspective to upgrade cotton dyeing performances when dyed with a red fluorescent pigment

This paper studied the dyeing with a fluorescent red pigment, and several dyeing performance problems were detected. This research aims to improve these performances, particularly those of dyeing fastness. Various surface treatments have been applied to bleached cotton fabrics to do this. Two commercial agents have been used, namely ST1 and ST2, which are essentially quaternary ammonium preparations with a cationic character. In addition, the dyeing process parameters have been studied, namely, the dyeing temperature, time and pH, to achieve the best conditions allowing acceptable dyeing performances with the fluorescent red pigment. Moreover, SEM images were taken for treated and untreated cotton fabrics, and no great morphological differences were detected. Finally, dyeing performances were evaluated based on the measurement of colourimetric coordinates, colour yield K/S and dyeing fastness properties. Very promising results have been found following a surface treatment with 8% of the agent ST1, a dyeing process of 30 inutes at 50°C for a pH of 8.

Keywords: *surface treatment, fluorescence, cotton, dyeing fastness, morphological aspect*

O perspectivă promițătoare pentru a îmbunătăți performanța vopsirii bumbacului cu pigment roșu fluorescent

În această lucrare a fost studiată vopsirea cu pigment roșu fluorescent şi au fost detectate mai multe probleme de performanță a vopsirii. Scopul acestei cercetări este de a îmbunătăți aceste performanțe, în special cele de rezistență la vopsire. Pentru a face acest lucru, au fost aplicate diferite tratamente de suprafață țesăturilor din bumbac albit. Au fost utilizați doi agenți comerciali și anume ST1 și ST2, care sunt în esență preparate de amoniu cuaternar cationic. În plus, au fost studiați parametrii procesului de vopsire, și anume temperatura de vopsire, timpul și pH-ul, pentru a obține cele mai bune condiții care să permită performanțe acceptabile de vopsire cu pigmentul roșu fluorescent. Mai mult, au fost realizate imagini SEM pentru țesături de bumbac tratate şi netratate şi nu au fost detectate diferențe morfologice mari. În final, performanțele de vopsire au fost evaluate pe baza măsurării coordonatelor colorimetrice, randamentului tinctorial K/S și proprietăților de rezistență la vopsire. Rezultate foarte promițătoare au fost găsite în urma unui tratament de suprafață cu 8% din agentul ST1, un proces de vopsire cu o durată de 30 de minute la 50°C, cu un pH de 8.

Cuvinte-cheie: *tratament de suprafață, fluorescență, bumbac, rezistență la vopsire, aspect morfologic*

INTRODUCTION

The world of fluorescence is a world of colour and beauty. In the dark, the tints usually perceived by day disappear. Hence, only the intense colours of the fluorescent substances touched by ultraviolet rays emit a startling clarity. This natural fascinating phenomenon has become a research effect on several applications to different types of textile fabric especially for smart textiles. Fluorescent materials are widely used in a variety of fields because of their unique properties. They can absorb light of one wavelength and emit light of a different wavelength, which makes them useful for a wide range of applications [1]. Textiles that fluoresce could unlock a lot of novel promises for innovation: human safety in outdoor sports, special services in the armed forces, fashion, and trends [2]. It could also be successfully used for making clothing textiles since safety gear with light-sensitivity features is essential to protect competitors in outdoor sports played in low-visibility environments [3]. Indeed, the fluorescence phenomenon is founded on the notion that some materials can absorb light of a particular wavelength (ultraviolet) and subsequently emit light of another wavelength (visible). Moreover, a fluorescent dye appears brighter and more saturated in daylight or black light compared to the colours around it. Dyeing textiles with fluorescent pigments arouses more and more interest in the textile field [4]. However, they also present several challenges namely low dye yield as well as very poor dye fastness. However, this dye once made allows to achieve an impressive range of shades the fluorescent pigments make it possible to create unique and shattering visual effects. To produce a fabric with the needed functionality, several steps are required [5]. Sizing agents were utilized to increase absorbent capacity while oxidizing reagents were used to increase strength, hygroscopicity, dye absorption, and brightness, and dyes were used to generate specific colourations [6]. The most common way to produce fluorescent textiles is to soak the textile materials in a solution containing fluorescent chemicals. However, covalent bonds between fluorophores and textile fibres should be formed to ameliorate the fluorescent features intensity and stability of the fluorescent characteristics. According to the literature, fluorescent pigments generally have no direct substance towards cotton since they contain an anionic dispersing agent whereas cotton is partially anionic. Thus, the substantivity between the cotton and the colouring pigment could be developed by creating cationic charges on the cotton using surface treatment agents with a cationic character [7–9]. Numerous experiments have been conducted to improve cotton dyeability with pigments using other chemical and physical modification approaches such as plasma treatment [10], ultrasound technique [11], microwave energy [12] and Gamma radiation [13]. Fluorescent dyes are one of those that are increasingly being used by manufacturers for dyeing textile materials to produce brighter colours. These pigments are brighter than traditional pigments, which enhances the colour of fabrics. Furthermore, cotton fabrics fade easily from light, washing, rubbing, and perspiration, so pigments are used more often to dye synthetic fabrics than cotton. To prevent coloured fabrics from fading or staining, cationization, antioxidants, and UV absorbers are often applied [14]. Several research used exhaust methods to dye cotton, polyester, and nylon 17 with fluorescent pigments and discovered that coloured had an unfortunate pigment accumulation and uniformity [15]. Therefore, fluorescent pigments are employed to dye the cotton-polyester blended textile under various conditions [16]. In addition, fluorescence dyes absorb ultraviolet (UV) or visible light and emit light at longer wavelengths. These dyes are defined as substances that absorb and emit strongly in the visible region, and which are concerned with their application potential due to their high fluorescence characteristics [17]. Normally, the fluorescent pigment's fastness qualities are poor. Thus, surface treatment with various levelling agents increased the levelness of the fluorescent pigment. This paper aimed to improve the dyeing performances of dyed cotton fabrics with a red fluorescent pigment. Hence, surface treatment was applied on cotton fabrics before the dyeing process as a preparation step for samples.

Table 1

GENERAL CHARACTERISTICS OF THE COTTON FABRICS USED	
Characteristics	**Values**
Armor	Plain weave
Matter	100% cotton
Thickness (mm)	0.69
Weight ($g \cdot cm^{-2}$)	2.80
Warp density ($threads \cdot cm^{-1}$)	49
Weft density ($yarns \cdot cm^{-1}$)	23
Warp fineness (tex)	39.1
Weft fineness (tex)	64

MATERIALS AND METHODS

Fabric and dye

The cotton fabrics used in this study were purchased from one of the shops in (Taif, Saudi Arabia) in May 2021, it is a bleached fabric with the characteristics summarized in table 1.

These characteristics were measured in standard conditions of temperature and relative humidity (20 ± 2°C for temperature and 65 ± 5% for relative humidity). The Red fluorescent pigment dye studied in this paper belongs to the range of Cepolprint fluorescent dyes. These are water-based fluorescent pigment dispersions, activated by a fluorescent brightener and embedded in a triazine resin in powder form. These compounds are slightly anionic.

Surface treatment process description

Bleached Cotton fabrics were treated at first in a preparative bath before being dyed. The bath contained a specific amount of a surface treatment agent. As surface treatment agents, ST1 and ST2 were used in this study, they are two commercial products, and their characteristics are summarized in table 2.

The surface treatment was applied on cotton fabrics for 25 minutes at 40°C. Cotton fabrics were dried at the end of the process.

Table 2

GENERAL CHARACTERISTICS OF SURFACE TREATMENT AGENTS APPLIED		
Surface treatment agent	**Characteristics**	**Properties**
ST1	Ionic character	cationic
	Solubility	Water soluble
	Composition	quaternary ammonium preparation
	pH	2–4
ST2	Ionic character	cationic
	Solubility	Water soluble
	Composition	quaternary ammonium preparation
	pH	3–5

Morphological characterization of surface-treated cotton fabrics

The untreated and surface-treated cotton fabrics by ST1 and ST2 agents were examined using an SEM Jeol JSM-6060 Scanning Electron Microscope EDX unit attached, with accelerating voltage18 kV. All the samples were coated with gold before SEM testing.

Dyeing process description

Cotton fabrics treated with a 4% surface treatment agent then undergo a dyeing step with 10% fluorescent red pigment. The dyeing lasted 30 minutes at a temperature of 40°C at a pH of 9. At the end, the dyed fabrics were rinsed and dried.

Colour yield and colorimetric parameters

A Spectra-flash spectrophotometer (DATACOLOR Spectraflash 600Plus, USA) was used. The colour yield K/S was estimated according to the Kubleka-Munck equation [18]:

$$K/S = \frac{(1-R)^2}{2R} - \frac{(1-R_0)^2}{2R_0} \quad (1)$$

where K is the absorption coefficient, S – the scattering coefficient, R – the decimal fraction of the reflectance of dyed fabric and R_0 – the decimal fraction of the reflectance of undyed fabric.

Fastness properties assessment

The dyeing fastness properties were estimated according to the ISO standards: the ISO 105-B02: 2013 for dyeing fastness properties to light and ISO 105-C10:2006 for dyeing fastness properties to wash.

RESULTS AND DISCUSSION

Study of cotton surface treatment action on dyeing fabrics

Surface treatment on cotton fabrics consisted of applying several agents to select the best one offering the best dyeing fastness for the red fluorescent pigment.

ST1 and ST2 are the two surface treatment agents that were chosen to be used as a pre-dyeing preparatory step of cotton fibres.

Action on the dyeing properties

According to figure 1, it can be observed that the surface treatment of cotton improves its dyeability using red fluorescent pigment.

Results show that when increasing the amount of the two agents ST1 or ST2, the dyeing quality of cotton fabrics increases. Based on table 2, it can be observed that both surface treatment agents are quaternary ammonium compounds. These agents are recognized for their potential to improve the affinity of cotton fibres and dye fastness to several types of dyes. [19]. The surface treatment agents bind to the fibre by replacing a fraction of the hydroxyl groups, which affects the surface chemistry of the material. The substitution will not necessarily make the fibre charge positive, but it will at least make it less negative, which improves the interaction with the red fluorescent pigment and therefore the fixation of the dye on the fibre.

Moreover, based on figure 1, it could be deduced that the best dyeing quality was obtained for 8% of ST1, in fact, a colour yield *K/S* of 3 was reached at this amount.

Action on the dyeing fastness properties of cotton fabrics

The action of using several treatment agents to prepare the cotton fabrics before the dyeing with the red fluorescent pigment was studied in this part. The fastness properties were evaluated for (0-2-4-6-8-10%) of each surface treatment agent. Based on table 3, it could be observed that when the amount of ST1 or ST2 was increased, the dyeing fastness (to wash and to light) was increased too. Furthermore, when the surface treatment agent ST1 was used in amounts equal to or greater than 8%, higher fastness qualities were obtained. Indeed, the modification of cellulosic fibres with cationic agents leads to better fastness properties [20] which could be explained by the increase in the substantivity of dyes for cotton fibres through the introduction of cationic sites.

Analysis of morphological structure of surface-treated cotton fabrics

A scanning electron microscope (SEM) is an instrument that produces images of a sample by scanning the surface with a focused beam of electrons. In this paper, the goal of using this instrument is to detect morphological differences at the surface of untreated and treated cotton fabrics with ST1 and ST2 agents. Based on SEM images described in figure 2 taken at different magnifications, it could be deduced that there is no great morphological difference between the untreated and treated cotton fabrics.

Study of red fluorescent pigment dyeing parameters process

In this part, cotton fabrics were treated with 8% ST1 agent before being dyed at several conditions process.

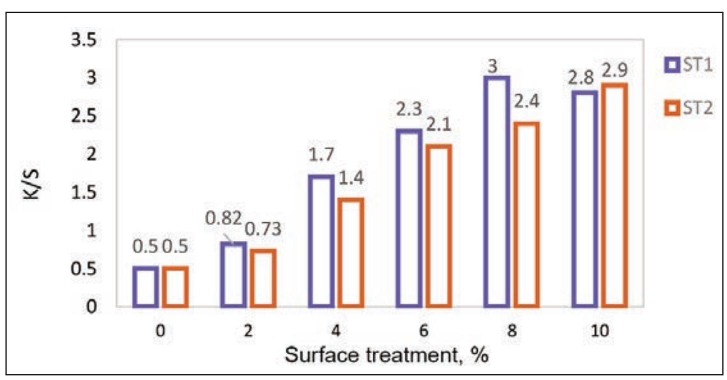

Fig. 1. Surface treatment action on colour yield (*K/S*) of dyed fabrics

Table 3

EFFECT OF SURFACE TREATMENT ON WASHING AND LIGHT FASTNESS PROPERTIES			
ST1 (%)	**Dyeing fastness to washing (ISO 105-C10:2006)**		**Dyeing fastness to light (ISO 105-B02:2013)**
	Colour change	**Colour staining (cotton)**	
0	1	1	1
2	1	1	2
4	1–2	1–2	2
6	2	1–2	3
8	3	2–3	4
10	3	2–3	4
ST2 (%)	**Dyeing fastness to washing (ISO 105-C10:2006)**		**Dyeing fastness to light (ISO 105-B02:2013)**
	Colour change	**Colour staining (cotton)**	
0	1	1	1
2	2	2	2
4	2–3	2	2
6	2	2–3	3
8	3	2–3	3
10	3	2–3	4

Study of dyeing temperature action

The effect of temperature on the dyeability of treated cotton fabrics with fluorescence pigment was conducted at various temperatures (from 40ºC to 80ºC).

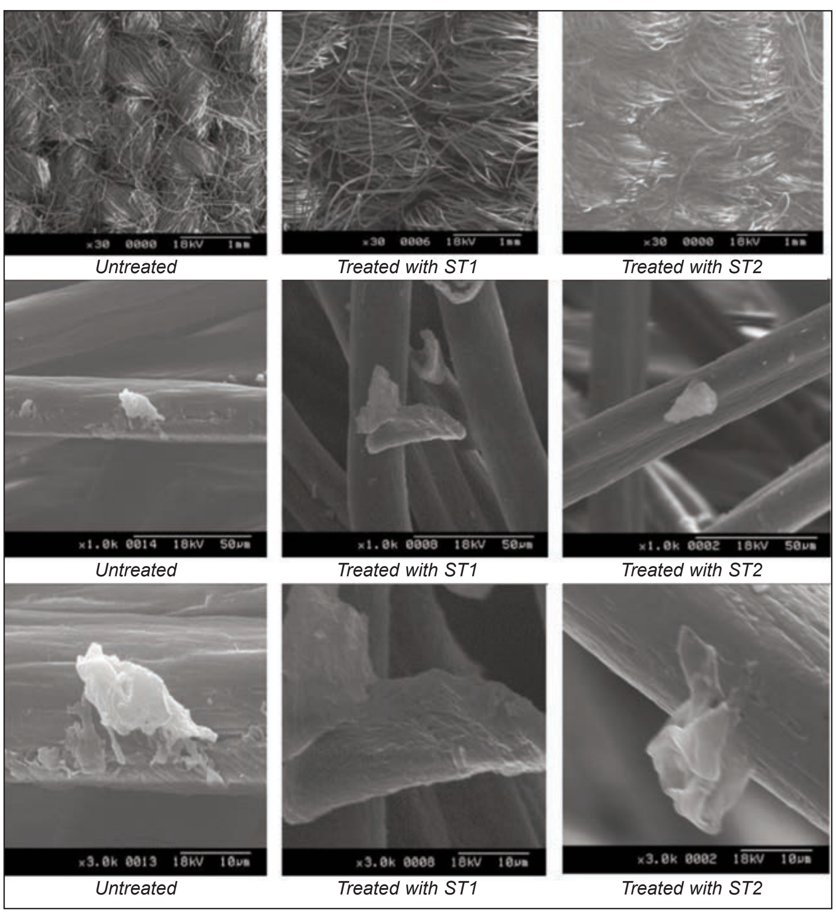

Fig. 2. SEM images at different magnifications of bleached cotton fabrics: untreated, treated with ST1 and treated with ST2 agents

The colour yield was measured to appreciate the dyeing quality obtained.

Figure 3 illustrates the influence of dyeing temperature on the colour yield (*K/S*). According to the obtained data shown in this figure, the *K/S* values of dyed materials increased gradually with the increase of temperature from 40°C to 50°C. The highest values of *K/S* are observed for dyed cotton fabrics at 50ºC temperature. As the temperature increases, the fibre swelling effects improve, allowing the molecular structure to become more open, allowing dye uptake and thus obtaining a higher *K/S* value. This indicates that this temperature has a greater impact on the dye uptake values for fabrics [21]. Up to 50ºC, the dye uptake results start to decline which could be attributed to dye diffusion from the fibre's core. All centralised sites are occupied. Hence, the optimum value of temperature used may be 50°C, which helps in saving energy and all other dyeing parameters.

Action on the dyeing fastness properties of dyed fabrics

Both light fastness and Washing fastness are performed to evaluate the colour change of samples dyed in different conditions of temperature. Grades of dyeing fastness are presented in table 4.

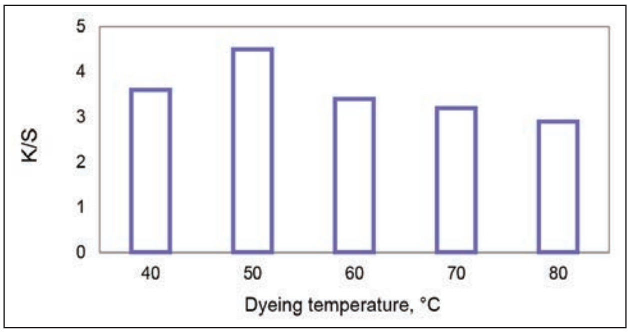

Fig. 3. Dyeing temperature action on colour yield (*K/S*) of dyed fabrics

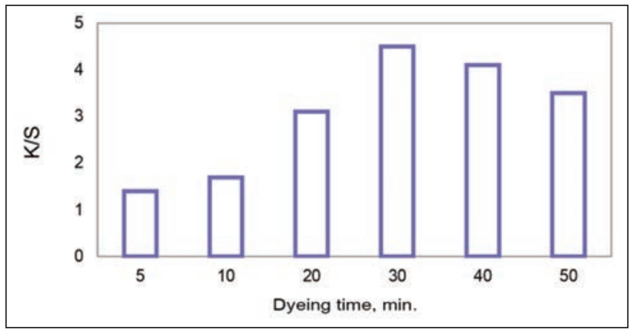

Fig. 4. Dyeing time action on colour yield (K/S) of dyed fabrics

Table 4

ACTION OF DYEING TEMPERATURE ON WASHING AND LIGHT FASTNESS PROPERTIES

Dyeing temperature (°C)	Dyeing fastness to washing (ISO 105-C10:2006)		Dyeing fastness to light (ISO 105-B02:2013)
	Colour change	Colour staining (cotton)	
40	2–3	3	4
50	3	3–4	5
60	3	4	4
70	2–3	3	4
80	2–3	3	3

The overall dyeing fastness to light results of the samples is good to excellent. The light fastness value decreases with high temperature but remains good, which may be owing to good fixing of the pigment molecules to cotton-treated fibres.

Washing fastness properties are average (between 2 to 4). The minimum range for washing fastness is obtained for 40ºC and 80ºC. It is observed that the fabric sample dyed at 60ºC exhibits both good colour change and staining properties.

The depth of shade decreases as the temperature increases, according to the K/S values measured. As a result, when the dyed samples are exposed to the washing test, dye molecules come out from the fabric surface, lowering the value, and indicating that the washing fastness quality is not excellent at high temperatures.

Study of dyeing time action

Action on the dyeing properties of cotton fabrics

The dyeing results are influenced by the variable duration of the process. The dyeing time effect was studied in the range of 5 min to 50 min, while other parameters were constant. The effect of dyeing time on the colour yield is shown in figure 4.

Obtained values of K/S revealed that duration affected the dyes exhaustion significantly according to figure 4 which showed maximum colour yield at 30 min, whereas at 40 and 50 min decreases.

Action on the dyeing fastness properties of dyed fabrics

The results of the obtained fastness are summarized in table 5.

Obtained values show a better fastness property when decreasing the dyeing time for both washing and light fastness. Indeed, the duration of the dyeing

Table 5

ACTION OF DYEING TIME ON WASHING AND LIGHT FASTNESS PROPERTIES

Dyeing time (min)	Dyeing fastness to washing (ISO 105-C10:2006)		Dyeing fastness to light (ISO 105-B02:2013)
	Colour change	Colour staining (cotton)	
5	2-3	2–3	2
10	3	2	3
20	3	2	3
30	3–4	3	4
40	4	3–4	4
50	4	4	5

Table 6

ACTION OF DYEING PH ON WASHING AND LIGHT FASTNESS PROPERTIES			
Dyeing pH	**Dyeing fastness to washing (ISO 105-C10:2006)**		**Dyeing fastness to light (ISO 105-B02:2013)**
	Colour change	**Colour staining (cotton)**	
3	3	3–4	3
5	3–4	4	3
6	3–4	4	4
7	4	4	4
8	4	4	5
9	4	4	5

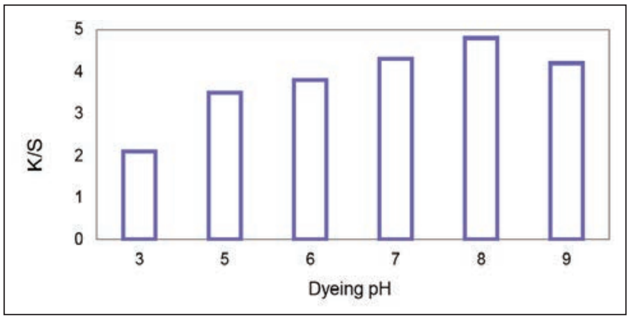

Fig. 5. Dyeing pH action on colour yield (*K/S*) of dyed fabrics

process can affect the uniformity and penetration of the dye into the fabric, which can, in turn, affect the dyeing fastness. The best results for washing and light fastness were obtained at 50 min.

Study of dyeing pH action

Action on the dyeing properties of cotton fabrics

The pH value of the dye bath can affect the dyeing fastness of the dyed textile. The influence of dye bath pH on the dyeability was investigated in the range of (3 to 9) and the obtained results are presented in figure 5.

Based on the results of this figure, it appears that the colour yield increases with increasing pH values, with the greatest result reached at pH 8. The effect of the dye bath pH can be explained by the correlation between the dye structure and surface-treated cotton fabrics. As the pH increased > 8, the *K/S* values of treated cotton decreased. Starting from this value, no additional dye is adsorbed since all of the protonated terminal amino groups attached to the surface of cotton fabric interact with the fluorescent dye [22].

Action on the dyeing fastness properties of dyed fabrics

The *K/S* values of cotton-dyed samples dyed at different pH are given in table 6.

From the tables, it can be seen that the *K/S* values of dyed fabrics are higher in alkaline conditions of pH than in acidic conditions. Wash fastness ratings for staining of adjacent fabrics are good (4) and also those for colour change. Dyeing fastness properties increase from 3 to 4 and 5 values when pH increases. As the pH increases, the dye uptake also increases which is reflected in the obtained results of *K/S*. This enhancement in *K/S* values is associated with the obtention of more solid fixation of fluorescent dye into the fibre structure which results in better fastness properties of washing and light. Also, this may be due to the degradation of the fluorescent dyes at acidic conditions.

CONCLUSIONS

Surface treatment is a very useful method to increase the dye uptake of cotton fabrics toward fluorescent dyes which have revealed a lot of not satisfying results of fastness properties.

Applying a surface treatment agent has two effects: the first improves the dye absorption of cotton fabrics; the other is that it greatly improves the dyeing fastness of the dyed fabrics.

The obtained fastness properties to wash and light of the treated dyed fabrics are good. Thus, the study of dyeing parameters on the colour yield and fastness properties has been developed for cotton fabrics treated with 8% of ST1 surface treatment agent which demonstrated better dyeing performances than ST2 surface treatment agent.

The best-obtained results of colour yield *K/S* and dyeing fastness are conditioned by the used dye parameters as temperature, duration and pH. According to the obtained results, temperature of 50, 30 min and pH of 8 are the best dyeing conditions.

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Supply chain integration and supply chain performance: evidence from the textile industry

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ABSTRACT – REZUMAT

Supply chain integration and supply chain performance: evidence from the textile industry

This study aims to determine the impact of supply chain integration on supply chain performance and the Internet of Things (IoT) mediating role in Sindh Pakistan's textile industry. Primary data was gathered with the help of questionnaires from previous studies. The employees were requested to complete the questionnaire online, and the concerned HR department was officially contacted. To achieve the research objectives of this study, SmartPLS version 3 is applied. The findings of this study confirmed the direct effect of internal integration, supplier integration, and the Internet of Things on supply chain performance. In addition to this, the present study also confirmed the partial mediation effect of IoT between internal integration, supplier integration, and supply chain performance in the textile industry of Sindh, Pakistan, a developing country. This research uses RBV theory to examine the textile industry's supply chain and effectiveness. Internal integration, partner integration, IoT, and supply chain performance are discussed in the research. This clarifies how these technologies operate together to give organizations a competitive advantage. The study shows how the Internet of Things (IoT) is a go-between for integration and supply chain success. Textile business managers should consider investing money into IoT devices and using their benefits. Companies can get real-time information about their supply chain by using IoT devices and monitors.

Keywords: *supply chain integration, Internet of things, supply chain performance, textile industry*

Integrarea și performanța lanțului de aprovizionare: dovezi din industria textilă

Acest studiu își propune să determine impactul integrării lanțului de aprovizionare asupra performanței acestuia și al rolului de mediere a Internetului obiectelor (IoT) în industria textilă din Sindh, Pakistan. Datele primare au fost colectate cu ajutorul chestionarelor din studiile anterioare. Angajaților li s-a cerut să completeze chestionarul online, iar departamentul de HR în cauză a fost contactat oficial. Pentru atingerea obiectivelor de cercetare ale acestui studiu se aplică SmartPLS versiunea 3. Concluziile acestui studiu au confirmat efectul direct al integrării interne, al integrării furnizorilor și al Internetului obiectelor asupra performanței lanțului de aprovizionare. În plus, studiul de față a confirmat și efectul de mediere parțial al IoT între integrarea internă, integrarea furnizorilor și performanța lanțului de aprovizionare în industria textilă din Sindh, Pakistan, o țară în curs de dezvoltare. Această cercetare utilizează teoria RBV pentru a examina lanțul de aprovizionare și eficiența din industria textilă. Integrarea internă, integrarea partenerilor, IoT și performanța lanțului de aprovizionare au fost examinate în cadrul studiului. Acest lucru clarifică modul în care aceste tehnologii funcționează împreună pentru a oferi organizațiilor un avantaj competitiv. Studiul arată cum Internetul obiectelor (IoT) este un intermediar pentru integrarea și succesul lanțului de aprovizionare. Managerii din domeniul industriei textile ar trebui să ia în considerare investirea banilor în dispozitivele IoT pentru beneficiile acestora. Companiile pot obține informații în timp real despre lanțul lor de aprovizionare utilizând dispozitive și monitoare IoT.

Cuvinte-cheie*: integrarea lanțului de aprovizionare, Internetul obiectelor, performanța lanțului de aprovizionare, industria textilă*

INTRODUCTION

Supply chain integration is the degree to which different parts of the supply chain are linked and work together smoothly [1]. Coordinating the flow of goods and information also means bringing wholesalers, producers, dealers, and stores together. Supply chain merging that works well can improve prices, speed, and the ability to meet customer needs [2]. On the other hand, supply chain performance is how well a supply network meets customer needs while keeping costs and earnings in check. This includes measuring wait times, inventory levels, on-time delivery, customer happiness, and product quality. High performance in the supply chain could lead to more loyal customers, better financial results, and an edge in the market [3]. Supply chain integration could significantly affect how well the supply chain works. When different parts of the supply chain are linked, information may move more quickly and adequately. This makes planning and coordinating more effective. Because of this, wait times might get shorter, product control might get better, and the company might be better able to respond to changes in market demand.

Putting the supply chain together may help find and lower supply chain risks [4]. By knowing more about how their suppliers are doing and how much product they have, companies can better plan for possible delays and take steps to lessen their effects. This could strengthen the supply chain and ensure people keep getting the things and services they need. Integrating and having a successful supply chain go hand in hand. Businesses may improve their supply chain performance by putting integration at the top of their list of priorities [5]. This can help their finances and give them an edge over their competitors.

Internet of Things (IoT) products and monitors are used everywhere [6–8]. These devices can be built into various things, like goods, tools, equipment, and cars. They gather and send real-time information about things like location, speed, usage, weather, and humidity. After IoT devices send their data, it is collected and put into a central system or platform [1]. Large amounts of data from different sources inside the company can be stored, processed, and analysed using this method. The whole business can be seen when IoT data is combined with data from other internal systems, like enterprise resource planning (ERP) or supply chain management (SCM) systems. When companies combine IoT with internal integration, they can use real-time data to make choices based on data, simplify processes, and improve teamwork. Businesses can become more competitive in the market by using these tools and methods to make their operations more efficient, cut costs, and make processes run more smoothly [7].

Information and communication technology (ICT) may significantly affect the supply chain's performance by making it easier for people in the chain to talk to each other and share information more quickly, accurately, and effectively [6]. ICT can show how the supply chain works in real-time, so businesses can see how goods and raw materials move through the chain, keep track of their stock, and spot any problems or slowdowns that might happen. Businesses can quickly adapt to changes in customer demand or the supply chain, which could help cut down on wait times and make the supply chain more flexible overall [7]. ICT can make it easy for people in the supply chain to work together and plan things. For example, cloud-based systems and data analytics tools could let wholesalers, producers, and dealers talk to each other in real time. For example, electronic data exchange (EDI) lets partners in the supply chain share data instantly. This means that no one has to enter the data by hand, which lowers the chance of mistakes. This could improve the supply chain and reduce the cost of entering and handling data [8]. ICT can help everyone in the supply chain see what is going on in real-time, work together, and share data, all of which can significantly enhance the success of the supply chain. When companies spend money on ICT solutions, they can improve how their supply lines work. This can lead to happier customers, more money, and an edge in the market [9].

Even though there is more and more publishing about the benefits of IoT and integrating suppliers in supply chain management, more real-world research is needed to fully understand the unique challenges and opportunities that Pakistan's textile industry supply lines face. In the textile business in Pakistan, there may be little information about how internal integration helps companies get the most out of IoT and partner integration. “Internal integration” refers to how well-coordinated and separate company units work together. It is well known that integrating with providers on the outside has benefits, but more attention should be paid to how internal integration makes these benefits possible. A possible study could be to look into the role that internal integration plays in enabling the benefits of IoT and provider integration on the performance of supply chain management in the Pakistan textile industry. This study might help supply chain managers in the Pakistani textile industry who want to improve their methods and make their businesses more efficient and competitive.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Theoretical framework

The Resource-Based View idea says that a company's tools and skills affect how well it does [2]. The independent factors in this case are Supplier Integration and Internal Integration. A company can use These essential tools and resources to improve supply chain performance, which is the dependent variable. Supplier integration is how well a company works with and combines with its sources. Sharing information, organizing methods, and building relationships that are good for both sides are all part of it. Integrating suppliers can help businesses access expert knowledge quickly and save money [3]. The level to which a company combines its tasks and departments is called its “internal integration”. Sharing information, ensuring everyone is working toward the same goals, and organizing processes between different parts of the company are all part of it. Internal integration can help the company communicate, work together, and make better decisions, making the company more efficient and effective [4]. In this approach, information technology can be seen as an intermediate variable. It is a significant part of integrating suppliers and employees within the company. Information technology allows different parts of the supply chain to share information, coordinate actions, and connect their systems [5]. It can help people talk to each other, work together, and make decisions better, which can help the link between the seller and internal integration and supply chain performance. As a result, the theoretical basis for this model would include looking at the clear links between Supplier Integration, Internal Integration, and Supply Chain Performance, as well as the role that IT plays in making these links possible. It is possible to look at how these different factors affect a company's general supply chain success through the lens of the RBV theory (figure 1).

Hypothesis development

Internal integration

Internal integration is all about aligning and merging a business's internal operations and teams [6]. The goal is to make the supply chain more effective and efficient. This could mean combining tasks like buying, making, sending, and selling and setting shared goals and measurements for all of these tasks. Internal integration could significantly affect the supply chain's efficiency by making it easier to coordinate, shortening wait times, and making the supply chain more efficient [7]. By coordinating their actions and areas, businesses can get a better result of how their whole supply chain is doing and find ways to make it better. By improving production plans and ensuring that internal operations have the tools and resources they need to meet customer needs, internal integration may also help to cut costs and improve product quality. By setting the same goals and key performance indicators (KPIs) for all of their internal processes, companies can improve supply chain management and make people more responsible and capable of making decisions. Internal mergers might not go as planned because of the need for good tools for working together and communicating and the fact that some internal functions and departments might want to stay the same [8]. Internal integration requires unity and dedication from all roles and departments, which some firms may need help with. Internal integration is an essential part of supply chain management that can significantly improve efficiency. Aligning internal departments and processes can help companies save money, work together better, and make customers happier [9].

H2a: Internal integration is positively related to supply chain performance.

H2b: Internal integration positively related to the Internet of Things.

Supplier integration

Partnering closely with providers to make the supply chain work better and more efficiently is called supplier integration [10]. Part of this could be working together to find and fix supply chain problems and bottlenecks, sharing information, and ensuring output plans are in sync. Supplier mergers affect the supply chain's efficiency by making it quicker, cutting down on wait times, and making the supply chain more efficient. By working closely with their suppliers, companies can get real-time information about their suppliers' performance [11]. This lets them respond quickly to changes in demand or the supply chain. Supplier integration also helps improve product quality and lower costs by ensuring sellers have the right tools and skills to meet customer needs and optimize production plans. Setting up long-term relationships with key providers is another way for companies to lower supply chain risk and generally make the chain more stable [12].

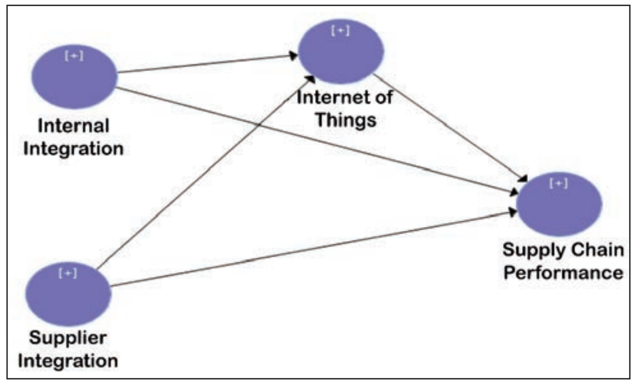

Fig. 1. Proposed conceptual framework

Nevertheless, integrating suppliers might be challenging because researchers need good tools for working together and talking to each other. There is a chance that the company has disagreements with suppliers. It also takes time for both sides to build the trust and commitment needed for provider integration.

H1a: Supplier integration positively related to supply chain performance.

H1b: Supplier integration positively related to the Internet of Things.

The mediating role of the Internet of Things

Along the supply chain, IoT devices and sensors can be built into goods, cars, and warehouses, among other places. These gadgets can show where things are, their state, and how they work in real-time as they move through the supply chain. Improved productivity, fewer stock-outs, and improved customer service result from simpler tracking, monitoring, and management. Supply chain partners can collaborate better using IoT [13]. Partners can see the whole supply chain network by merging IoT data from producers, shops, wholesalers, and transportation businesses. Sharing a perspective and data makes it simpler to collaborate, communicate, and make choices, improving supply chain efficiency and sync. Real-time data collection and analysis using IoT may enhance the supply chain. IoT devices can help you find bottlenecks, flaws, and ways to improve things by collecting data on stocking levels, shipping routes, and production methods. This data-driven improvement helps players in the supply chain simplify processes, cut costs, and improve the performance of the whole chain [14]. IoT creates enormous amounts of data that can be used to learn valuable things. IoT data can be used with advanced analytics methods like machine learning and artificial intelligence to find trends, predict demand, find the best stocking levels, and make supply chain forecasts more accurate. These views into the future help supply chain partners make intelligent decisions and stay ahead of how the market changes [15].

H3: The Internet of Things mediates the relationship between supplier integration and supply chain performance.

H4: The Internet of Things mediates the relationship between internal integration and supply chain performance.

METHODOLOGY

Data and procedure

The questionnaire used in this study was adapted from one used in earlier research and the poll method. The last study used an online survey of 380 supply chain managers in the Indian retail business to get real-world data. The results were then checked using structural equation modelling (SEM). The aim is to find out how supply chain performance measures (SCPM) affect retail organizations' success and test the regulating role. Also, the study needs to look at people's opinions in other industries for more helpful information. In the same way, another study uses the organizational capability theory to create an empirical model that looks at how IoT capabilities affect different aspects of integrating supply chain processes. This improves both the performance of the supply chain and the performance of the organization as a whole. Structural equation modelling (SEM) examined cross-sectional poll data from 227 Australian retail businesses. The current study, on the other hand, is based on the textile business in Pakistan, and IoT is used to measure the success of the supply chain. Due to their policy on privacy concerns, responders were asked to fill out an online questionnaire through Google Forms. The link to the questionnaire was shared with the appropriate HR department of the textile industry of Sindh, Pakistan, through WhatsApp, email, and Facebook. Because of this, the study's population comprises companies working in the industry. Middle-level only agreed to fill out the poll on their own. The employee's name was kept secret. From May to July 2023, three months will be used to gather information. There were 300 surveys sent to workers at Pakistani production companies. However, after cleaning up the data, the writers only looked at 250 surveys. So, 83% of people asked to participate in this study did so. The questionnaire was adopted from [16, 17].

The research instrument is taken from the study of [16, 17]. The supply chain management performance three items are "Improve supply chain delivery reliability, Reduce the total supply chain management cost, and Improve supply chain flexibility (react to product changes, volume, mix". The second variable supplier integration also has three items "Improve information exchange with our suppliers, accurately plan and adopt the procurement process in collaboration with our suppliers and Share real-time demand forecasts with our suppliers". The third concept internal integration had four items such as "Improve the integration of data among internal functions, improve real-time communication and linkage among all internal functions, improve inventory management in collaboration with cross-functional teams and Improve real-time searching of logistics-related operating data". Lastly, the internet of things items are "To provide real-time information to optimize supply chain activities, To provide real-time intelligence of supply chain operations, To strengthen inter and intra organizational information sharing within the supply chain and to strengthen communication and coordination between operators".

Statical tools

Structural equation modelling (SEM) is used to test the suggested theory in this work [18]. Through numerical proof, SEM helps to prove that current ideas are correct. So, the SEM is used to make sure that there is a link between hidden variables and their factors. As an extra sample, 5,000 bootstrap samples were also used. When dealing with complicated models like mediation or moderation, Smart-PLS should be taken into account [19].

RESULTS

Instrument's reliability and validity

When a researcher uses an online survey to get data, reliability means how stable and consistent those measures are. It ensures that the device always gives the same results, even if it is used by different experts or more than once [20]. High dependability means the tool measures the construct regularly and with a little mistakes. Cronbach's alpha checks how consistent a poll is by determining how strongly items on a scale or concept are linked. In this case, a more considerable number means more internal stability. Most people agree that Cronbach's alpha value of 0.70 or higher means the stability is good, though higher values are better [21]. Like Cronbach's alpha, composite reliability is a way to measure how consistent something is with itself [22]. This test checks how well different parts of a scale or design help measure the same central idea. Many 0.70 or higher is usually considered good, just like Cronbach's alpha. The validity of a poll is how well it measures what it is supposed to measure. It ensures the tool correctly measures the vital concept and gives valuable results. To correctly draw conclusions and inferences from the questionnaire data, it is crucial to ensure the data is accurate [23]. The average Variance Extracted is the term AVE stands for. Structural equation modelling (SEM) is a statistical measure used to check if a measurement scale or concept is accurate across all cases. AVE shows how much variation in a construct's signs can be explained by measuring error. The amount of variation recorded by the items is compared to the measuring error to get the AVE. Most of the time, an AVE level of 0.50 or higher means that the items explain at least half of the variation in the construct [21]. All the numbers in this study are good enough, so the theory can now be tested (table 1).

Hypothesis testing

The beta values, also called regression coefficients or slope coefficients, show how much the dependent variable changes when the related independent

Table 1

INSTRUMENT'S RELIABILITY AND VALIDITY					
Variable	**SPSS code**	**Item loading**	**Value of Cronbach alpha**	**Value of Composite Reliability**	**AVE**
Supply Chain Performance	SCP1	0.766	0.778	0.871	0.694
	SCP2	0.878			
	SCP3	0.850			
Supplier Integration	SI1	0.914	0.862	0.916	0.785
	SI2	0.888			
	SI3	0.854			
Internal Integration	II1	0.894	0.899	0.930	0.768
	II2	0.897			
	II3	0.819			
	II4	0.892			
Internet of Things	IOT1	0.871	0.861	0.907	0.709
	IOT2	0.897			
	IOT3	0.852			
	IOT4	0.740			

variable changes by one unit [20]. All other independent variables stay the same. The sum of the squared gaps between what was observed for the dependent variable and what was expected based on the independent variables is minimized to find these factors. The t-values, on the other hand, figure out how statistically significant the beta values are. To find them, divide the predicted regression coefficient by its standard error. The number of standard mistakes in the expected coefficient is not zero, as shown by the t-value. Statistically significant means that the coefficient is bigger than a particular value (usually a significance level like 0.05), and the t-value is more significant than that value [21]. These numbers, beta, and t-values, are essential because they show how a regression model's independent and dependent factors are related. The t-values show whether the effects of the independent variables on the dependent variable are statistically significant, while the beta values show the direction and size of the effects.

Internal integration

There is a positive link between internal integration and supply chain performance, as shown by the positive beta number for internal integration. The size of the beta number (0.282) shows that the link is moderately strong. The Internet of Things (IoT) has a positive beta number, which links with supply chain performance well. The more significant beta number (0.544) also indicates a more robust link than Internal Integration. The t-value of 3.562 shows a statistically significant link between internal integration and Supply Chain Performance. To put it another way, it probably did not happen by chance alone. The t-value for Internal Integration is 8.403, less than the t-value for the Internet of Things. It shows a statistically significant link between the Internet of Things and Supply Chain Performance, better than the link with Internal Integration (table 2 and figure 2).

Supplier Integration

These numbers help us understand what the results mean. They are the beta values and t-values for the regression coefficients for the variables "Supplier Integration" and "Internet of Things" concerning the dependent variable "supply chain performance". Supplier integration and supply chain performance are linked well if the beta number is positive. The beta number of 0.232, on the other hand, shows that the link could be more robust. The Internet of Things (IoT) has a positive beta number, which links with supply chain performance well. The more significant beta number (0.363) also indicates a more substantial link than supplier integration. The t-value of 3.068 shows a statistically significant link between supplier integration and supply chain performance. To put it another way, it probably did not happen by chance alone. A t-value of 5.591 for the Internet of Things is more significant than a t-value of 5.591 for supplier integration. It shows a statistically significant link between the Internet of Things and supply chain performance, which is better than the link between supplier integration (table 2 and figure 2).

Internet of Things (IT)

The number of betas for supplier integration is 0.119, which means a positive link exists between supplier integration and the Internet of Things. Internet of Things (beta = 0.119): The fact that the beta number is favourable for the Internet of Things shows that it positively affects supply chain performance. The t-value of 3.058 shows a statistically significant link between supplier integration, the Internet of Things,

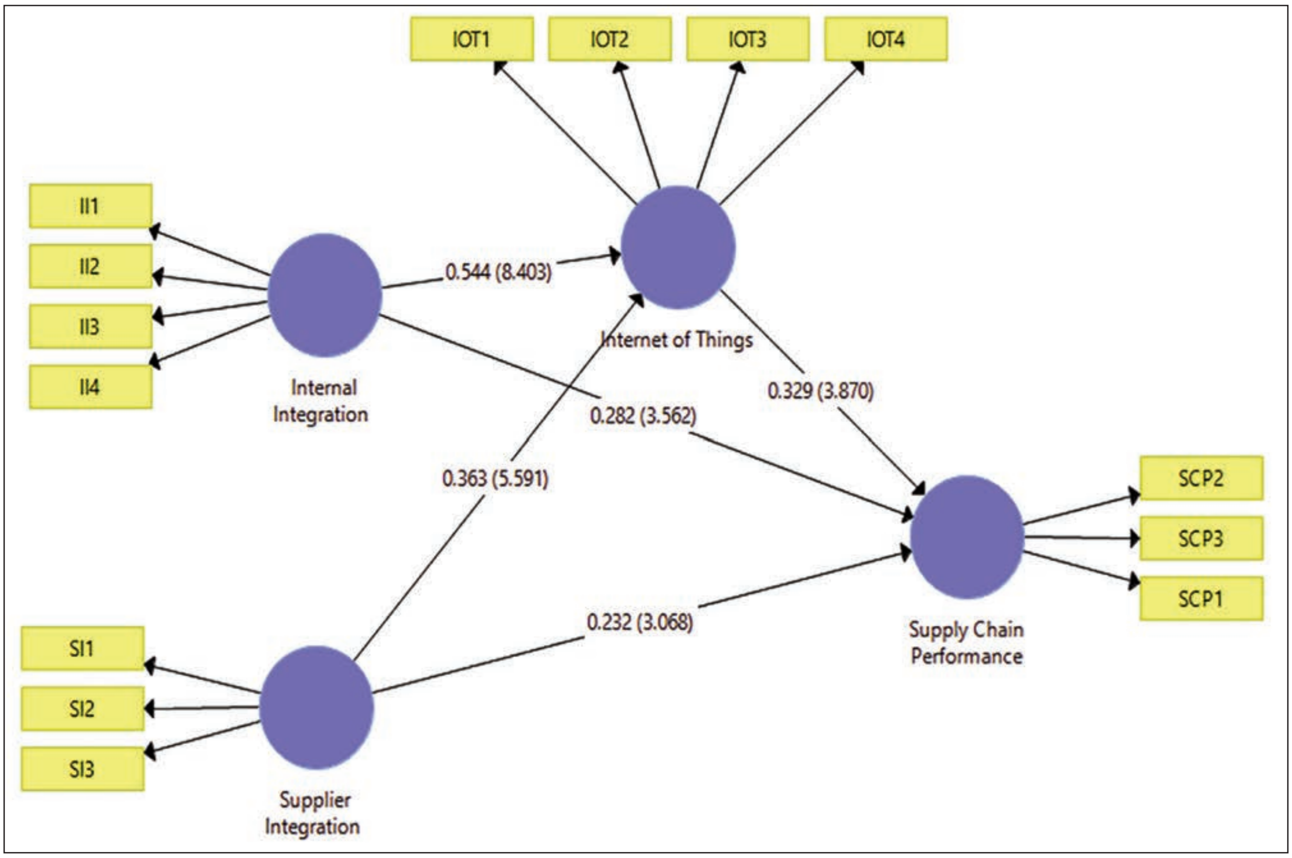

Fig. 2. Structural Equation Modelling

Table 2

HYPOTHESIS TESTING			
Path direction	**Value of Beta**	**T-Value**	**Remarks**
Internal Integration → Supply Chain Performance	0.282	3.562	Supported
Supplier Integration → Supply Chain Performance	0.232	3.068	Supported
Supplier Integration → Internet of Things	0.363	5.591	Supported
Internal Integration → Internet of Things	0.544	8.403	Supported
Supplier Integration→ Internet of Things → Supply Chain Performance	0.119	3.058	Partial medication
Internal Integration → Internet of Things → Supply Chain Performance	0.179	3.506	Partial medication

and supply chain performance. To put it another way, it probably did not happen by chance alone. Internet of Things (beta = 0.179): The fact that the beta number is favourable for the Internet of Things shows a positive link between it and supply chain performance. A mediating strong link exists between internal integration and supply chain performance, as shown by the beta number of 0.179. The t-value of 3.506 shows a statistically significant link between internal integration, the Internet of Things, and supply chain performance. To put it another way, it probably did not happen by chance alone (table 2 and figure 2).

DISCUSSION AND CONCLUSION

Supplier integration and supply chain performance are related effectively, which means that when suppliers are well integrated into the supply chain processes, performance can go up [24]. This result shows how important it is to work together, share information, and coordinate with providers to make the supply chain more efficient and effective. The fact that the Internet of Things and supply chain performance are positively related shows that using and adopting IoT technologies can positively affect how well the supply chain works [25]. IoT makes it possible to see, collect, and analyse data in real time, which helps people make better decisions, improve processes, and make the supply chain more flexible. This study highlights the possible benefits of IoT to improve supply chain management efficiency. It is possible to compare how strong the links are between the factors and supply chain performance by looking at the beta numbers. The beta value for the relationship between internal integration, the Internet of Things, and supply chain performance is 0.179, which is higher than the beta value for the relationship between supplier integration, the Internet of Things, and supply chain performance, which is 0.119. This means that internal integration has a more enormous effect on supply chain performance than supplier integration.

One important thing for managers in the textile industry to remember from the study is that they should first integrate different areas within the company before attempting to integrate with customers or providers outside the company [24]. This suggestion can help managers plan strategically and decide how to use their resources. Focusing on better internal integration helps managers set priorities for tasks like making it easier for teams within the company to communicate, coordinate, and work together. This can include assembling cross-functional teams, encouraging people to share information, and setting up good ways to measure success [26]. Once internal integration works well, managers can look for ways to integrate with users and sellers outside the company. Getting close to important clients and suppliers, working together on planning and projecting, and sharing valuable data and resources along the supply chain are some things that can be done to do this [27].

Furthermore, companies can get a competitive edge by learning how supplier integration, the Internet of Things, and supply chain performance are connected [28]. Businesses can use these connections to improve customer happiness, cut costs, and get ahead in the market by optimizing their supply chain processes. Employers can use this information to set themselves apart and boost their success. The results can help businesses make their operations more effective and efficient [29]. One example is that since supplier integration and supply chain performance are linked well, companies should improve their supplier management, get closer to their suppliers, and include them in their value chain. This can cut down on wait times, improve quality, make it easier to keep track of goods and make the whole supply chain run more smoothly [26, 27]. The data can help businesses figure out where they need to put more effort to improve their supply chains. For example, if the link between supplier integration and supply chain performance could be more vital, it could mean that the company must work together and coordinate with its sellers even more. In the same way, if there is a strong link between the Internet of Things and supply chain performance, companies may decide to spend more on IoT technologies and use their benefits to get ahead of the competition [30].

Theoretical contribution

Researchers in the textile industry used the Resource-Based View (RBV) theory to determine how internal integration, supplier integration, the Internet of Things (IoT) as a mediating variable, and supply chain performance are connected. This research uses RBV theory to examine the textile industry's supply chain and effectiveness. Internal integration, partner integration, IoT, and supply chain performance are examined in the research. This clarifies how these technologies operate together to give organizations a competitive advantage. We learn more about RBV theory by integrating the Internet of Things (IoT) as an intermediate variable. Adding technical capabilities to the RBV framework expands the study of how technology might enhance supply chain performance. Making this point clearer shows how important it is to use technology as a valuable tool to make integration work better for supply chain success.

Practical implications

The research on supply chain performance and how they work together in the textile industry, especially in Sindh, Pakistan, has many valuable applications for managers and workers in the textile industry. First, the study shows how important it is for textile companies to work together within their own companies. Managers should prioritize projects that make it easier for teams and functions within the company to talk to each other, work together, and coordinate. Second, the study stresses how important it is for textile companies to work with their suppliers. Managers should work together with critical providers and build strong relationships with them. Sharing information, planning and making predictions together, and ensuring that goals and objectives are all the same are examples. Lastly, the study shows how the Internet of Things (IoT) is a go-between for integration and supply chain success. Textile business managers should consider putting money into IoT devices and using the benefits they provide. Companies can get real-time information about their supply chain by using IoT devices and monitors. This information includes inventory amounts, production methods, and transportation.

FUTURE RESEARCH DIRECTION

First, the study may have had a small sample size, which could make it hard to apply the results to the whole textile business in Sindh, Pakistan. Second, because the study is cross-sectional, it only collects data at one point, making it harder to find causal links or look at how things change over time. Finally, the study's results only apply to the textile business in Sindh, Pakistan, and might not be easy to apply to other fields or places.

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Determining the mechanical properties of biomaterial-based economic thermoplastic composites reinforced with hemp fibres

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ABSTRACT – REZUMAT

Determining the mechanical properties of biomaterial-based economic thermoplastic composites reinforced with hemp fibres

In this study, continuous reinforcement materials of hemp fibres and matrix polymers (staple polylactic acid (PLA), staple bicomponent PLA) were carded in a conventional carding machine. Various proportions of the hemp fibre reinforcement material, ranging from 20%, 30%, 40%, 50%, and 60% were used in the production of biocomposite structures. We have further studied the effect of several carding passages (up to 3 passages) on the strength performance of both the staple PLA and the staple bicomponent PLA matrix. To obtain composite samples, the carded webs were further consolidated in the hot press machine. Further mechanical performance analysis was carried out in both the cross direction as well as parallel to the machine direction. It was observed that the introduction of reinforcing hemp fibre shows an increase in tensile strength up to the critical fibre loading amount and a decrease in tensile strength after the critical fibre loading amount. The highest tensile strength of 35.84 MPa was obtained for (40HEMP / 60PLA / M / P3), applied to the composite structures in the machine production direction, while the lowest value was 14.70 MPa (60HEMP / 40BPLA / M / P1), respectively.

Keywords: *natural fibres, biomaterials, oriented UD tape composites, lightweight materials, bio-composites, staple polylactic acid (PLA), staple bicomponent PLA, hemp fibres*

Determinarea proprietăților mecanice ale compozitelor termoplastice economice pe bază de biomateriale armate cu fibre de cânepă

În acest studiu, materialele de armare continuă cu fibre de cânepă și matrice polimerică (acid polilactic discontinuu – PLA, PLA bicomponentă discontinuă) au fost prelucrate pe o mașină de cardare convențională. Diverse proporții de material de armare cu fibre de cânepă, variind de la 20%, 30%, 40%, 50% și 60% au fost utilizate în producția de structuri biocompozite. A fost studiată în continuare influența numărului de treceri de cardare (până la 3 treceri) asupra performanței de rezistență atât a PLA discontinuu, cât și a matricei bicomponente discontinue de PLA. Pentru a obține probe compozite, vălurile cardate au fost consolidate în continuare în mașina de presare la cald. O analiză suplimentară a performanței mecanice a fost efectuată atât în direcția transversală, cât și în paralel cu direcția mașinii. S-a observat că introducerea fibrei de cânepă pentru armare arată o creștere a rezistenței la tracțiune până la cantitatea de încărcare critică a fibrei și o scădere a rezistenței la tracțiune după cantitatea de încărcare critică a fibrei. Cea mai mare rezistență la tracțiune de 35,84 MPa a fost obținută pentru (40HEMP / 60PLA / M / P3), aplicată structurilor compozite în direcția de producție a mașinii, în timp ce cele mai mici valori au fost de 14,70 MPa (60HEMP / 40BPLA / M / P1).

Cuvinte-cheie*: fibre naturale, biomateriale, compozite cu bandă UD orientată, materiale ușoare, biocompozite, acid polilactic discontinuu (PLA), PLA bicomponentă discontinuă, fibre de cânepă*

INTRODUCTION

The development of structural plant fibre composite components started about 80 years ago and there is considerable interest in them nowadays because of the growing environmental and ecological pressures facing industries. Characteristics and properties of biocomposites have evolved, but improvements are still needed for the effective and durable use of plant fibre reinforcement of composites [1]. As compared to pristine metals and polymers, fibre-reinforced composite materials provide significant advantages in terms of weight, strength, and hardness. However, despite exhibiting good mechanical properties, these materials are prone to the price fluctuations of crude oil-based materials and the high cost of recycling processes of carbon and glass fibres. On the other hand, bast fibre (densities from 1.2 to 1.5 g/cm^3) based reinforced composites can be an alternative to the glass fibre-based (2.6 g/cm^3) reinforced composites, particularly as a low-density replacement, in non-load bearing and partial load-bearing parts. The absence of such natural fibre-reinforced products in structural load-bearing parts has led researchers to alternative studies [1, 2].

Bast fibres such as flax, hemp, and jute are used as reinforcement materials in fibre-reinforced composites as not only do they have long lengths (fibre length 50–120 mm) but also have lower weight and cost than their synthetic counterparts [3]. These “carbon positive” fibres are biodegradable, and recyclable as their carbon dioxide (CO_2) consumption is higher than their emissions [4]. For instance, it has been shown that the cultivation of hemp on an acre absorbs about 2.5 tons of atmospheric CO_2 in one planting season. On the other hand, more than 3 tons of CO_2 are emitted with the production of 1 ton of polypropylene [5].

In addition to the positive environmental effects of the natural fibres, they also provide some cushion towards oil price fluctuations and supply uncertainty. In the global market, the share of natural fibre composites is estimated at 12 billion USD by 2030 with an expected growth of 9 % between 2022–2030 [6]. The increase in the demand for biocomposites in the construction and automotive sectors is being driven by the requirements of superior product properties, environmental sensitivity of the end-users and indeed, legal requirements. The lightweight nature and high rigidity/weight ratio further add to the advantages of using biocomposites [7, 8].

Whilst, based on the fibre length, there are several application methods in the literature for the use of bast fibres (hemp, flax, jute, etc.) in the composites as reinforcement materials. Nonetheless, as discussed below, all the methods exhibit certain advantages and disadvantages:

- The extruded composites produced by mixing short wood-based fibres (acting as filler material, fibre length less than 5 mm) with thermoplastics have poor mechanical properties and their use is limited to non-structural applications [2].
- Short natural fibre nonwovens (usually combined with thermoplastic matrix fibres) are preferred in the composite industry owing to their low cost [9]. These discontinuous fibres are often used for a randomly oriented reinforcement (nonwoven) when there is no preferential tension direction. The random orientation of the fibres in the nonwovens results in an extremely low stress and strain performance in composites. Mechanical properties cannot be designed for non-woven surface applications produced by the random orientation of 30–60 mm fibres [4].
- For the long-spun flax and hemp threads, woven and used as reinforcement elements of composite structures, the optimization of the yarn to be used in textile reinforcement is an important criterion. The tenacity and processability of yarns with fewer twists are low. Woven fabrics produced with spun long linen and hemp yarns are used to reinforce composite structures [10, 11].
- The twist applied to increase the strength of the yarns becomes a disadvantage for the composite structures as it prevents the resin from penetrating the yarn [4, 12].
- In the hybrid yarn production method, the central parallel reinforcing fibres, are wrapped with synthetic filament. In these yarns, the tension applied by the spun yarn to the reinforcement fibres causes the core yarn to displace, which reduces its mechanical properties [2].
- For the woven surfaces produced by the 90° intersection of the yarns in the composites, the intersection points of the yarns lead to the formation of air gaps or localized tension. Therefore, woven natural fibre fabric composite applications do not optimally utilize mechanical strength [4].

For the automotive industry, lightweight structures are an indispensable prerequisite for ensuring high-efficiency, energy-saving vehicles and thus promoting a judicious use of important energy resources. The leading automotive manufacturers are therefore expected to reduce the weight and require composites which are low-priced, extremely lightweight, highly efficient, and more recently, biological-based structural solutions [13].

Studies have shown that natural fibres, especially flax and hemp can be substituted for synthetic composite reinforcements in some cases. There are commercial natural fibre composite products in the market. Therefore, the researchers have increased interest in the subject [10, 14]. For example, the work of Akondaa et al. produced flax/polypropylene unidirectional (UD) thermoplastic tapes using their own developed technology. They obtained 60–110% higher flexural modulus and 35–65% higher tensile modulus results when compared to flax/PP yarn composites. They recognized that the UD flax/PP tapes are an important progress in reinforcing the impact of natural fibres in composite applications [15]. There are commercial UD thermoplastic products in the market one of them is Bpreg's EcoRein®. According to a company statement, the EcoRein® UD family offers thermoplastic-based prepreg reinforced aligned flax fibres which provide high performance possible through fibre direction. The products of Bpreg can be applied as interior trims, body panels of electric vehicles, and trucks by replacing/reducing the use of glass fibre or even carbon fibre in the automotive industry [8, 16]. In a different study, Couture et al. investigated the mechanical properties of two different types of UD flax composites. Aligned flax rovings and flax paper layer were reinforcing filling and PLA was used as the matrix. The mechanical test results have shown that specific tensile properties of the flax/PLA and flax-paper/PLA composites were between 217 to 252 $MPa \times cm^3 \times g^{-1}$. The results of the study are close to woven glass fabrics impregnated with epoxy (227–278 $MPa \times cm^3 \times g^{-1}$) so, it is promising for industrial applications [17].

In this study, the hemp tow reinforcing fibres were intermingled with thermoplastic polylactic acid (PLA) and bicomponent PLA matrix fibres. The bicomponent matrix fibres in the web are heat-treated and shaped under pressure. Composite sheets were produced by melting the thermoplastic fibres. The novelty of this approach is that the application of low-priced hemp tow as reinforcing material without yarn can form textile surfaces. Unlike the numerous process steps of the existing production methods which can affect the production capacity and the costs negatively, our proposed process provides an economical route for the production of the oriented fibre semi-finished products.

MATERIALS AND METHODS

Material

In this study, bio-composites are reinforced with hemp fibres. The properties of the hemp fibres are shown in figure 1. Two different types of bio-fibres, PLA and bicomponent PLA fibres, were used as the matrix materials. The properties of the matrix PLA and the bicomponent PLA fibres are shown in figure 2 and table 1, respectively.

Fig. 1. Image of hemp fibre

Table 1

PLA AND BICOMPONENT PLA PROPERTIES		
Fibre type	**Fibre fineness (denier)**	**Staple length (mm)**
PLA	6.0	51
Bicomponent PLA	4.0	51

The hemp fibre used as reinforcing filler in this study was kindly supplied by Şiteks Şişmanlar Tekstil Sanayi A.Ş., Türkiye. Also, the polymer matrix used is polylactic acid (PLA) and bicomponent polylactic acid (PLA) was provided by Merkas Tekstil Sanayi ve Tic. A.Ş., Türkiye. The bicomponent content of the PLA fibre used a structure with 50% low melting temperature and 50% high melting temperature.

Methods

In this study, a carding process was used to parallelize the staple fibres. Discontinuous bio-fibres of both PLA, biocomponent PLA and hemp fibres were blended in five specified mixing ratios of 20%, 30%, 40%, 50%, and 60% for the production of biocomposite structures. Blended fibres were paralleled to each other and carded in a laboratory carding machine. To determine the effects of the amount of carding passage on fibre orientation, which is one of the main objectives of our study, the webs were produced by passing through three different passes: 1, 2, and 3 passages. A total of 32 samples were produced in line with these variable parameters. The web obtained after combing is wrapped around the drum of the carding machine.

The composite structure was obtained by using the thermoplastic properties of PLA and bicomponent PLA in the hot press machine which is a product of HURSAN and the model number is 50T. The experimental conditions on the hot press were total application time of 2 minutes at 165°C for PLA and 145°C for the bicomponent PLA, respectively. Owing to the heating conditions utilized in the press, the thermoplastic bio fibres melted at the specified temperature and time conditions and contained inside the mould. The composites were further set in the mould with the help of the cooling system present in the press to obtain the final samples. The properties of the produced biocomposite structures are detailed in table 2. The scheme of the application is shown in figure 3. For the tensile strength measurements, the composite plate samples were prepared as specified in the ASTM standard D3039/D3039M-14. These tests were conducted on an INSTRON 4411 testing machine. The samples were selected both in the machine direction, which is the carding direction and in the cross direction. The tensile test was repeated on 20 test samples for each of the settings.

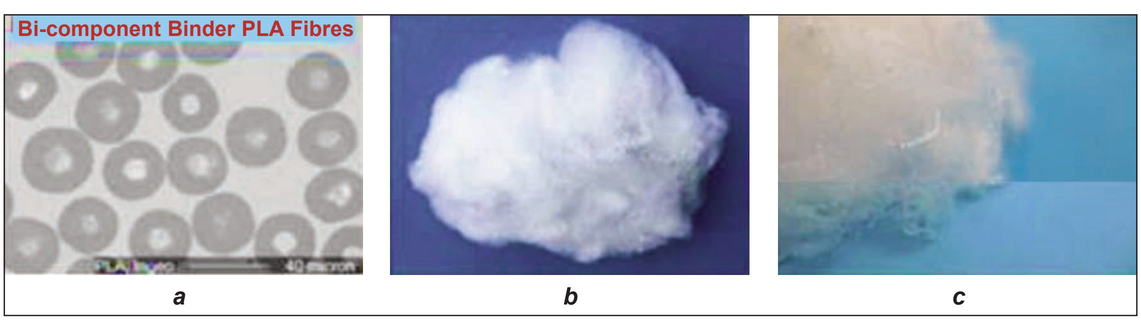

Fig. 2. Images of: *a* – cross-section of Bi-component binder PLA fibres; *b* – PLA fibres; *c* – Bi-component binder PLA fibres

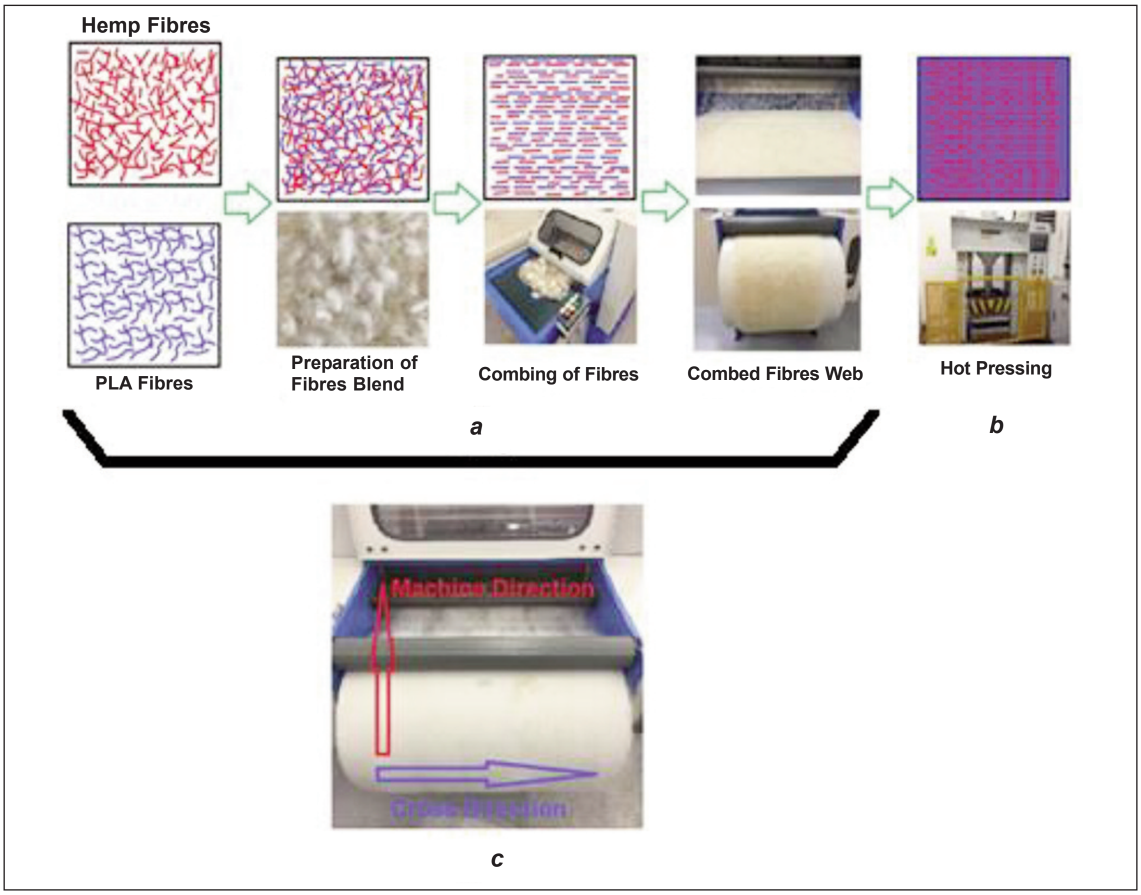

Fig. 3. Schematic drawing of the process: *a* – fibre blend; *b* – pressing process; *c* – machine views of the carding

Table 2

STRUCTURAL PROPERTIES OF BIO-COMPOSITE PLATES

Fibre type	Weight			Thickness			Composition		
	g/m^2	%CV	SS	mm	%CV	SS	HEMP, %wt	PLA, %wt	BPLA, %wt
PLA	275.15	03.34	09.18	0.33	13.64	0.05	-	100	-
BPLA	291.80	09.15	26.71	0.28	11.75	0.03	-	-	100
20HEMP/80BPLA/P1	254.80	05.96	15.20	0.30	13.30	0.04	20	-	80
30HEMP/70BPLA/P1	294.80	09.78	28.82	0.37	18.41	0.07	30	-	70
40HEMP/60BPLA/P1	278.20	08.48	23.59	0.43	16.01	0.07	40	-	60
50HEMP/50BPLA/P1	285.60	09.42	26.89	0.46	14.14	0.07	50	-	50
60HEMP/40BPLA/P1	282.40	11.18	31.56	0.52	14.13	0.07	60	-	40
20HEMP/80BPLA/P2	289.20	08.62	24.93	0.37	15.31	0.06	20	-	80
30HEMP/70BPLA/P2	270.40	08.67	23.45	0.39	13.48	0.05	30	-	70
40HEMP/60BPLA/P2	254.80	11.89	30.30	0.38	13.43	0.05	40	-	60
50HEMP/50BPLA/P2	247.20	11.40	28.18	0.46	12.08	0.06	50	-	50
60HEMP/40BPLA/P2	300.80	09.83	29.55	0.49	11.75	0.06	60	-	40
20HEMP/80BPLA/P3	292.20	08.09	23.63	0.36	15.71	0.06	20	-	80
30HEMP/70BPLA/P3	303.80	10.89	33.07	0.39	13.40	0.05	30	-	70
40HEMP/60BPLA/P3	281.80	09.45	26.64	0.41	14.25	0.06	40	-	60
50HEMP/50BPLA/P3	284.20	10.28	29.21	0.41	13.75	0.06	50	-	50
60HEMP/40BPLA/P3	277.80	10.64	29.55	0.47	13.87	0.06	60	-	40
20HEMP/80PLA/P1	289.46	08.65	25.02	0.25	16.49	0.04	20	80	-
30HEMP/70PLA/P1	293.20	08.89	26.06	0.32	15.56	0.05	30	70	-
40HEMP/60PLA/P1	311.60	08.07	25.16	0.36	17.55	0.06	40	60	-

Table 2 (continuation)

50HEMP/50PLA/P1	298.18	11.85	35.33	0.40	13.61	0.05	50	50	-
60HEMP/40PLA/P1	284.00	09.05	25.69	0.43	10.94	0.05	60	40	-
20HEMP/80PLA/P2	284.60	07.14	20.32	0.24	16.73	0.04	20	80	-
30HEMP/70PLA/P2	300.00	08.35	25.06	0.33	14.83	0.05	30	70	-
40HEMP/60PLA/P2	293.60	07.47	21.92	0.32	15.98	0.05	40	60	-
50HEMP/50PLA/P2	263.60	11.40	30.04	0.34	17.32	0.06	50	50	-
60HEMP/40PLA/P2	289.00	08.34	24.10	0.43	13.82	0.06	60	40	-
20HEMP/80PLA/P3	281.00	09.91	27.86	0.25	15.23	0.04	20	80	-
30HEMP/70PLA/P3	297.00	06.87	20.39	0.25	14.91	0.04	30	70	-
40HEMP/60PLA/P3	272.00	09.01	24.52	0.31	14.72	0.05	40	60	-
50HEMP/50PLA/P3	277.20	09.57	26.54	0.35	14.07	0.05	50	50	-
60HEMP/40PLA/P3	261.80	08.68	22.72	0.39	14.66	0.06	60	40	-

RESULTS AND DISCUSSION

For composite structures consisting of reinforcement and matrix materials, it is known that by increasing the amount of reinforcement material in composites, the strength of the structures can be increased. The mechanical properties of the developed materials mainly depend on the fibre content and their interfacial strength. Generally, the interfacial bonding strength between the hemp fibres and the PLA matrix is weak, which is a disadvantage of the natural fibre composite [18]. However, when the composite reinforcement material reaches saturation, the strength decreases. The reason for this decrease in the strength is caused by exceeding the critical fibre loading amount. In composite structures, the interface between the reinforcement material and the matrix material, as a result of excessive fibre loading, loses strength by not being able to bond with sufficient matrix material [2, 19, 20].

As the fibre web is obtained by carding on a conventional carding machine, the fibres are oriented in cross and machine directions. Consequently, the mechanical strength tests were carried out on the composite surface samples in both these directions.

The results in figure 4 show that for each of the mixture ratios, the strength in the machine direction is higher than the strength in the cross direction. Also, for both PLA and bicomponent PLA, the strength values of the composites increase with the increase of the reinforcement material. The strength value of the PLA matrix is higher than bicomponent PLA, as the PLA matrix creates a better interface with hemp fibre. The difference between these strength values is due to the direction of the fibres in the carding machine. The strength values increase with the

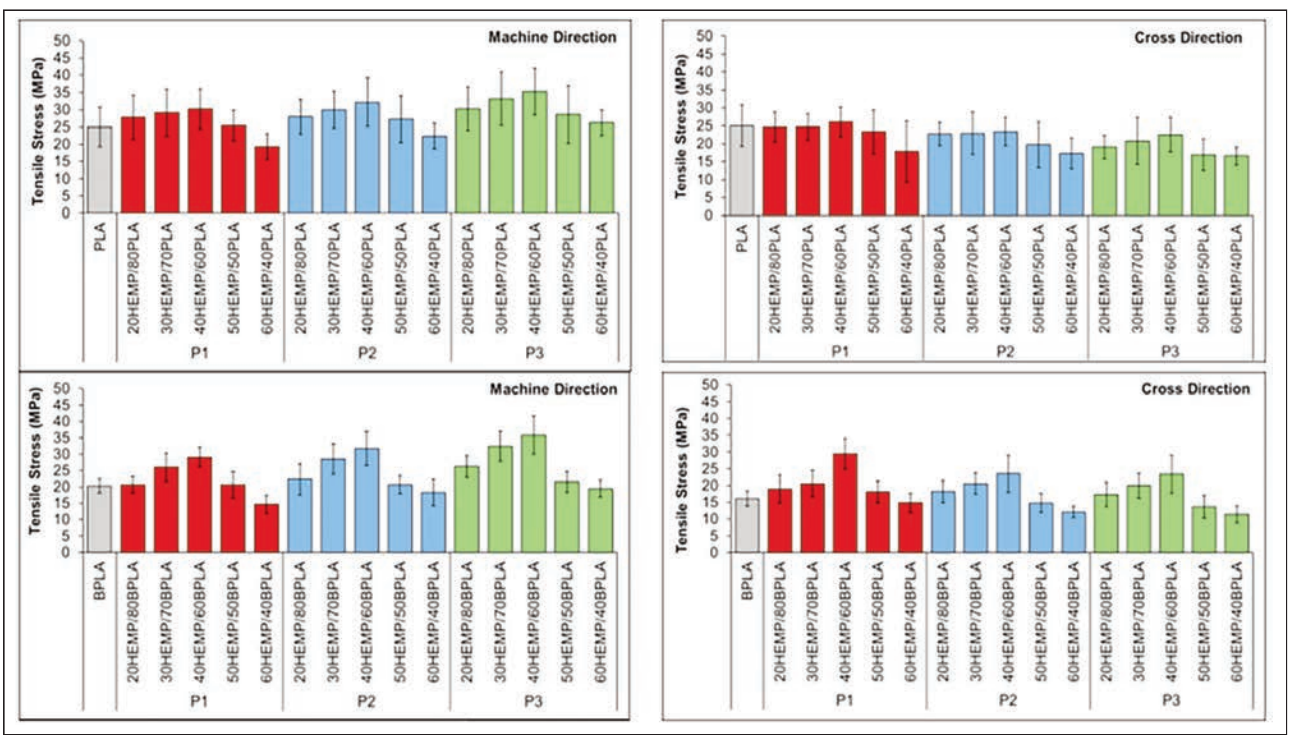

Fig. 4. The effect of reinforcement material on strength in biocomposite structures

increase in the loading amount of the reinforcement material in both the machine direction and the cross direction. The strength increase (by weight) is up to 40% reinforcement material. Since the increase in the reinforcement material after this loading amount causes saturation, the strength decreases above 40% of reinforcement.

The two main components of composite structures are the reinforcing elements and the matrix material. When the fibre web is obtained by the carding process on the carding machine, it is important to control the orientation of the fibres and to have a regular orientation. Multiple passages (three) of the carded hemp fibres were shown to be more effective and enable the control of the orientation of the reinforcement material [2, 19]. The number of carding passages was limited to 3 as it was predicted that a further increase in the number of carding passages would lead to fibre breakage and disorientation.

The results in figure 5 show that the strength in the machine direction is higher than the strength value in the cross direction for each mixture ratio. It is observed that the strength values for both PLA and bicomponent PLA matrices increase in the machine direction with the increase in the number of passages. However, the strength decreases with increasing the number of passages in the cross direction. This is an expected result because the hemp reinforcement material is aligned in the machine production direction.

Looking at figure 6, it can be observed that the elongation amount in the machine direction is higher than the elongation in the cross direction for each mixing ratio. This is because the fibre orientation is in the machine direction in the carding machine [21, 22]. The elongation amounts for both PLA and bicomponent PLA matrices decrease with the increase of the reinforcement material in both the machine direction and the cross direction. The elongation value of the PLA matrix is lower than the bicomponent PLA matrix. This is because the bicomponent PLA matrix partially melts away and the remaining thermoplastic fibres show a higher elongation value than the PLA matrix. In addition, the elongation value of the PLA matrix increased at 20% fibre amount, but with a further increase in the amount of reinforcing fibre, the elongation value decreased as the hemp fibres are of vegetable origin and therefore only allow limited elongation.

As can be observed in figure 7, the elongation value in the machine direction is higher than the elongation value in the cross direction for each mixture ratio. Tensile strength and the modulus of PLA/hemp biocomposites were improved with the increase of adhesion and better composite effect of hemp fibre and PLA. The movement of polymer chains may be restricted by their partial adsorption and by the friction between PLA and hemp fibre, leading to reduced elongation of the obtained biocomposites compared to neat PLA [23]. The elongation amounts of both PLA and bicomponent PLA matrices decrease in the machine direction as well as in the cross direction with the increase of the number of passages applied in the card web production. Since the reinforcement material is plant-based fibre, the elongation amount is limited.

According to the results shown in figure 8, it can be seen that the modulus in the machine direction is higher than the modulus in the cross direction for each of the mixing ratios. The modulus for both PLA

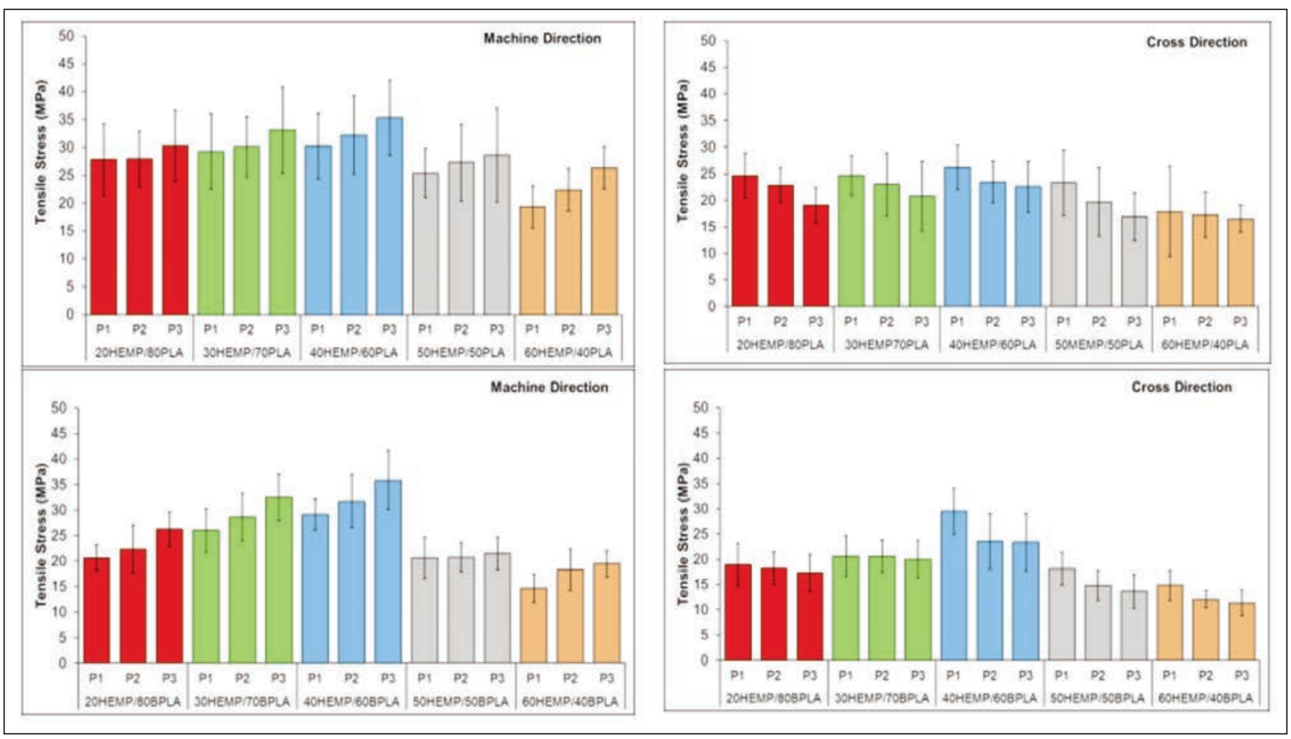

Fig. 5. The effect of the number of carding (passage) of the reinforcement material on the strength of bio-composite structures

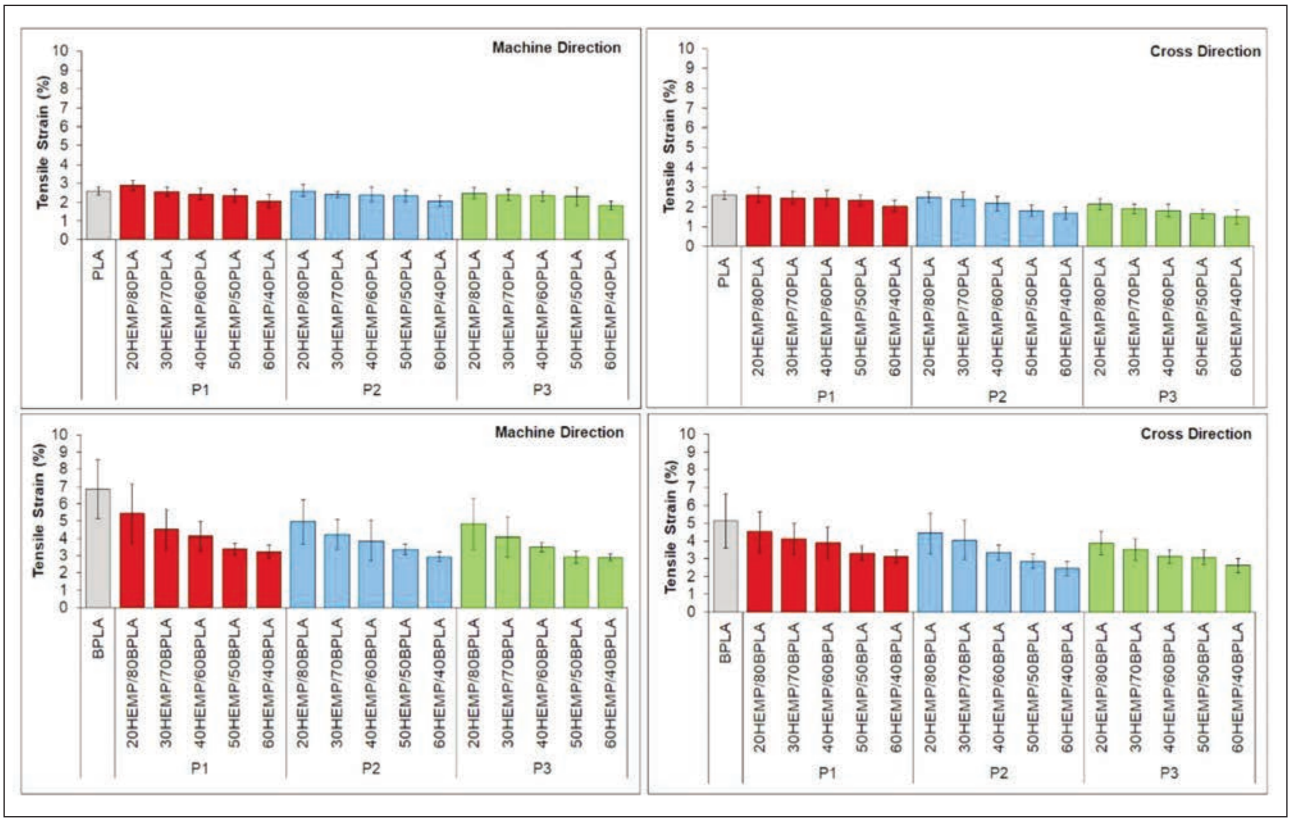

Fig. 6. The effect of reinforcement material on percentage elongation in bio-composite

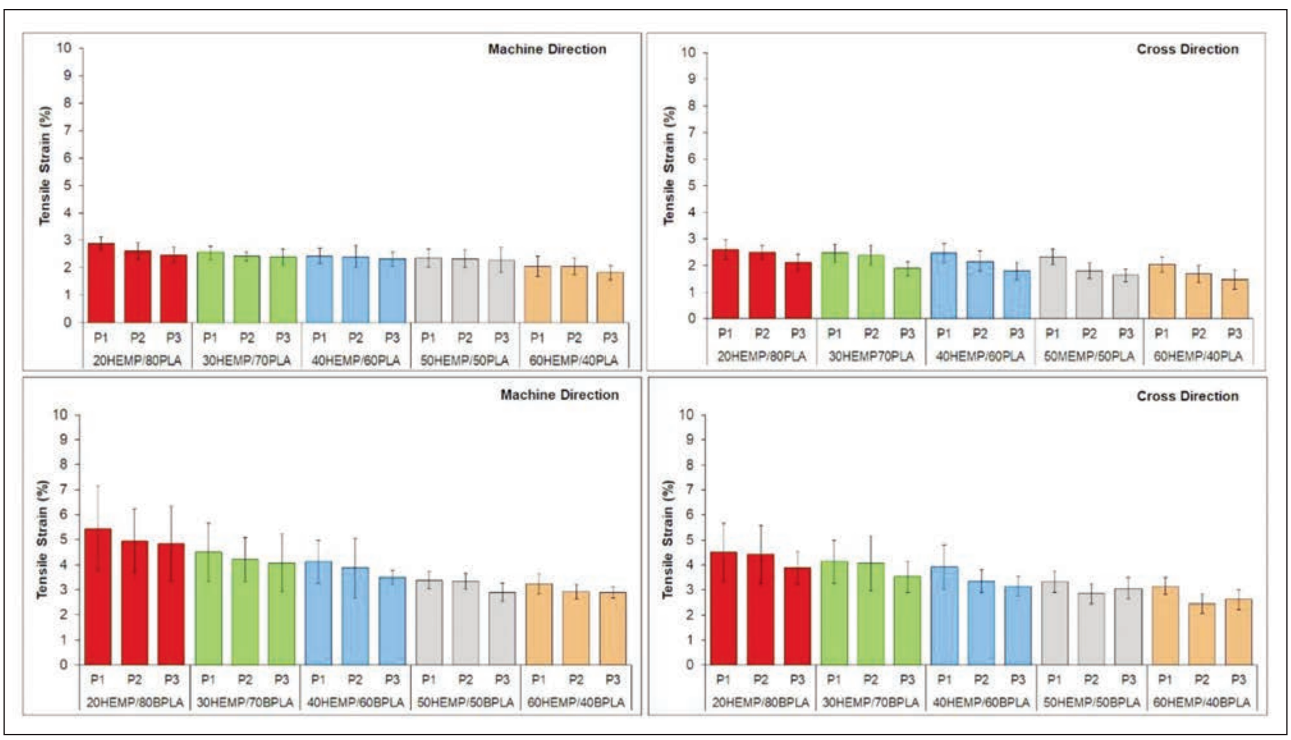

Fig. 7. The effect of the carding passage number of the reinforcement material on the percentage elongation in bio-composite structures

and bicomponent PLA matrices used in the samples increases with the increase of hemp fibre in both the reinforcement machine direction and the direction perpendicular to the machine direction [24]. The modulus value of the PLA matrix in composite samples is higher than the bicomponent PLA as the result of a better interface bonding that has occurred between the PLA matrix and hemp fibre. The reason for the difference between the modulus is the result of orientation in the carding machine. The obtained modulus values increase with the increase in the loading amount of the reinforcement material both in the direction of the reinforcement machine and in the cross direction. The modulus increases for up to 40% reinforcement material and with further loading, reduces.

On examining the results of figure 9, the modulus in the machine direction is higher than the modulus in the cross direction for each mixture ratio. For composite structures produced using PLA and bicomponent PLA matrix materials, the modulus increases in the machine direction as the number of carding web passages increases. However, it is seen that the modulus decreases in the cross direction with the increase of the number of passages applied in the production of the carded web. This is an anticipated

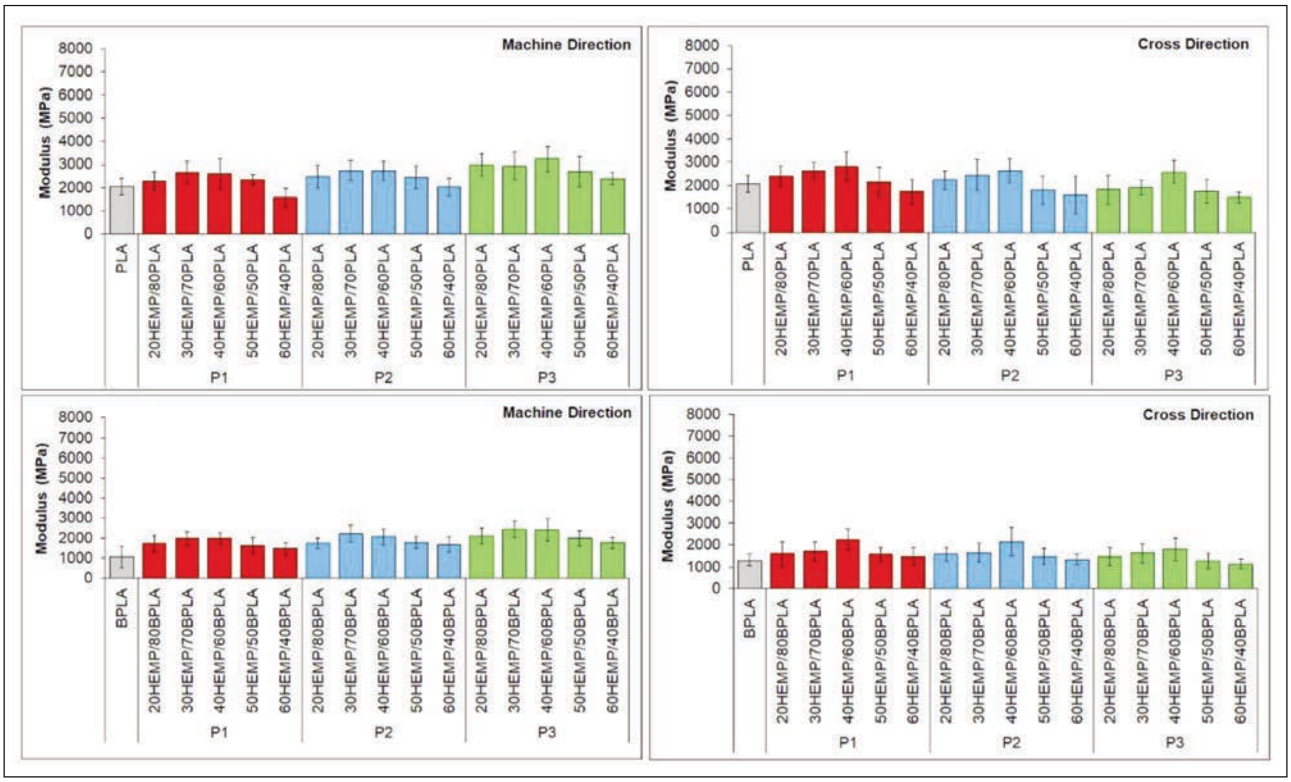

Fig. 8. The effect of reinforcement material on modulus in bio-composite structures

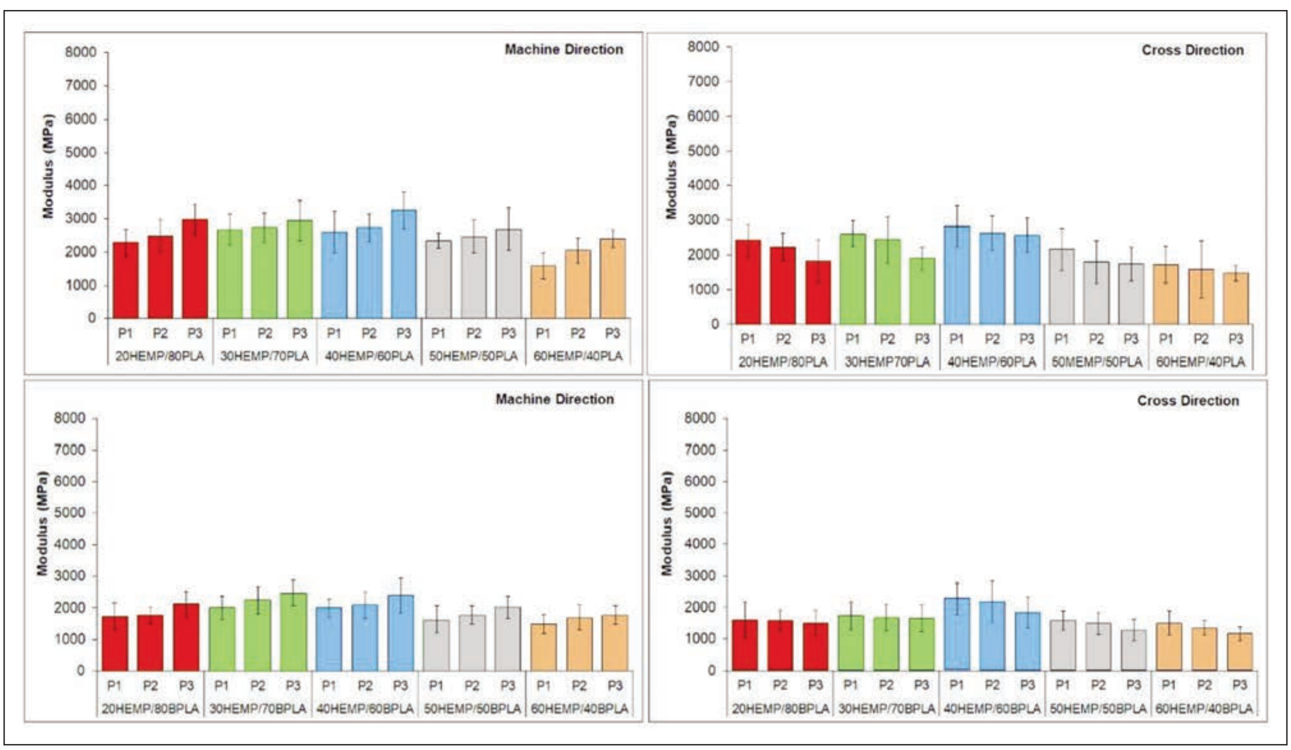

Fig. 9. The effect of the carding passage number of the reinforcement material on the modulus in bio-composite structures

result as the reinforcement material is aligned in the machine direction only [24–26].

CONCLUSION

In this study, bio-based matrix materials of PLA and bicomponent PLA, and natural plant-based hemp fibres were used in the preparation of bio-composites. Matrix and hemp fibres in the continuous form are blended and carded in a conventional carding machine. The carding web was formed in different material amounts ranging from 20%, 30%, 40%, 50%, to 60%. The main aim of the study is to explore the effect of hemp tow proportion, the number of carding passages, and the effect of orientation on the structural properties of fibre-reinforced composite structures. Carding webs containing different amounts of material were consolidated in the hot press process *via* heat and pressure to obtain composite surface samples. Mechanical tests were applied to composite specimens and their structural performances were examined. It was observed that the introduction of reinforcing hemp fibre leads to an increase in the tensile strength up to the critical fibre loading amount with an eventual decrease in the tensile strength beyond the critical fibre loading amount. The highest tensile strength of 35.84 MPa was obtained for the sample (40HEMP / 60PLA / M / P3) in the machine production direction, while the lowest value was 14.70 MPa (60HEMP / 40BPLA / M / P1), respectively. The tensile strength applied to the composite structures perpendicular to the machine direction was highest at 26.13 MPa (40HEMP / 60PLA / M / P3) with the lowest being 11.38 MPa (60HEMP / 40PLA / C / P3), respectively. The tensile strength was shown to increase with an increase in the number of carding passages. The breaking strength obtained in the machine direction is higher than the tensile strength in the cross direction. The strength value of composites obtained from the PLA matrix materials is higher than the bicomponent PLA. The elongation value of the composite structures produced from both the matrix materials decreases both in the machine direction and cross direction with the increase in the number of passages applied in the production of the carding web. The elongation at break in the machine production direction of the composite structures is the highest at 5.47% for 20HEMP / 80BPLA / M / P1 and the lowest at 1.83% (60HEMP / 40PLA / M / P3). The elongation of composite structures' cross direction is the highest at 4.82% (20HEMP / 80BPLA / C / P1) and the lowest at 1.49% (60HEMP / 40PLA / C / P3), respectively. The modulus value of the composites increases with an increase in the loading amount of the reinforcement material (hemp fibre) in both the reinforcement machine direction and the cross direction as well. The internal structures of PLA fibres are different from the internal structures of Bi-component PLA fibres. For this reason, when using PLA as the matrix material, the obtained modulus value Bicomponent PLA is higher. The highest modulus value of the composite structures in the machine production direction is 3245 MPa (40HEMP / 60PLA / M / P3) while the lowest is 1483 MPa (60HEMP / 40BPLA / M / P1). The highest modulus value cross direction of composite structures was obtained as 2823 MPa (40HEMP / 60PLA / C / P1) while the lowest value obtained is 1141 MPa (60HEMP / 40BPLA / C / P3). Hemp tows, a by-product of the hackling process, were used as reinforcement material in this study. The composite structures are just produced with cost-effective carding and hot press processes, without intermediate processes. Lightweight semi-finished composite materials have been produced. The surfaces developed in this study can be used in multi-layer lamination applications like the products in the literature and it is thought that they can be used in similar application areas.

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AdaBoost algorithm for the recognition of young women's body shapes based on 2D images

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ABSTRACT – REZUMAT

AdaBoost algorithm for the recognition of young women's body shapes based on 2D images

Classifying and recognizing the human body shape during human body measurements based on 2D images helps to improve measurement accuracy. In this paper, 430 young women's 2D body images were selected to establish 2D body datasets. The characteristic indices used to represent the body shape in 2D images were extracted by computer vision technology, namely the body height pixel value, projected unit area, and projected area ratio of the front and side of the body. The two-step cluster model was used to classify the body shape into three clusters: the tall, flat, and medium fatness type; the short, thin, and medium roundness type; and the round, fat, and medium height type. Then, the decision tree model and AdaBoost algorithm, an ensemble learning algorithm with the decision tree as the weak classifier, were used to recognize the body shape. The results show that the recognition accuracy of the decision tree recognition model was 93.19%. The body shape recognition method using AdaBoost achieved a better recognition effect than the decision tree model, and the recognition accuracy of the test set reached 97.35%. Through comparative study, we found that the recognition accuracy of the 2D body shape recognition method based on AdaBoost was improved and that the recognition accuracy was relatively stable. This study provides a new method for the recognition of human body shape in clothing customization and online shopping.

Keywords: *body shape classification, body shape recognition, 2D images, AdaBoost, decision tree*

Algoritmul AdaBoost pentru recunoașterea formelor corpului persoanelor tinere de sex feminin pe baza imaginilor 2D

Clasificarea și recunoașterea formei corpului uman în timpul măsurării acestuia pe baza imaginilor 2D ajută la îmbunătățirea preciziei măsurării. În această lucrare, au fost selectate 430 de imagini corporale 2D ale persoanelor tinere de sex feminin pentru a stabili seturi de date corporale 2D. Indicii caracteristici utilizați pentru a reprezenta forma corpului în imagini 2D au fost extrași prin tehnologia recunoaşterii vizuale computerizate, și anume valoarea pixelului înălțimii corpului, aria unității proiectate și raportul suprafeței proiectate a părții frontale și laterale a corpului. Modelul de tip cluster în doi pași a fost folosit pentru a clasifica forma corpului în trei clustere: tipul de înalt, plat și mediu de grăsime corporală; tipul scurt, subțire și mediu de rotunjime corporală; tipul rotund, gras și mediu de înălțime. Apoi, modelul arborelui decizional și algoritmul AdaBoost, un algoritm de învățare de ansamblu cu arborele decizional în calitate de clasificator slab, au fost utilizate pentru a recunoaște forma corpului. Rezultatele arată că precizia recunoașterii modelului arborelui decizional a fost de 93,19%. Metoda de recunoaștere a formei corpului folosind AdaBoost a obținut un efect de recunoaștere superior decât modelul arborelui decizional, iar precizia recunoașterii setului de testare a atins 97,35%. Prin studiu comparativ, s-a constatat că precizia metodei de recunoaștere a formei corpului 2D bazată pe AdaBoost a fost evident îmbunătățită și că precizia recunoașterii a fost relativ stabilă. Acest studiu oferă o nouă metodă de recunoaștere a formei corpului uman în personalizarea îmbrăcămintei și cumpărăturile online.

Cuvinte-cheie*: clasificarea formei corpului, recunoașterea formei corpului, imagini 2D, AdaBoost, arbore decizional*

INTRODUCTION

Intelligent customization of clothing has become indispensable in personalized clothing consumption at present. However, the realization of remote, fast, and accurate human body size acquisition has become the biggest bottleneck facing clothing enterprises during intelligent customization [1, 2]. The body shape affects the morphological features of the body. The rapid classification and recognition of the body shape can be applied to the anthropometry of clothing customization enterprises to improve measurement accuracy [3]. The existing classification standards of female body shape mainly include girth difference, cross-sectional shape, body surface angle, and characteristic index. According to the way of obtaining classified data, the body classification methods are divided into three categories: body shape classification based on 3D body scanning size, 3D–2D interactive body shape classification, and body shape classification based on 2D images. Wang et al. extracted data on 24 lower body parts with a 3D body scanner and divided the lower body into a tall and obese body type, a short and intermediate body type, and a tall and lean body type [4]. This is a body shape classification method based on 3D body size, which is mostly used in current body shape classification research [5]. With the development of 2D anthropometry research, multiple 3D–2D interactive body shape classification methods have been developed. Cai et al. proposed to use "3D scanning+photos" to classify and identify the waist–abdomen–hip figure of young women [6]. In this method, the body size from 3D scanning is used to classify the body shape, 2D body photo data are converted into a 3D body size, and then the body shape is identified. The method of body shape classification and recognition based on a 2D image refers to body shape classification by using the information features reflected by the 2D image, and it does not involve the 2D–3D transformation process. Based on the concept of 2D body type classification, Zhang et al. used the 3D point cloud data of young men to extract the 2D human angle. They selected the forward angle, back angle, shoulder oblique angle, neck-to-shoulder width ratio, and neck transverse sagittal diameter ratio to classify the neck and shoulder. Then, based on the front and side 2D photos of young men, the neck and shoulder shapes were automatically recognized [7], which simplified the process of the conversion of 2D data to a 3D size in literature [6]. At present, there are few studies on body type classification using 2D images exclusively, and mostly concentrated on the angle and some parts of the human body. The main reason is that 2D images reflect less human data information, which requires researchers to broaden the scope of classification feature selection.

The essence of human body shape recognition is the process of identifying the category to which body characteristic indices belong by using appropriate recognition rules based on body shape classification. The methods of recognition rules mainly include the interval method, the formula method, and methods based on artificial intelligence. The interval method involves dividing a certain feature of the body into several intervals, and the numerical value indicates the corresponding interval to which the body shape belongs. For example, the classification and discrimination method of body shape in the Chinese clothing size standard. The formula method is, to sum up multiple body shape characteristics into functional equations by statistical methods and then complete body shape recognition by bringing the characteristics of the unknown body shape into the formula during body shape recognition [8]. The body shape recognition method based on artificial intelligence has high accuracy and wide applicability, making it the most widely used method in research on body shape recognition at present. The two types of body shape recognition methods based on artificial intelligence are recognition algorithms based on an individual learner and recognition algorithms based on ensemble learning. Recognition algorithms based on individual learners mainly include decision trees, SVM, and naïve Bayes algorithm. Jing et al. used the naïve Bayes algorithm to differentiate the body shape of girls based on 27 measurement sizes [9]. In contrast, recognition algorithms based on ensemble learning mainly include the Boosting and Bagging algorithms [10]. XGBOOST is one Boosting learning algorithm [11]. Liu et al. used the back hip length-to-waist girth ratio and back hip length-to-hip girth ratio as clustering indexes, divided the hip shape of young women in Xinjiang into three types, and used Python software to establish a hip recognition model based on the XGBOOST algorithm to realize automatic body shape recognition [12]. Moreover, random forest [13] is a special Bagging algorithm. Yin et al. described and classified the female body shape from three aspects: whole body type, morphological characteristics, and torso silhouette. They used the random forest algorithm to identify the three types of characteristics [14].

Through much literary analysis, researchers have found that the previous body characteristic analyses and recognition methods are based on the obtained body size, but it is difficult to obtain 3D body sizes remotely during clothing customization. Therefore, in this paper, 2D body photos, which are the easiest to collect in garment remote customization, were used as the research object. First, the characteristic indices of the body were extracted based on computer vision technology, and the body shape was divided into three types by using the two-step cluster model. Then, the decision tree and AdaBoost models were used to recognize bodies in 2D images. The research framework of this paper is shown in figure 1. This

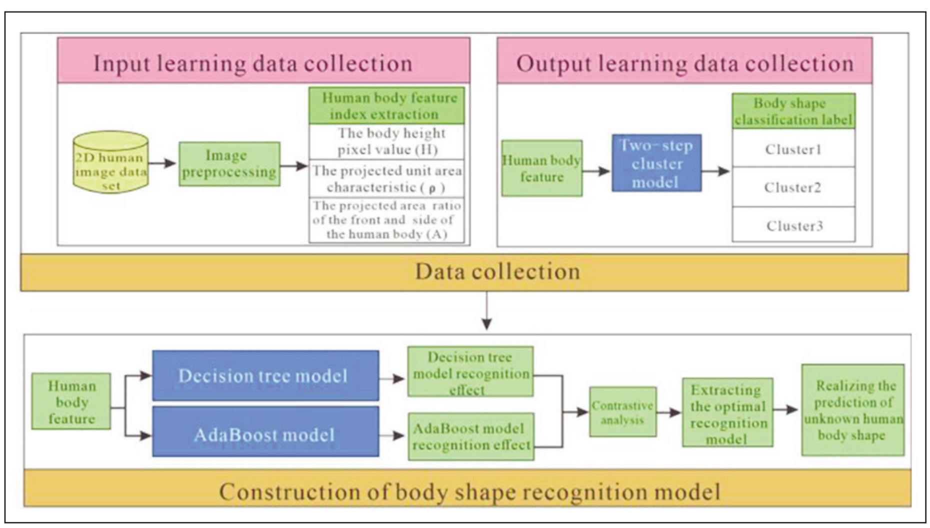

Fig. 1. Framework of the proposed methodology

method realizes the classification and recognition of the body shape without the body size, and it is a body classification and recognition method based entirely on 2D images. The realization of this method is crucial for anthropometric technology based on 2D images and further promotes the development of garment remote customization.

RESEARCH METHOD

Establishment of a 2D image dataset

The 2D body images were obtained from a 3D body database in this study, and a 2D image dataset was established; a total of 430 young women aged 18–25 years were randomly measured, with a height of 145.7–178.6 cm and a weight of 35.6–90 kg. During measurement, the subjects wore tight-fitting underwear, kept their bodies straight, and kept their shoulders straight but not stiff. There were two postures for measurement. The first posture was to stand with the feet apart, arms at a 20° angle to the body, and palms facing inward. The second position was to stand with the arms together and positioned against the sides, with the feet together, while breathing normally and not sucking in the stomach.

2D body characteristic index extraction

Effective characteristic extraction is the premise of body type classification and recognition [15]. In this paper, a human characteristic extraction method based on 2D photos is proposed by using computer vision technology. This characteristic can be used in the classification and recognition of human body shapes in 2D images.

The body height pixel value characteristic extraction (H)

The body height is used as the normalization standard to normalize 2D digital images to eliminate the influence of size factor on body characteristic extraction. Select the maximum height of the sample, and set the distance from the top of the head to the bottom of the feet as P pixels in the body area. In this paper, $P = 700$, and we normalized the height data by using formula (1), where H is the normalized height, h – the body height of any sample, h_{max} – the maximum value of the body height, and h_{min} – the minimum value of the body height.

$$H = P * \frac{h - h_{min}}{h_{max} - h_{min}} \quad (1)$$

Extraction of the projected unit area characteristic (ρ)

As shown in figure 2, *a* and *c*, the front and side 2D images of the body were $M \times N$ in size. After binarization, the body area was white, and we set the pixel value to 1, and the background area was black, and we set the pixel value to 0. Let the height direction of the body be the Y-axis, and the vertical direction of the Y-axis be the X-axis. The cumulative distribution of points with the pixel value of 1 in the X- and Y-axis directions of the body area, that is, the cumulative distribution of pixel value $f(i,j) = 1$, was calculated using the statistical method as follows:

$$X_{(i)} = \sum_{j=1}^{N} f(i,j) \; (i = 1,2,3,\ldots,M),\; f(i,j) = 1 \quad (2)$$

$$Y_{(j)} = \sum_{i=1}^{M} f(i,j) \; (j = 1,2,3,\ldots,N),\; f(i,j) = 1 \quad (3)$$

Figure 2, *b* and *d* show the histograms of the grey distribution of the binary image of 2D digital photos. The maximum height difference of the distribution of white dots along the X-axis and the Y-axis was calculated as follows:

$$X\_I = \max(X(i)) - \min(X(i)) \; (i = 1,2,3,\ldots,M) \quad (4)$$

$$Y\_I = \max(Y(j)) - \min(Y(j)) \; (j = 1,2,3,\ldots,N) \quad (5)$$

X_I represents the height characteristics of the body, and Y_I – the body fat characteristics. The distribution of the grey histogram is different for different body heights, fatness, and thinness. The greater the X_I, the higher the height, and the greater the Y_I, the fatter the body. However, only using X_I and Y_I can roughly explain the height and thinness of the body, which is not suitable for comparative analysis. Therefore, we used the projection unit area ρ to represent the average fatness of the body. We set the body height pixel value to be H and the cumulative white point count in the frontal image of the body to be F, and then, ρ was calculated as follows:

$$\rho = \frac{F}{H} \quad (6)$$

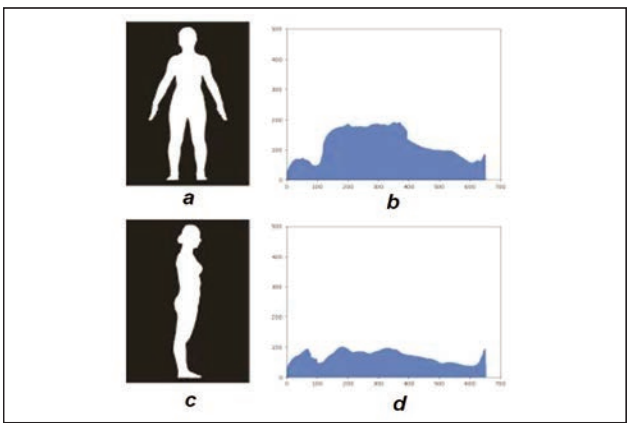

Fig. 2. Binary image and grey histogram of a 2D body image: *a* – front 2D images of the body; *b* – histogram of the grey distribution of the binary image of 2D digital front photos; *c* – side 2D image of the body; *d* – histogram of the grey distribution of the binary image of 2D digital side photo

Extraction of the projected area ratio of the front and side of the body (A)

Only using ρ cannot accurately express the body shape information when classifying the body shape, and the roundness of the torso also affects the body shape and the effect of clothing. According to the Chinese national standard GB/T 16160-2017 “Parts and Methods of Body Measurement for Clothing” and the proportional relationship between human body parts and height, using the local ergodic method determined the side neck point and shoulder endpoint, then the head and neck information of the body was removed along the side neck point, and the arm information was removed along the shoulder endpoints. Also, the ratio of the front and side projection areas of the body was extracted to characterize the degree of roundness of the body. We set the cumulative number of white points on the front of the body as Z and the cumulative number of white points on the side of the body as B. The ratio of Z to B is defined as follows:

$$A = \frac{Z}{B} \tag{7}$$

Body shape recognition method

Decision tree recognition model

Decision tree, including the root node, decision node, and leaf node, is a natural processing mechanism for decision-making based on the tree structure [16]. The leaf node corresponds to the category attribute of the decision tree, and the decision node corresponds to an attribute test. The root node contains the complete set of samples. The path from the root node to each leaf node corresponds to a decision test sequence. Decision tree has the advantages of a simple structure, clear logic, and good interpretability. The best decision tree can be constructed by known prior data to predict the category of unknown data. In this paper, the decision tree ID3 algorithm was used to identify the body shape. This algorithm is a machine learning algorithm first proposed by Quinlan in 1975. It takes information entropy and information gain as the measurement indices of node splitting to study the classification problem.

AdaBoost recognition model

Ensemble learning completes the learning task by constructing and combining multiple individual learners, which is also called a multi-classifier system or committee-based learning. The general structure of ensemble learning is to generate a group of "individual learners" and then combine them with some strategy. Individual learners are usually generated from training data by an existing algorithm. There are two types of integration: homogeneous integration and heterogeneous integration. Homogeneous integration means that all individual learning algorithms are of one type; heterogeneous integration means that individual learners are composed of different types of learning algorithms. The ensemble learning algorithm overcomes the overfitting problem caused by the sampling strategy and improves the overall performance, accuracy, and stability of the machine learning algorithm [17]. In this paper, an AdaBoost homogeneous ensemble learning algorithm based on a decision tree model is proposed for 2D human body shape recognition.

AdaBoost is an efficient ensemble learning method proposed by Yoav Freund. It combines many weak classifiers to create a strong classifier, and there is a strong dependence among individual learners. The algorithm includes an iterative training process of weak classifiers and an integration process of weak classifiers [18, 19]. The steps of AdaBoost are as follows: first, initialize the weight of each sample, train a weak classifier, and calculate the error rate of the classifier. Then, according to the performance of the classifier in the previous iteration, the weight of each sample is updated, the weight of the incorrectly identified sample is increased, and the weight of the correctly classified sample is decreased. The essence of AdaBoost's learning process is to change the weights of samples in constant learning until the error of learning results is zero or the number of learners reaches the preset value and then synthesize the learning results of all weak classifiers according to the weights to output the final results [20]. The algorithm flow is as follows:

a. Determine the decision tree as a weak classifier;

b. Determine a 2D body feature sample training set S: $S = \{(x_1,y_1), (x_2,y_2), \dots, (x_n,y_n)\}$, $x_i \in X$;

b. The body shape classification label is $y_i \in Y = \{1, 2, \dots, k\}$;

d. Initialize the weights of the training sets of the samples and endow all training samples with the same initial weights, that is, $w_i = \frac{1}{n}$. Then, the initial weight distribution of the sample is $D_1 = (w_1, w_2, \dots, w_n) = (\frac{1}{n}, \dots, \frac{1}{n})$, where D_1 is the initial weight of the training set samples, and n – the number of samples in the training set;

e. Using the weighted sample training set to learn, obtain a weak classifier, $h_m : X \rightarrow Y$;

f. Calculate the classification error rate of the sample training set as follows:

$$e_m = \sum_{i=1}^{n} w_i^{(m)} [h_m(x_i) \neq y_i] \tag{8}$$

g. The weak classifier weight is given by

$$\alpha_m = L_r \left[\ln \frac{1 - e_m}{e_m} + \ln (R - 1) \right] \tag{9}$$

where L_r is the learning rate, and R – the number of the body type;

h. Update the sample weight:

$$w^T = \frac{w^{T-1} \exp(\alpha_T F)}{Z_T} \tag{10}$$

The F condition is used to represent the prediction result of the weak classifier. Here, Z_T is the normalization factor, and its calculation formula is as follows:

$$Z_T = \sum_{i=1}^{m} w_i^T \tag{11}$$

i. The weighted sum of all weak classifiers is

$$f_{(x)} = \sum_{m=1}^{T} \alpha_m h_m(x) \tag{12}$$

j. The final classifier is obtained as follows:

$$H(x) = sign(f(x)) = sign\left(\sum_{m=1}^{T} \alpha_m h_m(x)\right) \tag{13}$$

where T is the number of iterations, and α_m – the weak classifier weight.

RESULTS AND DISCUSSION

Cluster analysis

In this study, the two-step cluster (TSC) model in Statistical Product and Service Solutions (SPSS) software was used to cluster the body shape. The most significant advantage of TSC is that it can automatically calculate the optimal number of clusters, and the classification variables were H, ρ, and A. The body types are divided into three types. Information such as the number of people and the centroid of each type is shown in table 1.

Table 1

CLUSTER RESULTS				
Cluster		**1**	**2**	**3**
Sample size		164	162	104
Proportion (%)		38.1	37.7	24.2
The centroid of each element	H	652.68	611.30	632.95
	A	1.54	1.52	1.46
	ρ	105.81	101.87	108.20

As can be seen from table 1, the greater the H of the centroids of the three types of body shapes, the higher the body height, and the closer A is to 1, indicating that the cross-sectional shape of the whole body is closer to the circle, and the greater ρ indicates that the body is fatter. By analysing the centroids of H, A, and ρ, we can divide the three types of body shapes as follows. For the first cluster, H = 652.68 indicates that it is the highest among all body types, A = 1.54 indicates that its cross-sectional shape is the flattest among the three body types, and ρ = 105.81 indicates that it is in the middle of the three clusters; thus, this cluster is called the tall, flat, and medium fatness type. For the second cluster, H = 611.30 indicates that it is the shortest of all body types, A = 1.52 indicates that the cross-sectional shape of its body is close to the standard ellipse, and ρ = 101.87 indicates that it is the thinnest of these three clusters; thus, this is called the short, thin, and medium roundness type. For the third cluster, H = 632.95 indicates that it is of medium height, A = 1.46 indicates that the cross-sectional shape of its body is a relatively round ellipse, and ρ = 108.20 indicates that the body is the fattest among the three clusters; thus, this is called the round, fat, and medium height type.

Body shape recognition

If the feature extraction and classification methods involved in this study are to be applied in practice, the intelligent recognition of body shape is important. Based on Python software, this paper establishes the decision tree model and AdaBoost model to recognize the body shape of unknown females in 2D body images. Training data are usually a large part of the dataset, which is used to learn discriminant rules. The more training data collected, the higher the accuracy of the results. The test data are used to obtain the correct rate of the classifier. In this paper, the ratio of training data to test data was 8:2, that is, 344 groups were randomly selected as training sets, and the remaining 86 groups were test sets. The features used for body shape identification were H, ρ, and A, and the results of body type classification were used as body shape identification labels.

Body shape recognition based on decision tree

We established the ID3 recognition model of the decision tree, trained the features of 2D digital images using the training set, and then tested the recognition effect of the model using the testing set. We set the number of tree nodes to (7, 15) and the number of iterations to 100, and we compared the classification accuracy of different tree nodes to determine the optimal number of tree nodes.

Table 2 shows the classification accuracy corresponding to the number of different nodes. When the number of selected nodes increases, the classification effect of the decision tree model on body shape is improved. When the number of nodes is 12, the classification accuracy of the decision tree model to the test set reaches 93.19%. When the number of nodes exceeds 12, the classification accuracy of the model starts to stabilize.

From the data in the table, it can be seen that the accuracy of the decision tree model in body shape classification is not high. To avoid misjudgement in practical application, it is necessary to improve the classification accuracy of body shape. Ensemble learning algorithms such as AdaBoost can greatly improve the classification effect of weak classifiers; so, this paper attempts to establish a body shape recognition model using AdaBoost.

Table 2

RELATION BETWEEN THE NUMBER OF NODES AND CLASSIFICATION ACCURACY OF DECISION TREE MODEL

Node number	**Recognition accuracy rate (%)**	**Node number**	**Recognition accuracy rate (%)**
7	90.83	11	93.14
8	92.07	12	93.19
9	92.07	13	93.19
10	93.14	14	93.19

Table 3

RELATION BETWEEN THE NUMBER OF NODES AND CLASSIFICATION ACCURACY OF THE ADABOOST MODEL			
Node number	**Recognition accuracy rate (%)**	**Node number**	**Recognition accuracy rate (%)**
7	95.26	11	96.30
8	94.87	12	96.30
9	94.87	13	97.35
10	96.30	14	96.30

Body shape recognition based on the AdaBoost model

In this paper, AdaBoost was used to train the sample data in the training set, and the recognition effect of the model was also tested by the test set. Using the decision tree model as the weak classifier, we initialized the sample weight, set the node number of the weak classifier to (7, 15), and set the number of iterations to 100. The classification accuracy of AdaBoost under different node numbers is shown in table 3.

As can be seen from table 3, when the number of nodes in the decision tree as its weak classifier is 13, the classification effect of the AdaBoost classifier on the test set is 97.35%. After 100 iterations, the AdaBoost algorithm improves the classification accuracy of test sets from 93.19% to 97.35% compared with the decision tree algorithm, and it improves the recognition accuracy by 4.16%. The above analysis proves that the classification effect of AdaBoost is better than that of the weak classifier.

Modelling verification

To verify the superiority of AdaBoost in body shape recognition when the data volume is small and the classification is complex, we adjusted the sample size of the dataset to 362 samples for body shape recognition, and at the same time, we increased the number of clusters for body shape classification and divided the body shape into six clusters. With the same number of nodes and iteration times, the recognition accuracy of the decision tree model is reduced to 81.45% at this time, while that of AdaBoost is 95.8%, which is 14.35% higher than that of the decision tree model. Thus, AdaBoost shows more stable recognition accuracy in the case of few samples and complicated classification.

CONCLUSION

In this paper, 2D digital images of the human body in garment remote customization were taken as the research object, and computer vision technology was used to extract body shape features for classification and recognition. The principles of the decision tree and AdaBoost were deeply analysed. The comparative experiment showed that AdaBoost had high accuracy in recognizing the body shape in 2D images. The following conclusions were drawn:

Using computer vision technology, we extracted the body height pixel value (H), the feature of the projected unit area (ρ), and the feature of the projected area ratio of the front and side of the body (A) as the body feature indices for body type classification and recognition. Using the two-step clustering model, we divided the bodies into the following types: the tall, flat, and medium fatness type; the short, thin, and medium roundness type; and the round, fat, and medium height type. The recognition accuracy rate of 2D body shape in the test set by the decision tree model was 93.19% and that of AdaBoost based on the decision tree was 97.35%. Compared with the decision tree model, the AdaBoost model had higher recognition accuracy, especially when there were many classifications and insufficient data. Moreover, AdaBoost effectively solved the over-fitting problem of recognition. Therefore, the method can be used in human body shape recognition and related fields.

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Traditional marketing mix helps clothing store brands analyse service value and increase customer retention

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ABSTRACT – REZUMAT

Traditional marketing mix helps clothing store brands analyse service value and increase customer retention

This study sought to determine how the conventional marketing mix might assist low-cost clothes in assessing the value of their services and increasing client retention. Due to this shortage, contemporary authors have suggested introducing an additional crucial aspect, namely after-sales support, while studying the service marketing mix (SMM) for "cheap clothes". This study examined and included one new dimension of the service marketing mix instead of the conventional 7 P's of SMM. In this study, the effects of SMM cloths on service quality and client retention in Hubei Province were also examined. These effects included advertising, place, people, product, pricing, process, physical evidence, and after-sales service. Clothing Store brand providers from "Hubei Province" compete with one another in a crowded market since there are so many new entrants selling and providing comparable goods and services. Retention consequently becomes an issue. Surveys with different persons in various positions, such as professors, PhD students, MSc students, and BSc students of various nationalities, were done, and data was obtained using the convenience sample technique. In "Hubei Province", the sampling technique was utilized to gather information from clothes whose guests had ever stayed in low-cost Hubei Province clothes. The Partial Least Square Method was utilized to evaluate the data from the 385 valid questionnaires that were obtained for this investigation. The results showed that both directly and indirectly, through service value, the service marketing mix had a considerable beneficial impact on customer retention. This study will be valuable to the low-cost Cloth sector since it will clarify the role that marketing mix strategies have in sustaining long-term client connections.

Keywords: *service marketing mix, service value, customer retention, clothing store brands, Hubei province*

Mixul de marketing tradițional ajută brandurile magazinelor de îmbrăcăminte să analizeze valoarea serviciilor și să crească retenția clienților

Acest studiu a încercat să determine modul în care mixul de marketing convențional ar putea ajuta sectorul de îmbrăcăminte cu costuri reduse să determine valoarea serviciilor și să crească retenția clienților. Din cauza acestui dezavantaj, autorii contemporani au sugerat introducerea unui aspect crucial suplimentar, și anume suportul post-vânzare, studiind în același timp mixul de marketing al serviciilor (SMM) pentru „produsele ieftine de îmbrăcăminte". Acest studiu a examinat și a inclus o nouă dimensiune a mixului de marketing al serviciilor în locul celor 7 P convenționali ai SMM. În acest studiu, au fost examinate, de asemenea, efectele îmbrăcămintei SMM asupra calității serviciilor și retenţiei clienților în Provincia Hubei. Aceste efecte au inclus reclamele, locul, oamenii, produsele, prețurile, procesele, dovezile fizice și serviciile post-vânzare. Furnizorii brandurilor de magazine de îmbrăcăminte din Provincia Hubei concurează între ei pe o piață aglomerată, deoarece există atât de mulți nou intrați pe piaţă care vând și oferă bunuri și servicii comparabile. Prin urmare, retenţia clienţilor devine o problemă. Au fost efectuate sondaje cu diferite persoane de diferite profesii, cum ar fi profesori, doctoranzi, masteranzi şi studenţi de diferite naționalități, iar datele au fost obținute utilizând tehnica eșantionului de conveniență. În Provincia Hubei, tehnica de eșantionare a fost utilizată pentru a colecta informații referitoare la îmbrăcăminte de la persoane din provincia Hubei care nu au purtat niciodată îmbrăcăminte ieftină. Metoda celor mai mici pătrate parțiale a fost utilizată pentru a evalua datele din cele 385 de chestionare valide care au fost obținute pentru această investigație. Rezultatele au arătat că atât direct cât și indirect, prin valoarea serviciului, mixul de marketing al serviciilor a avut un impact benefic considerabil asupra retenţiei clienților. Acest studiu va fi valoros pentru sectorul de îmbrăcăminte cu costuri reduse, deoarece va clarifica rolul pe care strategiile privind mixul de marketing îl au în susținerea conexiunilor pe termen lung cu clienții.

Cuvinte-cheie*: mixul de marketing al serviciilor, valoarea serviciului, retenția clienților, brandurile magazinelor de îmbrăcăminte, provincia Hubei*

INTRODUCTION

Nowadays, clothing store brands go beyond addressing basic needs such as food and shelter; they also offer additional services, such as personalized assistance. The Chinese clothing sector has emerged as a crucial driver of the country's economic growth and development amid ongoing organizational and sectoral transformations [1]. To stay competitive, clothing store brands in this dynamic sector must innovate and enhance their services through diverse and comprehensive programs that set them apart from their competitors. To achieve this, managers must thoroughly grasp their customers' needs and expectations, and adapt product and service offerings accordingly [2]. Recognizing that service characteristics can significantly influence customer retention, clothing store brands should prioritize service quality, including tangibles, assurance, reliability, responsiveness, and empathy. Neglecting these aspects may result in negative customer evaluations, jeopardizing the brand's potential to attract more customers. Recent research underscores the impact of various marketing factors such as promotion, price, place, product, people, process, and physical evidence on consumer retention in the clothing sector. These factors are crucial in fostering consumer loyalty and satisfaction [3].

The Service Marketing Mix (SMM) can be a command strategy and offer the organizational margins required to dominate the service value (SV) market. Customers of these service providers will be impacted by their active usage of SMM components, which will increase customer retention (CR), enable them to remain longer, and provide them with a more competitive position in their business lives. This study aims to determine whether there is a significant relationship between SMM and SV Cloth services and Clothing Store brand retention in Hubei Province [4] description of a lack of exploration and research in this Clothing Store brand area.

The Service Marketing Mix can be command strategies and offer the organizational margins required to dominate the service value (SV) market [5]. Customers of these service providers will be impacted by their active usage of SMM components, which will increase customer retention (CR), enable them to remain longer, and provide them with a more competitive position in their business lives [6]. This study intends to determine whether there is a significant relationship between SMM and SV Cloth services and Clothing Store brand retention in Hubei Province [4] description of a lack of investigations and research in this Clothing Store brands sector.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Customer retention

A sales organization must pay great attention to the details to decrease client complaints. Customer retention starts with the first time a customer interacts with a business and lasts the duration of the relationship. The cost of obtaining a new client is significantly higher than the cost of sustaining an existing customer relationship, hence customer retention is crucial for most firms [7]. In low-cost clothes, studies have underlined the value of client retention [3].

Customer retention is a relatively simple case to make. Keeping existing clients is more difficult than gaining new ones. Obtaining customers to “replace” those who have left comes at a high cost. This is because the importance of attracting customers is only realized during the early stages of a business relationship [4]. Furthermore, happy and satisfied long-term customers buy more and can generate positive word-of-mouth marketing for the brand. As a result, long-term customers take less time and are less susceptible to price changes [8]. These findings reflect management's ability to acquire referral firms, which are frequently of high quality and low cost. As a result, it is claimed that reducing product failures by just 5% will double revenue [8].

Service Value

According to earlier literature, there is a lack of agreement on several aspects surrounding the core issue in the building of service value, including the uncertainty in how it is defined [9, 10]. Value definitions are ambiguous, which makes it difficult to determine service value. As a result, they shouldn't be employed in research studies to prevent service value from being abused or overused [11].

Although most of the terms are related to the same definition, researchers used a variety of terms to describe the construct of service value [12].

According to Woodall [13], the market benefit resulting from purchasing and using the brand contact has been given eighteen different names. However, according to Woodall, the most commonly used words in advertising literature are “customer interest” [13, 14], “perceived value” [15, 16], and “value” [17].

Furthermore, many researchers have asserted that service value is a mediating variable that can influence whether or not customers are retained [18–21]. Treacy, Sheth, and Reichheld claim that there is a dearth of research on the connection between marketing mix, service value, and client retention. Sweeney looked studied the effects of various pricing techniques on service value in Thailand's telecom sector. Customers have been seen to be perplexed by extremely complicated pricing schemes. Butz and Goodstein [22] established a model of service value for the telecom sector that focuses on quality, value, and pricing, all of which are crucial elements in determining customer satisfaction. The conception of service value was explained in numerous ways to meet the research project's setting. The proper customer satisfaction concept must be used to prevent any interference with performance results or outcomes from the customer target group. The majority of definitions of service value in the literature were process-based, suggesting that the evaluation process was involved [23].

Service Marketing Mix

It has been stressed how crucial SMM's leadership is in resolving consumer concerns over advertising. The 7P's, an expansion of the 4P's, includes seven MM components, including: service/product, cost, promotion, place, people, process, and physical evidence. To obtain and sustain competitive advantages, it can be said that each organization needs to implement an effective MM strategy. The marketing mix and the target audience are two interrelated components of the advertising strategy. A target market, by Kiran and Diljit [24], analyses the profile of various consumer groups with various wants, desires, and expectations, and builds an integrated marketing communications plan to highlight and convey the advantages of an organization's goods or services. The next section provides a succinct explanation of each of the nine SMM dimensions: Another idea put up at the time by Boom and Bitner was applicable in the manufacturing industry and applied to services like "after-sales service" in the banking, airline, and cloth industries [25].

The process of developing the Service Marketing Mix (SMM), which consists of the 4Ps and 7Ps, is currently underway. To increase earnings, this mixture is changed in a range of sectors. Anderson and Narus [26] found that the 8Ps of the SMM are necessary for Cloth and tour services. Haq et al. [27] also made some other 2Ps for cloths. These 8Ps are insufficient for such services, according to other studies [28], and the SMM for clothes [29] needs to be raised, especially in low-cost lodgings.

There are some gaps in this area despite the increased importance of customer retention research. Saccani et al. [30], customer retention has been widely accepted as an important topic over the past decades. However, research focusing on management processes associated with customer retention performance is limited. In addition, various studies on customer retention and its key antecedents have been conducted in developed countries. Nevertheless, only a few works have been done in the developing world on customer retention. Based on the identified gaps, this study examined the impact of selected marketing mix elements on customer retention in the clothing industry. However, limitations of this research include the lack of a unified body of work supporting and explaining the intricate interplay of the service marketing mix, service quality, service value, and customer retention in different labels of apparel stores. Despite these constraints, five knowledge gaps were uncovered, and they include; the elements and methods utilized to support the marketing mix notion are mostly unknown, as well as how they are being implemented in the context of apparel shop brands in China [31, 32]. Furthermore, the conflicting findings on customer satisfaction, including its methodology, have not been thoroughly studied, which may make it difficult to adequately assess the service marketing mix rendered in apparel shop brands [33, 34]. The lack of empirical studies on the relationship between service value and customer retention in a model where service marketing mix and service quality operate as stimulation factors is also an identified gap in the literature [35].

Marketing academics continue to focus on the marketing mix idea despite its drawbacks and objections. Without undermining the concept's contribution, prior research has attempted to advance or strengthen the theoretical and practical marketing mix principles that are pertinent to the marketing context. Additionally, earlier studies have attempted to broaden the marketing mix concept from an internal focus on operational and managerial functions to a customer focus on customer orientation strategy and relationship marketing cloth services [36, 37]. Additionally, prior research on the marketing mix has shifted from a managerial to a customer perspective, particularly following the release of Boom and Bitner's framework in 1981.

The Boom and Bitner framework can be used in the manufacturing industry, as well as in the provision of services like after-sales support and relationship marketing, as well as by banks, cloths, and cloth agencies. By incorporating personalization [38], publication [39], productivity, and quality [12], and emphasizing people rather than participation, several scholars extended the 7Ps paradigm to service marketing [40–42] and suggested an extra 8^{th} P to broaden the marketing mix for cloth services. As a result, corporate organizations in the twenty-first century can use the 7Ps of service marketing in combination as a fundamental tool to develop marketing strategies and operational-tactical techniques to increase customer happiness, brand loyalty, and company performance (table 1).

As a result, the goal of this study is to examine seven dimensions of service marketing and determine their impact on service value and customer retention

Table 1

PROPOSED CHANGES TO NOMENCLATURES OF SERVICE MARKETING MIX (CLOTHING STORE BRANDS)

Dimensions	Argument	Source
Product Price Promotion Place	• Service marketing lacks interaction with consumers. • The inappropriateness of the 4Ps is not the proper basis of the 21^{st} Century marketing. • 4Ps applicable for internal orientation and need to shift to customer orientation. • Incompleteness of 4Ps for effective today's marketing. • 4Ps focus only on products and ignore the service sector, especially in cloth services (Budget Hotel).	[43]
People Process Physical evidence	• Additional 3Ps were considered as part of the marketing mix for the service sector. • The service sector needs more concentration on customer satisfaction and loyalty. • Services are more critical to handle as compared to products that's why additional functions were required to make this mix more practical and oriented to fulfil the exact needs of service users.	[44, 45]

among Cloth customers. The elements of the service marketing mix, namely product, price, promotion, place, people, process, and physical evidence are discussed for a better understanding.

Hypotheses development

The background of the analysis was used to establish the current study hypothesis (figure 1). The study's stated aims were to be accurately and directly addressed by the hypotheses. All hypotheses are balanced by the items in the questionnaires for this report. According to the current study's hypothesis, the mix of product promotion affects the dependent factor for customer retention. These two independent factors are important predictors of customer retention in Clothing Store brands since they are constantly present in the context of Cloth customer experience concerns. In this study, the service value offered the indirect relationship as a mediating element. As a result, the current study suggested testing four hypotheses; the process of developing hypotheses is covered in the subsection below.

The relationship between service marketing mix and customer retention

Ali and Amin [1] concur that the marketing mix is a crucial element for streamlining the management of marketing activities and enabling the division of marketing efforts to meet client wants and retention. In support of this claim, Sarker et al. [46] discovered that six components of the product marketing mix – excluding service costs – were crucial for retaining customers in the tourism industry. In a similar vein, Thalib [47] found in his tourist research a relationship between customer retention and five components of the service marketing mix, namely service item, service cost, service location, service people, and service physical evidence. In other words, putting into practice a product marketing mix would affect client retention.

The position of the service marketing mix as a single construct, however, has been left unclear and undefined by earlier studies, including that of Othman et al. [48] and Jobhaarbima [49]. There is a void in the existing research that must be filled. As a result, the first supposition for this inquiry is as follows:

H1: Higher perceptions of the service marketing mix performance are associated with high customer retention.

The relationship between service marketing mix and service value

According to the theoretical perspective of the stimulus-organism-response paradigm, external stimulus variables aid in thinking and analysis of interior individual states [50]. Goi et al. [51] study overcame environmental factors that significantly affected the organism. It implies that motivating elements, such as the service marketing mix, can influence people's perceptions of a service's worth.

In the past, fragments of this link have been investigated. The results of the Cengiz and Yayla [52] study show that service location and price are crucial components of service value. Ye et al. [53] found that the location, cleanliness as a component of the physical evidence, and service to the employee's service value were all important variables. In contrast, Ryu et al. [54] found a connection between the value of good customer service and the standard of the cuisine served in Chinese restaurants across the country. Due to a lack of coverage in earlier literature, the relationship between the service marketing mix and service value is still not generally known or fully understood. Further research into this relationship produces a valuable finding that closes the knowledge gap. On the other hand, the outcome of the report was given more value by using the formative approach to service marketing and service value. The current study makes the following claim in light of multiple other findings and an appealing theoretical idea:

H2: Higher perceptions of the service marketing mix performance are associated with high service value.

The relationship between service value and customer retention

An in-depth discussion of the connection between service value and client retention can be found in the literature on service marketing. Numerous researches on this relationship imply that service value comes before customer retention and that service value significantly affects customer retention [55, 56]. Based on earlier discoveries about the significance of linkages between these two concepts, the current study is not restricted to further research in this area. In the context of car parking services, the study's findings add to what is already known about this link. According to the discussion that came before, the third theory was put forth as follows:

H3: Higher perceptions of the service value performance are associated with high customer retention.

The mediating role of service value between service marketing mix and customer retention

The ideal service marketing mix creates organizational elements that are active and serve as a driving force for service value and client retention. Customer satisfaction building and promotion may be more variable if service value is considered in the relationship between the service marketing mix and customer retention. According to earlier studies, the value of the service influences customer retention [57, 58].

Prior research has examined the components of the service marketing mix independently, as was noted in the paragraph before, but this review argues that doing so violates the marketing mix theories by evaluating the components of the service marketing mix separately for the dependent variable [59]. The findings regarding the contribution of the service marketing mix to service value and client retention were contradictory. However, a few studies have found that the relationship between the components of the service marketing mix and customer retention is mediated by service value. For instance, food quality and menu variety are somewhat mediated for female customer retention by service value, according to Kwun [60]. In Kwun's study, service value elements incorporating the service people feature were mediated by service value in terms of customer retention.

It is worthwhile to look at the relationship between service marketing mix, service value as a mediating component, and customer retention as there are currently no empirical explanations for it. As a result, the following is the fourth hypothesis put out in this study:

H4: Service Value has a significant positive relationship between Service marketing mix and customer retention.

Conceptual framework

The following model was chosen as the conceptual model of this study based on the literature review: The SMM includes seven essential elements known as P's, including "price, product, place, process, promotion, physical evidence, and people all of which are independent variables, and customer retention is the dependent variable. In addition, as shown in figure 1, service value is a mediator. The purpose of elements is to assess the relationships between SMM, SV, and CR.

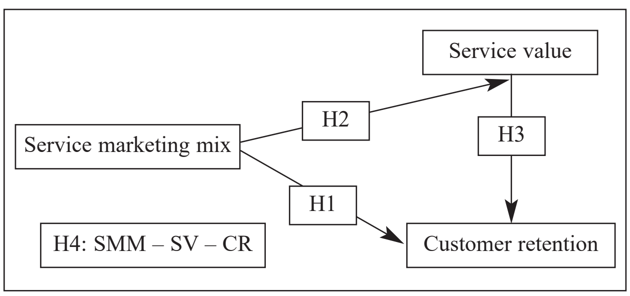

Fig. 1. Research Framework

METHODOLOGY

The participants in this study were Cloth guests who stayed in a Hubei Province Clothing Store brand. The questionnaire is a quantitative tool. It is the tool that is used to collect data from respondents through their responses. The researcher creates a list of questions and then asks respondents to rate their responses on a scale (Likert scale). The respondents were chosen from a sample of cloth customers who had prior experience with the Cloth using a nonprobability sampling design, more specifically, a convenient sampling technique. A detailed ethical approach to data collection is followed to preserve objectivity and collect data responsibly. Initially, the researcher requested permission to collect data from Chinese authorities. To collect data for this study, researchers used a quantitative and cross-sectional survey method. Data was collected from Cloth customers in China during July and August 2019.

All of the respondents were chosen by convenience sampling, which means that they were freely available to answer questions. It's also worth noting that all of the questionnaires are self-administered in person with various people in various positions, such as professors, PhD students, MSc students, and BSc students of various nationalities in "Hubei Province". The sample size for this study was 385 respondents who participated in the survey, with the data being analysed using the Partial Least Square method. The current study employs a reflective-formative modelling strategy that is appropriate for the evaluated constructs. At a higher order construct level, one construct, namely SMM, was measured using formative modelling, which included eight variables coded as product (PRD), price (PRC), place (PLC), promotion (PRM), people (PEP), process (PRO), and physical evidence (PHY). With the aid of clever PLS software and confirmatory factor analysis, the validity of the questionnaire was examined. Additionally, the reliability of the questionnaire was examined using composite reliability and Cronbach's alpha. Results that were above 70% show that the questionnaire is extremely dependable [61]. The survey was divided into four parts. In the first section, the respondents' demographic data is shown. In the survey's second segment, questions are posed regarding promotion [62], pricing [63], product [63], place [64], physical evidence [23], people [64], and process [65] Items of service value were the subject of the third part [66]. The final paragraph addressed problems with consumer retention [67].

FINDINGS AND DISCUSSION

Profile of respondents

The purpose of the respondent profile is to examine the respondents' characteristics of the study samples that were established. The percentages and frequencies in table 2 define the sample by gender, age, occupation, qualification, marital status, monthly salary, and the number of Cloth stays per month, as well as the Source of Information for the type of Cloth the respondents stayed in each month. The following information pertains to each of them.

Male Cloth consumers accounted for 38.7 percent of the total, while female Cloth consumers accounted for approximately 61.3 percent. It was discovered that men are less likely than women to stay in Clothing Store brands. Age is a proxy for people's knowledge about their purchasing behaviours, and it demonstrates that those aged (26–35) place a higher premium on Cloth purchases.

The preceding explains the respondents' demographic characteristics: 30.6 percent are between the ages of 36 and 45 years. Customers' capacity to have a Cloth is fuelled by their acquisition of them as the personification of their financial capabilities. The data in table 2 demonstrates that consumers with a monthly salary of 5000 to 7000 (RMB) imitated customers of Clothing Store brands at a rate of 24.7 percent. Consumers can currently reserve rooms at a

Table 2

DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS			
Demographic	**Characteristic**	**Frequency**	**Percentage**
Gender	Male	149	38.7
	Female	236	61.3
Age	Below 18 years old	25	6.5
	19–25	92	23.9
	26–35	118	30.6
	36–45	96	24.9
	Above 45 years old	54	14.0
Qualification	Higher school	39	10.1
	Degree	90	23.4
	Master	44	11.4
	Doctoral and above	212	55.1
Occupation	Student	14 151	3.6 39.2
	Professionals	65	16.9
	Service personnel	58	15.1
	Freelancer	23	6.0
	Government	151 14	39.2 3.6
	Others	74	19.2
Marital Status	Single	197	43.8
	Married	169	51.2
	Other	19	0.05
Monthly Salary (RMB)	Below 3000	59	15.3
	3001 to 5000	89	23.1
	5001 to 7000	95	24.7
	7001 to 9000	64	16.6
	Above 9000	78	20.3
How many times you stay in a hotel per months	1 time	45	11.7
	2 times	68	17.6
	3 times	109	28.3
	4 times	103	26.8
	More than 4 times	60	15.6

variety of Clothing Store brands. The buyer's choice of Clothing Store brands is highly dependent on how much information is readily available. Clients with a higher level of qualification will be more selective and specific in their Cloth reservation selections. Buyer developments in the acquiring service Clothing Store brands dominated respondents with a master's qualification level of approximately 55.1 percent. This can be described as customers who make a service Clothing Store brand reservation having sufficient information, which can be used to make service Cloth purchases. Additionally, the users stayed at a service Clothing Store brands due to their marital status, and family offers have a significant impact on buyer behaviour. Additionally, husbands, children, and wives can procure services. Purchase intentions are influenced by a variety of factors, including marital status [39]. According to table 2, consumers who are married have a 51.2 percent influence on their purchase of services at Clothing Store brands. These instances demonstrate that the service Clothing Store brands range provides a high level of petition to clients who have been conjugal, as the family service Cloth's maximum modifications are purposefully shaped. The type of work that is processed corresponds to the customer's movement to resolve their situation [39]. A person's occupation also affects their consumption habits. For example, the characteristics of respondents by occupation subjugated by students equal 39.2 percent. The respondents' average number of Cloth stays per month is 11.7%, with the majority of respondents buying cloths three or more times per month to bought (28.3%), four or more times per month (26.8%), and twice per month (16.6%), with the remaining respondents staying in cloths more than four times per month (15.6%).

The findings in table 2 demonstrate where the respondents found their knowledge of cheap motels. The respondents had the option of selecting more than one response option, which was made available to them. 42 respondents received source information on low-cost clothes via friends, making up a significant portion of the respondents (272 respondents) who accessed their sources online. Meanwhile, 11 respondents cited a relative as their primary source of information regarding cheap clothes (s).

Measurement model

For all variables in the study, the value of (AVE) is greater than 0.5, and for all latent variables, the value of Composite Reliability is greater than 0.7, indicating that the qualified components maintain acceptable reliability. According to table 3, "latent variables" are classified according to their "convergence validity". Additionally, all latent values are greater than 0.6 when the "Cronbach's" test of reliability is used, which is adequate proof that the research material is dependable. Table 4 shows that the values of the AVE root square are bigger than the inter-structure correlations for all variables when evaluating discrimination validity. Thus, it can be said that the measurement model is quite trustworthy, and its validity is both useful and trustworthy in identifying the study's variables.

Hypothesis test

The idea is that every aspect of the service marketing mix (SMM) significantly improves customer retention (CR). The findings show that the route coefficient between SMM and CR was statistically significant, with a robust standardized estimate and a significant t-value of larger than 2.58 (p=0.000). Furthermore, the variance's R2 was 0.753, a significant level of explanation. The findings of the hypothesis testing show that CR was positively affected by all of the SMM dimensions in a statistically meaningful

Table 3

CONVERGENT VALIDITY AND MEASUREMENT MODEL				
Variables	**Code**	**Cronbach's Alpha**	**Composite Reliability**	**Average Variance Extracted (AVE)**
People	PEP	0.942	0.958	0.852
Physical evidence	PHY	0.944	0.957	0.818
Place	PLC	0.928	0.946	0.778
Price	PRC	0.917	0.942	0.802
Product	PRD	0.915	0.940	0.797
Promotion	PRM	0.876	0.915	0.730
Process	PRO	0.905	0.934	0.780
Service Marketing Mix	0.986	0.986	0.986	0.672
Service value	SV	0.931	0.948	0.785
Customer retention	CR	0.851	0.900	0.692

Table 4

DISCRIMINANT VALIDITY OF LATENT CONSTRUCTS										
Variables	**PEP**	**PHY**	**PLC**	**PRC**	**PRD**	**PRM**	**PRO**	**SMM**	**SV**	**CR**
PEP	0.923									
PHY	0.834	0.904								
PLC	0.811	0.828	0.882							
PRC	0.735	0.807	0.784	0.895						
PRD	0.745	0.798	0.774	0.814	0.893					
PRM	0.801	0.842	0.839	0.816	0.800	0.854				
PRO	0.861	0.906	0.827	0.809	0.859	0.841	0.883			
SMM	0.897	0.786	0.895	0.824	0.880	0.789	0.771	0.775		
SV	0.766	0.840	0.770	0.733	0.738	0.769	0.832	0.821	0.886	
CR	0.751	0.807	0.749	0.712	0.690	0.739	0.800	0.877	0.823	0.832

Note: PEP = people; PHY = physical evidence; PLC = place; PRC = price; PRD = product; PRM = promotion; PRO = process; SV = service value; CR = customer retention.

way. The results of focus groups on the known reasons for the positive and significant impacts of SMM on CR were used to determine the factors that contribute to the positive impact and significance of SMM on CR. This resulted from the clientele's misconception that low-cost accommodations offer excellent vacation experiences, have affordable rates, cleverly execute sales promotions, and have approachable office staff. The existence of proper facilities and infrastructure, along with employees who were responsible for the well-being of the clientele, led to the activation and construction of an enormous CR. According to the statement, developing CR requires utilizing all the aspects of the service marketing mix rather than just one.

The claim that all positive SMM aspects significantly influenced SV is the one being examined. The Smart PLS results showed that SMM and SV had a substantial association (p=0.000). A considerable level of variance was also explained by the service marketing mix, as indicated by the R2 for SV, which was 0.734. The results showed that each SMM parameter significantly and favourably affected the SV of low-cost clothes. The results of the recognition institution talk show that some of the things that drive SMM have a big, good impact on SV. The outcome of conversations held in a single low-cost Cloth acknowledged the SMM's enormously beneficial influence on SV. Usually, this was because the clothes were excellent businesses and the guests profited from the availability of comprehensive offerings. The high degree of interest and desire for clients to acquire services and use offers across the Cloth industry was also a result of an effective shopping system.

Contrary to what the literature normally suggests, the hypothesis is that service value (SV) has a positive and significant impact on customer retention (CR). In the Cloth service setting, the association between these constructs was also significant (β=0.503, S.E.=0.066, t=7.573, p=0.000). Five consumers have complained about the acquisition of offers due to the high quality and significant impact of SV on CR. Excessive CR occurs when customers view the worth of an enterprise in terms of both its characteristics (usage of the service) and the lack of such criticism (the impact on the client's readiness to apply for or

Table 5

SUMMARY OF HYPOTHESES TESTING RESULTS FOR DIRECT AND INDIRECT EFFECT						
Hypotheses		**β**	**Standard Deviation (STDEV)**	**T Statistics (|O/STDEV|)**	**P Values**	**Decision**
H1	SMM → CR	0.397	0.070	5.659	0.000	Supported
H2	SMM → SV	0.857	0.023	38.029	0.000	Supported
H3	SV → CR	0.503	0.066	7.573	0.000	Supported
H4	SMM → SV → CR	0.431	0.060	7.131	0.000	Supported

Note: SMM = Service Marketing Mix; SV = service value; CR = customer retention.

acquire the goods and services offered). Happy customers are more likely to become CRs. An individual's continued use of the company's goods and services is referred to as retention.

It is possible to confirm that the SMM has a substantial impact on SV, SV has a significant impact on CR, and SMM also has a significant impact on CR by linking the mediating variables of service value to the effect of the SMM on CR. The indirect effect of SV was reduced to β=0.431, after service marketing was combined with regression and bootstrapping procedures, reaching a statistically significant value at t=7.131 (p=0.000), and after dividing by the standard error, S.E.=0.060. Reduced to β=0.397, the direct route coefficient between SMM and CR is statistically significant at the level of (p 0.000). As a result, it was proven that SV fully served as a mediator between SMM and CR, proving that hypothesis H4 was correct. Table 5 displays the coefficient for each path. The data show that every conclusion of the Hypothesis is strongly and favourably related to service value and client retention.

Discussion

The study examined the effect of SMM on SV as well as the effect of SV on CR in the Hubei Province Clothing Store brands industry. The study was conducted using primary data. The data was gathered using questionnaires completed by guests of Clothing Store brands in Hubei Province. This finding indicates that Cloth customers in Hubei Province believe their rooms are spacious and comfortable. The Cloth provides guests with a sense of security and provides food and beverages, entertainment, recreation, and other complimentary services. Additionally, practitioners were required to conserve their marketing efforts, such as A price that is commensurate with the benefits you receive during your Clothes stay. Affordability of Cloth services, such as food, beverages, entertainment, and recreation, was also deemed critical. While obtaining promotional rates from the Cloth in comparison to the competition's pricing from other clothes was crucial for the establishment of Clothing Store brands, it was also important for the guest's decision-making. These promotional aspects included the production of advertisements (for example, in electronic or print media) and obtaining promotional rates from the cloth. Customers of cloths in Hubei Province have shown a demand for tangible evidence, such as a consistently clean and welcoming Cloth environment. Additionally, they like a management system that takes customer complaints into account, professional Cloth personnel, employee confidence in servicing clients, and the right Cloth staff.

In addition to this finding, it was discovered that the main factors influencing service marketing mixes were closely linked to SV and CR, with the location and process actively influencing SMM for SV and CR assessment. Customers of low-cost lodgings in Hubei Province were inclined to stay there again because they thought the Cloth manager provided a clean, safe, and orderly atmosphere. Customer satisfaction will also rise for the Cloth owner who consistently makes sure that there are enough rooms for all of their visitors and offers a convenient parking space. Additionally, customers valued helpful staff, a well-organized service process, easy booking and payment options, and access to cutting-edge information technology (IT).

Additionally, they liked telephone calls to fix any problems after the transaction, calls to get feedback on the services, fast service requests, and appealing post-sale support. Because of this, after-sales support was an essential part of the service marketing mix. Customer retention at cloths was positively and statistically significantly impacted by the after-sales service factor. These results serve as a reminder to practitioners to continue to acquire a deeper awareness of consumer needs when creating SMM strategies to be incorporated into the vision and mission statements of their organizations.

This result is consistent with the concept definition of service marketing mix utilized in the current investigation, which states that the service marketing mix aims to elicit the desired response from the target market [25]. Research by Senguo et al. [28] on low-cost airlines in Ali and Amin [1] on the Chinese tourism industry, and Han and Sean [67] on the satisfaction of Indonesian ship passengers all found a strong correlation between the service marketing mix and the value of the service provided. Due to the potential differences between the concept and approach used in the cited research and the present investigation, the latter was deemed to provide only limited support.

The results showed a strong and direct association between SMM factors that were wholly unrelated to one another. It was found that SMM, SV, and CR were all considerably and strongly related to one another. The impact of the SMM on CR can be explained in large part by SV. This suggests that marketing is the real beneficiary of SMM for CR. The outcomes also showed that everyone's dimensions significantly influence SV. The findings are in line with those from other studies [68].

Product, Price, Promotion, Place, People, Process, and Physical Evidence, are the components of the service marketing mix. A well-planned strategy for integrating these elements successfully boosts the importance of these components as a stimulant for customer retention. In terms of encouraging customer retention, the service marketing mix is still in its infancy. The S-O-R hypothesis, which asserts that people tend to think and judge in their response system in reaction to a specific stimulus, is another explanation that supports this conclusion.

CONCLUSION

As was already said, this study considers one tradition-integrated feature, namely after-sales service. Due to the significance of the after-sales service dimension in the service marketing mix, this research discovered that after-sales service has a considerable impact on SV and CR. Thus, confirming the usefulness of the present findings would require expanding and replicating this study in additional parts of the world and adding more services.

It may also be used as a foundation for additional validation of the analysis methodology created during this study to understand variances in customer behaviour. For academics and researchers, the study provides a wide range of practical consequences. The study's findings can be applied to a better understanding of the interactions between SV, CR, and service-selling companies.

The results of the current study are relevant to a range of experts in the low-cost Cloth industry. The market for inexpensive clothes is continuously developing. According to the study's conclusions, Clothing Store brands must prioritize SV to experience CR to grow sustainably. Policymakers and other high-level professionals will find the findings to be very helpful as they create various plans and strategies for this industry. The study can also be used by academics from other fields and nations around the world.

Despite the study's enormous scope, which goes beyond national boundaries, and its numerous unique elements, discoveries, and consequences in a variety of scenarios within companies at the micro level as well as for society at large, there is still a great deal of restrictions. The consumers of these services come from all over the world, however, the respondents in this study are all from Hubei Province. Therefore, while communicating and putting the study's findings into practice, researchers, government organizations, regulatory agencies, academics, and politicians should do so with prudence. If information was obtained from many districts and areas around the nation, the study would be more thorough. It is possible to carry out additional research to look at SMM, SV, and CR in other industries. Comparative studies can be helpful in a variety of industries, and most countries use these services to identify variations in SV and CR.

IMPLICATIONS OF THE STUDY

The current study showed that while the service marketing mix has a varying impact on service value and customer retention, it has a large direct impact on these two factors. In this study, the dimensions of product and people all play a crucial role in the service marketing mix, influencing how customers perceive the value of Cloth services, while all of the dimensions of the service marketing mix show a crucial role in generating customer retention.

When managing client retention, managers are urged to periodically measure and determine which features and advantages of the services they offer should be prioritized for customers. Since retention is one of the results of service consumption, managers must identify crucial elements from the outset, promote low-cost clothes, and refrain from switching to competing brands and service consumptions. Managers can monitor process flow, keep an eye out for changes in customer behaviour, and take the right action by developing a consumption system strategy. Managers can put their attention on the key performance indicators while contributing to the creation of marketing initiatives that are adapted to the needs of the client.

As a mediating construct between service marketing mix and customer retention, this study used service value rather than emotion, which was widely used in the S-O-R model [69]. There are a few studies that only focus on partnerships that mediate. As a result, this study offers important findings that support the notion that service value mediates the relationship between service marketing mix and customer retention to some extent.

Additionally, the diagrammatically demonstrated links between the service marketing mix, service value, and customer retention in the research framework have not been examined in low-cost Cloth environments, especially in China. By offering yet another research input on consumer behaviour in a service setting, the data and findings in this study contribute to the body of academic knowledge.

LIMITATIONS

The study's limitations should be taken into account when interpreting the results, even if the study's findings shed light on several important concerns. To learn more about the topics covered, however, these restrictions offer some directions for further research. To capture a person's internal response to behaviour, this study concentrated on customer retention. No company's main objective is to keep its customers. Customer retention is a strong predictor of a wide range of other outcomes, such as behavioural intention, retention, patronage, customer loyalty, and word-of-mouth. The results of this investigation were therefore limited to internal response.

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Analysis of influencing factors of raw cotton quality and prospect of optimisation pathway

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ABSTRACT – REZUMAT

Analysis of influencing factors of raw cotton quality and prospect of optimisation pathway

The paper discusses the issue of raw cotton quality and summarises it in the context of the current state of research. The article highlights the importance of cotton seeds for improving cotton quality and points out the problems in cotton seed selection and breeding. The article also mentions other factors affecting cotton quality, such as planting technology, light factors, defoliation and ripening technology, anisotropic fibre content and cotton picker operation quality. Based on these findings, ways to optimize the quality of raw cotton are proposed, including exploring suitable cotton varieties for machine picking, mitigating differences in raw cotton quality due to differences in geographic location and climatic conditions, and optimizing the use of picking techniques and processing machinery to reduce the impact on raw cotton quality. In conclusion, the paper provides a useful reference for promoting the application of cotton mechanical picking technology.

Keywords: *cotton seed, cultivation, fibre quality*

Analiza factorilor de influență ai calității bumbacului brut și perspectiva metodei de optimizare

Lucrarea dezbate problema calității bumbacului brut și o rezumă în contextul stadiului actual al cercetării. Articolul evidențiază importanța semințelor de bumbac pentru îmbunătățirea calității bumbacului și subliniază problemele în selecția și cultivarea lor. Articolul menționează, de asemenea, alți factori care afectează calitatea bumbacului, cum ar fi tehnologia de plantare, lumina, tehnologia de defoliere și coacere, conținutul de fibre anizotrope și calitatea operațiunii de culegere a bumbacului. Pe baza acestor constatări, sunt propuse metode de optimizare a calității bumbacului brut, inclusiv explorarea soiurilor de bumbac adecvate pentru culesul mecanizat, atenuarea diferențelor de calitate a bumbacului brut din cauza diferențelor de localizare geografică și condițiilor climatice și optimizarea utilizării tehnicilor de cules și procesarea tehnologică, pentru a reduce impactul asupra calității bumbacului brut. În concluzie, lucrarea oferă o referință utilă pentru promovarea aplicării tehnologiei de recoltare mecanică a bumbacului.

Cuvinte-cheie: *semințe de bumbac, cultivare, calitatea fibrei*

INTRODUCTION

In 2021, the domestic cotton planting area exceeded 45 million mu, with a total cotton output of 5.7 million tons. As shown in table 1, the cotton planting area in the Xinjiang region (subsequently recorded as XJr) was 2.5 million hectares, with an output of about 500 tons, whose share was more than 80%. The National Agricultural Mechanization Statistical Bulletin issued by the Department of Agricultural Mechanization Management in August 2022 [1] shows that, by 2021, the comprehensive mechanization rate of cotton in China has reached 87.25%, the mechanical harvesting rate of cotton in XJr has exceeded 80%, and cotton production has accounted for more than 85% of China's total cotton production. According to the China Agricultural Machinery Industry Association data, The cost of machine-picking cotton is reduced by 1.5 RMB per hectare compared to the labour cost, reducing the cost per mu of machine-harvested cotton by approximately 520 RMB. As a result, it can save about 60% on costs. Cotton cultivation in XJr is concentrated, with a large area and limited human

Table 1

XINJIANG COTTON PRODUCTION AND NATIONAL SHARE, 2016–2023

Item	2016	2017	2018	2019	2020	2021	2022
Total output (tons)	407.8	456.6	511.1	500.2	516.1	512.9	539.1
Share of the country (%)	76.3	80.8	83.8	84.9	87.9	89.5	90.2

Source: Statistical Bulletin of the National Economic and Social Development of the Autonomous Region.

resources, so the comprehensive mechanization of various processes in XJr cotton has become an inevitable trend [2]. In the face of expanding cotton production and the increasing demand for high-quality lint in the market, the cotton industry needs to continuously improve and innovate in various aspects, such as cotton seed cultivation, cotton planting, cotton harvesting, warehousing, and processing, to actively adapt to the current situation and trend of machine picked cotton processing, as well as further improve the quality of raw cotton.

FACTORS AFFECTING THE QUALITY OF RAW COTTON

By analysing the current research results involving raw cotton quality, it can be obtained that the main factors affecting the quality of raw cotton are as follows:

Cotton seed selection with multiplicity and heterogeneity

The two relatively important factors affecting the quality of raw cotton are cotton varieties and cotton processing technology [3]. The selection of cotton varieties, especially for the different harvesting and processing techniques, is important to improve the overall quality of cotton fibres. As shown in table 1 and figure 1, XJr's major cotton production areas and climatic environments are complex, especially with significant differences in climate between the north and south of XJr [4]. Some areas have shorter frost-free periods, the cotton growing season is limited, and the growth of cotton is greatly influenced by these natural conditions.

As shown in table 2, in recent years, XJr has applied for dozens of cotton varieties to be approved by the state, and the varieties approved by the autonomous region are more diverse. Therefore, the selection of cotton varieties in various regions has shown a "multiplicity and heterogeneity" state. As shown in figure 2, from the overall quality perspective, more than half of the cotton varieties selected by the main cotton-producing areas have a seed length of less than 31 mm and a fracture ratio strength of less than 31 cN/tex. The fibre length and specific strength of cotton have shown a trend of recovery, but the genetic quality of the cotton varieties currently being promoted is still insufficient [5–8].

At present, research on cotton seed mostly focuses on the aspects of cotton yield and fibre quality, including seed cotton yield, lint yield, boll weight, fibre strength, fibre length and fibre fineness. But the suitable cotton seeds for mechanized picking have higher requirements for plant height and bolls concentrated spitting flocculent. There are currently no reports of cotton varieties suitable for machine harvesting in XJr, and there is relatively little research on cotton varieties suitable for machine harvesting, too. There is still a lot of room for research [9, 10].

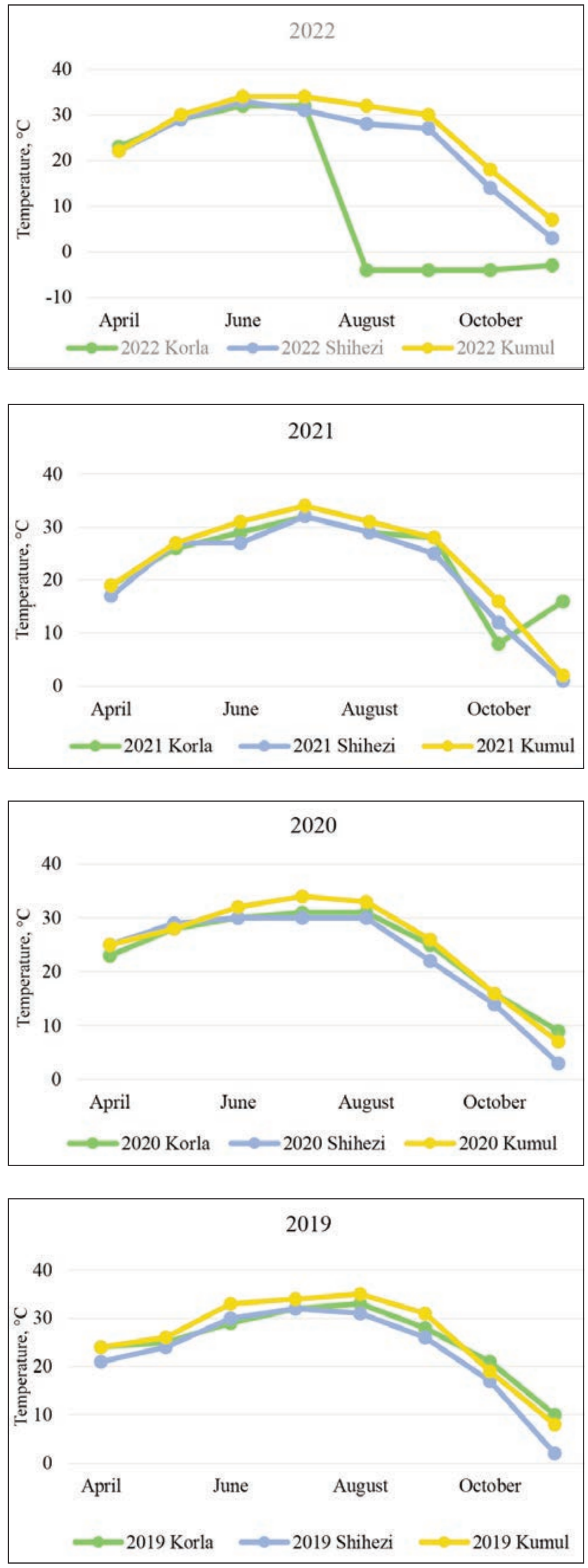

Fig. 1. Trends in cotton growing season temperatures in the three major cotton-producing regions of XJr

Planting technique's insufficient standardization

Every cotton seed sowing season, Due to non-standard cotton planting techniques and inadequate application of scientific cultivation methods, the growth potential of cotton is limited and the quality

Table 2

COTTON VALIDATED VARIETIES IN XJR IN 2018–2022					
National validated varieties		**Autonomous region-validated varieties**			
Validation Number	**Variety Name**	**Validation Number**	**Variety Name**	**Validation Number**	**Variety Name**
20210013	China Cotton 698	2022 No. 192	Ginken Brown 11	2021 No. 32	Santamu 6
20210011	Ginken 1746	2022 No. 191	Brown 620	2021 No. 31	Huiyuan 722
20210010	V Division 16-13	2022 No. 189	Anonkhai 1	2021 No. 30	Sky Cloud 2119
20210009	V Division 16-15	2022 No. 188	Jinfenghe 1	2021 No. 27	Ginken 1565
20210008	Huiyuan 162	2022 No. 187	Xinto 5	2018 No. 45	Ginken Miscellaneous 1062
20210007	Medium 7700	2022 No. 186	Xinto 4	2018 No. 44	Y21
20210005	New 19075	2022 No. 183	Brown 928	2018 No. 43	K2725
20210002	Huiyuan 1502	2022 No. 182	Brown 2305	2018 No. 40	Ginken 1441
20200025	K7	2022 No. 181	Gaming 21	2018 No. 39	Ginken 1161
20200023	Bar 43541	2022 No. 180	Gaming 22	2018 No. 38	Ziding 6
20200022	X19075	2022 No. 178	K432	2018 No. 61	MCR3915
20200020	Ginken 1643	2022 No. 177	Changfeng 2	2018 No. 60	New 78
20200019	H216	2022 No. 176	H163	2018 No. 59	Kono 2186
20200018	H219	2022 No. 175	Xinto 102	2018 No. 58	Source Cotton New 13305
20200015	Guoxin Cotton 26	2022 No. 174	New 825	2018 No. 57	Kinkai 9
20200001	Guoxin Cotton 31	2022 No. 173	CT256	2018 No. 55	Sheng Cotton 2
20190023	J8031	2022 No. 172	K622	2018 No. 64	H39012
20190019	Huiyuan 1401	2022 No. 171	K621	2018 No. 63	Yuanlong 17
20190017	H33-1-4	2022 No. 170	Xinto 3	2018 No. 62	Lutai 700Q
20190016	F015-5	2022 No. 169	Anonlu 1	2018 No. 56	Tower River 2
20190007	Guoxin Cotton 25	2022 No. 167	Rufunhua 861	2018 No. 54	Shin Try 518
20190003	Guoxin Cotton 18	2022 No. 164	Ginken 1775	2018 No. 53	Spring and Autumn S36
-	-	2021 No. 42	Changfeng 10	2018 No. 52	K418
		2021 No. 41	K426	2018 No. 51	Ginken 1402
		2021 No. 39	Brown 234	2018 No. 50	Z1146
		2021 No. 38	New 6015	2018 No. 48	Ginken 1442
		2021 No. 37	AW05	2018 No. 47	NH12026
		2021 No. 36	AW04	2018 No. 46	T115

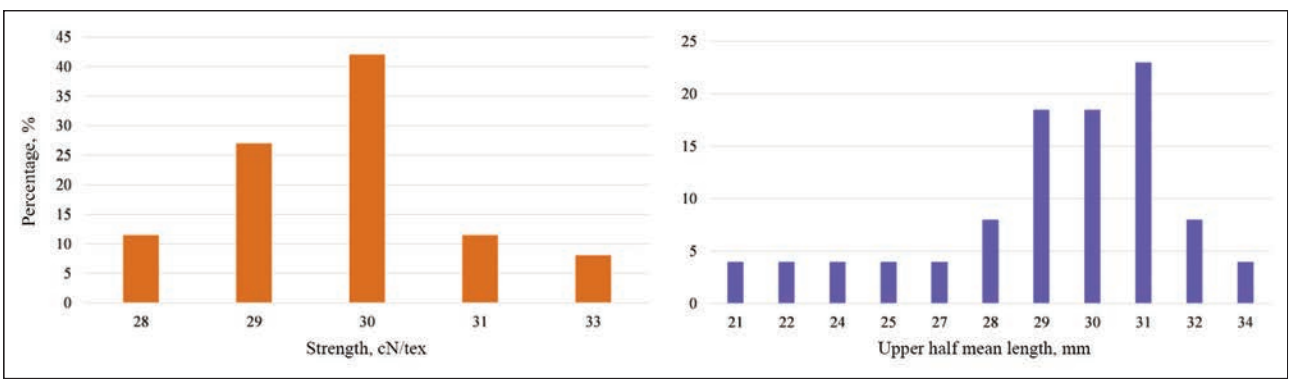

Fig. 2. The distribution of fibre quality grades among 26 cotton cultivars widely planted in the XJr Region (Source: China Seed Industry Big Data Platform)

potential of high-quality cotton is reduced. For example, in some areas, the cotton plant cultivation density is high, and row spacing is narrow [11], which leads to the narrower cotton boll-bearing part in cotton growth and the limited growth of fruiting branches. Cotton maturity in the boll area is too centralized, resulting in the late shedding of cotton bolls seriously. The same piece of cotton has different maturity conditions, plant height and boll development [12], etc. In addition, too high plant density may bring larger difficulties in field fertilization and management. It is also difficult to ensure the good growth of cotton plants, limiting the production of high-quality cotton fibres. The leaves are too dense, which is not conducive to the spraying of defoliant maturing agents and other pesticides [13, 14]. The leaves are too dense for the spraying of defoliant and other pesticides.

In recent research, it is found that in different regions of XJr, the sowing, cultivation and harvesting of cotton are not regulated in a certain way, and there may be a mixing of cotton seeds, which at the same time results in different heights of cotton plants, maturity and output fibre quality.

It can be seen, in the cultivation mode, field water and fertilizer application management, as well as other natural and man-made factors, achieving integrated control, added with the reconstruction of cotton field conditions, seeding and cultivation of cotton canopy structure will lead to “uniform distribution and structural fit” characteristics in cotton growth.

Unreasonable distribution of sunlight exposure

Plants cannot grow without light. Efficient light energy utilization is one of the criteria for responding to population dominance. The ability to intercept photosynthetically active radiation of plants is a major factor affecting crop yield [15–18].

Studies have shown that the photosynthetic rate of the middle leaves is the highest in all crops, and the boll yield in the middle and lower parts of the cotton is the main component of cotton yield. The plant canopy is regulated to reduce the number of upper leaves through different densities and row spacing configurations [19]. The number of leaves in the upper layer is reduced, which reduces the light interception in the upper layer and improves the light interception in the middle and lower parts of the leaves [20]. This will lead to an efficient light interception cluster to result in a higher accumulation of cotton dry matter and a consistent growth of the cotton plant [21]. The growth of cotton plants can also be maintained uniformly.

The temperature and light conditions during the growth period of cotton have a crucial impact on the formation of cotton bolls and the further development of cotton fibres. The night-time air temperature in the XJr decreases significantly. Lower night-time temperature limits the growth of cotton boll and fibre. The appropriate temperature for cotton boll growth is about 27°C ~ 30°C. Low temperature affects the metabolism of plants, which is not conducive to the accumulation of nutrients in cotton bolls, increases the weight, and reduces the rate and the amount of cellulose accumulation. The specific strength at the break of cotton fibres depends mainly on the continuous accumulation of fibre bundles. The change of cellulose accumulation characteristics directly affects the formation of specific strength at break [22, 23]. The formation of high-strength fibres should be coordinated with the accumulation of cellulose. The longer the cellulose accumulation time and the faster the accumulation rate, the greater the increase in fibre strength. The high-strength fibres can start accumulating cellulose at an early stage [24]. The study concluded that the timing of cellulose deposition has a great influence on fibre maturity and yield [25].

Immature use of defoliation technology

Defoliation refers to the use of specific chemicals to catalyse the leaf abscission and promote cotton boll splitting. The main effect of defoliation is to inhibit the function of growth hormone, inducing abscisic acid, ethylene and other plant hormones to exert their effects to a greater extent. The use of defoliation and ripening technology in cotton fields before mechanical harvesting is an important measure to protect the quality of cotton at the harvesting stage. Before harvesting, chemical agents are usually used for defoliation and ripening. Reasonable spraying time, application dosage and use method of defoliant ripening agent will produce good defoliant ripening effect, and can also reduce the negative impact on cotton yield and quality [26–29]. The use of chemical agents can also reduce the negative impact on cotton yield and quality.

Temperature changes after the use of defoliant ripening agents may become a major factor affecting the effectiveness of defoliant ripening. At present, the use of defoliation ripening technology is not mature and standardized. The temperature difference between daytime and night-time is large. Temperature is a key factor for the effective application of defoliation and ripening agents in cotton [30, 31]. The temperature after the application of defoliant ripening agent is required to be maintained at close to 15°C, with a maximum temperature greater than 27.5°C, and an effective cumulative temperature greater than 4.6°C. Some studies have pointed out that, in the spraying of a defoliant ripening agent, the cotton leaf shedding rate can reach 55% to 79% in 7.0 ± 1.0 days after the application.

As shown in figure 1, the early growth of cotton fibres is influenced by high temperature and sustained high temperature, so plastic film covering is generally used in cotton cultivation to keep warm. In the late stages of cotton growth, there is a wide range of temperature changes and long periods of low temperature at night. The variety of defoliant ripening agents available in the market is relatively limited. The application amount, application time and environmental conditions of defoliant ripening chemicals have a high impact on the effect [32] and also have an impact on mechanical cotton harvesting, harvesting machinery work process and harvesting effect.

The high content of anisotropic fibres

The cotton picking process contains profile fibres that can damage the quality of raw cotton ginning and processing. The test report from the State Fibre Inspection Bureau shows that, in mechanized cotton harvesting, there may be profile fibres such as grass, hair, plastic rope, bare mulch, not completely off-cotton leaves, broken shells, etc. mixed into the harvested cotton fibres [33]. Separating high-quality cotton fibres in subsequent fibre processing faces more difficulties, which will exacerbate the secondary damage of cotton fibres in the machine, leading to a decrease in cotton fibre length and an increase in short fibre rate, damaging the original quality of cotton fibres [34].

The harmfulness of profile fibres in cotton fibres has attracted great attention in the textile industry. In the national standards of GB 1103.1-2012 and GB 1103.2-2012 [35], regulations for various profile fibres have been added and specifically stated in the cotton picking, delivery and sale of cotton. It is also prohibited to use non-cotton pockets, coloured or non-cotton threads, and rope ties that are prone to producing anisotropic fibres. The standard strictly divides the anisotropic fibre content of wrapped cotton.

Insufficient quality of cotton picker operations

In our country, the cotton machine picking rate exceeded 80% in 2022 in XJr. Mechanical picking has occupied the absolute seat in cotton picking. The quality of mechanically harvested cotton has undoubtedly become a focus that needs to be sustained and highly concerned. Mechanical picking of cotton will lead to a decline in the quality of cotton fibre production, concentrated in the fibre breaking strength, and fibre neatness decline, while leading to a large increase in the rate of short fibres [36].

The rate of machine-picked cotton in XJr is all over 90%, with the highest rate reaching 99% [37, 38], far exceeding the relevant regulations in the "Cotton Picking Machine Quality" standard. Excessive picking rate will inevitably lead to an increase in impurity content in machine-harvested cottonseed and potential damage to fibres [39].

Due to the large cotton planting area in XJr, different regions use different types of harvesting machines. It is found that spindle pickers mainly introduced by Deere Company (John Deere Co.) and Case Company (JI Case Co.) are widely used. In recent years, there has also been part of the cotton area to use the bowl of Schr Ran company products (Boshiran) and also varies mechanical picking cotton fibre length shortening, breaking specific strength reduction [40, 41].

As shown in figure 3, there are differences in the impact of cotton mechanical harvesting on fibre quality indicators. Compared with hand-picked cotton, fibre length and micronaire do not significantly change, fibre strength, neatness and spinning consistency index reduce, short fibre rate increases, significantly. Between the different test points, fibre length and micronaire value in the two ways of picking are no significant difference. The fibre strength of machine-picked cotton was reduced by 3.3% to 11% than hand-picked cotton. The spinning consistency index decreases by 6.1% to 26%. The degree of neatness reduces with a small amount only 0.6% to 2.7%. The change in short fibre ratio is the largest, which is 1.0–1.9 times that of the hand-picked cotton short fibre ratio. Machine-picked cotton fibre quality factors and quality improvement pathway research 73 different varieties, machine-picked cotton fibre length and hand-picked cotton differences are very small, the micronaire and neatness are increased or decreased; fibre strength and spinning consistency index are the lowest machine-picked cotton, 63% of varieties to reach the significance of the level; machine-picked cotton short fibre rate increased significantly, is hand-picked cotton 1.6~2.3 times.

Due to the high impurity content and moisture regain of mechanically harvested cotton, cotton fibres with more impurities require more mechanical cleaning during the processing stage. More cotton fibre cleaning processes will exacerbate the damage to cotton

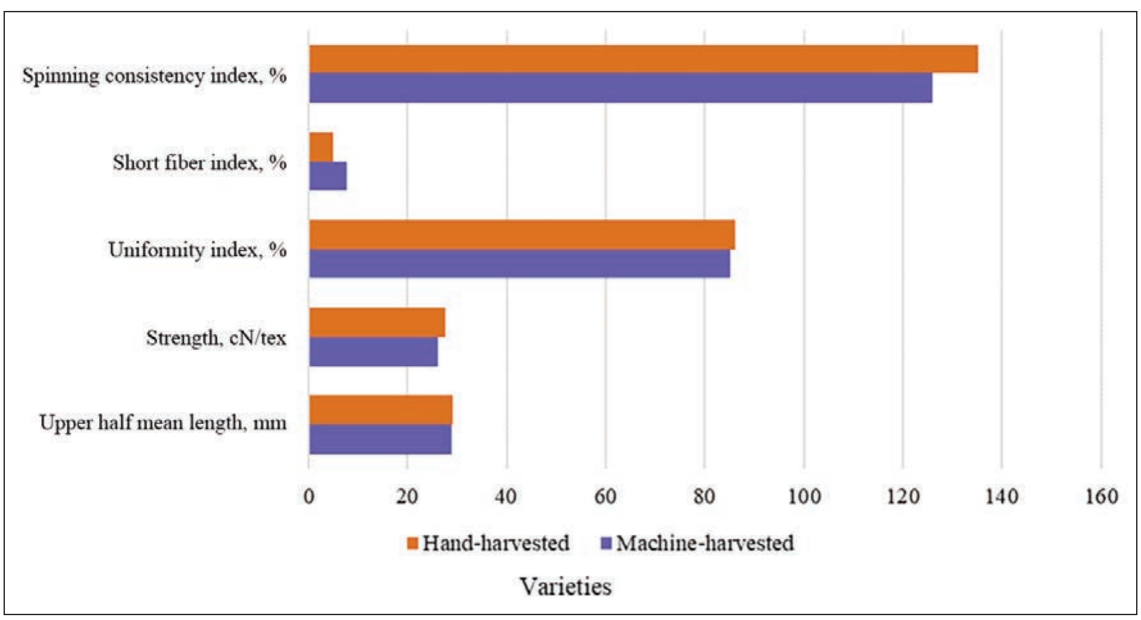

Fig. 3. Comparative indicators of differences in harvesting methods

fibres during mechanical processing, further reducing the overall quality of lint cotton [42]. Cotton processing enterprises in the processing of different grades of cotton also need to further lean processing data to ensure that the quality of cotton is effectively protected.

RAW COTTON QUALITY OPTIMIZATION PATH

1. Machine-harvested cotton varieties require good early maturity, excellent fibre quality, fast and concentrated boll opening, high position of initial fruit nodes, more cotton in the middle and upper parts, loose and lodging resistant cotton plant type, and the ability to plant with high density. Only cotton that is sensitive to defoliation and ripening agents and has strong boll content can improve the quality of machine-harvested cotton.
2. Selection of compact, resistant, early-maturing and high-quality varieties with a high distance between the first node of the first fruiting branch and the ground (generally more than 18 cm); mechanical precision sowing by a more suitable pattern (76 cm equidistant rows, three rows in one film or six rows in one film).
3. After 20d of spraying defoliation and ripening agent, the cotton defoliation rate reaches more than 90%, and the flocculating rate reaches more than 95% when mechanical harvesting is carried out. General weather conditions require sunny days. Rainy days should not be harvested with the rate of impurity <10%, and the rate of return <12%.

CONCLUSION

Further research is still needed in the selection and cultivation of high-quality cotton varieties and cotton cultivation. At present, research on high-quality cotton varieties focuses on high yield and disease resistance, and there may be insufficient research on cotton suitable for machine harvesting. The problem of unstable cotton quality caused by climate differences in different regions and years still needs to be studied.

From the above point of view, according to the current mechanical harvesting technology, the variety of cotton varieties suitable for mechanical harvesting in different regions is not yet diverse enough. There is still room for optimization in seeding, defoliation, ripening, and control of foreign fibres

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Innovative approaches to optimized cutting planning in the garment industry

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ABSTRACT – REZUMAT

Innovative approaches to optimized cutting planning in the garment industry

The garment industry is responsible for large amounts of waste. The current line of making the industry sustainable imposes rethinking of all stages, from design to assembling. The research starts from the observation that the optimization of the cutting plan is resourceful regarding the reduction of waste. The paper proposes an original software dedicated to the planning of cutting. The markers for a given product, onto which are arranged one to four sizes are characterized by four parameters: coefficient of utility of fabric, total length of the fabric, number of layers and length of the marker. The use of the software is demonstrated for the product coat, to which the best marker is established. Numerical results show how variable the coefficient of utility can be, thus how important is the optimization of markers before cutting the fabric. For the product coat, whose patterns are long (the dimension along the length of the fabric is significantly bigger than the dimension along the width) the utility coefficient is optimized from 57% to 78%. Several observations (applying to all markers) are noticed regarding the shape of the patterns and the number of sizes on a marker. The software should be of interest to companies which assemble garment pieces. The mathematical model and logic applied within the software are validated using an experimental study on the product's dress and coat, to which the practical coefficients of utility are 75% and 87% respectively.

Keywords: *cutting, garment industry, planning of cutting, coefficient of utility of fabric, digitalization*

Abordări inovatoare în planificarea optimizată a croirii în industria de îmbrăcăminte

Industria de îmbrăcăminte este responsabilă pentru cantități mari de deșeuri. Tendința actuală de creare a unei industrii durabile impune regândirea tuturor etapelor, de la proiectare până la asamblare. Cercetarea porneşte de la observația că optimizarea încadrării este o resursă importantă, în ceea ce privește reducerea deșeurilor. Lucrarea propune un software original dedicat planificării croirii. Încadrările pentru un produs dat, pe care sunt aranjate una până la patru mărimi, sunt caracterizate de patru parametri: coeficientul de utilizare a materialului, lungimea totală a materialului, numărul de straturi și lungimea încadrării. Utilizarea software-ului este demonstrată pentru produsul palton, căruia i se stabilește cea mai eficientă încadrare. Rezultatele numerice arată cât de variabil poate fi coeficientul de utilizare, deci cât de importantă este optimizarea încadrărilor înainte de croirea materialului. Pentru produsul palton, ale cărui tipare sunt lungi (dimensiunea de-a lungul lungimii țesăturii este semnificativ mai mare decât dimensiunea de-a lungul lățimii), coeficientul de utilizare este optimizat de la 57% la 78%. Rezultă mai multe observații (aplicabile tuturor încadrărilor) cu privire la forma tiparelor și numărul de mărimi de pe o încadrare. Software-ul ar trebui să fie de interes pentru companiile care produc articole de îmbrăcăminte. Modelul matematic și logica aplicate în cadrul software-ului sunt validate prin intermediul unui studiu experimental asupra produselor rochie și sacou, la care coeficienții experimentali de utilizare sunt de 75%, respectiv 87%.

Cuvinte-cheie: *croire, industria de îmbrăcăminte, planificarea croirii, coeficient de utilizare a materialului, digitalizare*

NTRODUCTION

Presently, society is strongly involved in assessing the harmful effect of technology on the environment and in finding solutions to diminish or remove this effect. The large amount of waste, generated by industrial activities i.e., electronics [1], plastics [2], textiles [3, 4], pharmaceutics [5–7], chemical [8], manufacturing and building [9] and by the social activities [10] are relevant parts of the issue.

Consequently, international political and economic organizations plan to invest important resources in implementing new concepts regarding the design, manufacturing, and use of products.

For instance, at the European level, in 2020, the European Commission communicated, under the title "European Green Deal" the new circular economy action plan, including proposals on more sustainable product design and reducing waste. In 2021, the European Parliament adopted a resolution on the new circular economy action plan demanding additional measures to achieve a carbon-neutral, environmentally sustainable, toxic-free, and fully circular economy by 2050 [11].

The textile and garment industry is responsible for polluting water, spreading greenhouse gas and landfilling. The impact of manufacturing fibres and different fabrics, assembling clothing and discarding wasted products by the users is documented in Europe by the European Parliament [12]. Reducing waste is a target not easy to achieve. The solutions, as a result of multidisciplinary research, should be identified for all stages beginning with the manufacturing of fabric and ending with the customs of users.

Fabric as a raw material represents about 60% of the production expenses in this field, demanding an effective utilization of fabric resources. Consequently, it is essential to lower the overall price of raw materials and achieve an optimal rate of use while fulfilling every need by limiting the length of the demanded fabric [13]. Significant interest has been demonstrated in resolving this issue because a minor adjustment to the arrangement of the fabric-cutting procedure could result in substantial cost savings [14]. Marker planning constitutes one of the textile industry's most vital planning procedures. The main purpose is to create a set of markers to be used as cutting instructions or cutting templates in a cutting procedure [15].

The industry's current methods for marker planning vary from manual ad hoc processes to dedicated software [16, 17]. Nevertheless, a lot of apparel manufacturers prefer to generate this plan using the expertise of a planner or industrial software.

As there are no scientifically based guidelines to plan the cutting and no specific software, the present paper addresses the design and planning of the cutting process as the most important step in obtaining high efficiency in using the fabric and, thus, in reducing the waste. The idea of the necessity to reduce waste in the assembling garment stage and a mathematical approach regarding the utility coefficient of fabric was developed by the authors in previous works [18, 19]. Our research started from the following notices:

- The fabric used by a company which assembles garments generates most of the waste, thus its use must be first optimized;
- The garment industry uses specific CAD programs, which generate markers. However, all software applications optimize the arrangement of patterns based on data provided by the human operator. This data includes the number of sizes to be arranged on the marker and which sizes to be associated; the orientation of the patterns depending on the grainline and the nature of the fabric; and the number of products in the order for each size (which is generally different). Thus, the making of markers is not fully automated. CAD applications only achieve the best arrangement for a plan given as input data by a human operator;
- To get a high utility coefficient, it is necessary to imply human intelligence in planning cutting. Previous research went to trying to find the best arrangement of patterns on the marker [16, 20–25].

The present paper proposes a new software to plan the cutting, whose results should be implemented in the existing CAD applications, to ensure high utility coefficients. By estimating the characteristic parameters for the entire production (i.e., the total length of fabric required, the number of layers, and the fabric's coefficient of utility), this software optimizes the cutting plan and can substantially reduce fabric consumption and, therefore, costs and the amount of resulting waste. The theoretical approach is intended to be tested within an experimental program.

MATERIALS AND METHODS

The marker is a surface on which the patterns are arranged. It is subsequently used to cut fabric. Considering the cost of fabric, it is very important to use the fabric efficiently. Furthermore, reducing waste is a major goal of the current policies to make the industry sustainable. The method proposed in this paper is based on simulations performed in an original software, which estimates three characteristic parameters for the whole production: total necessary length of fabric, number of layers and coefficient of utility of fabric.

Figure 1 presents a logical scheme of the process which provides an optimal cutting plan. For a given order, the input data is total number of pieces of garment (*N*), the number of sizes to be placed on a marker (*m*), the width of the fabric (*l*), the loss at the end of the layer (*p*), the area of patterns for one, two, three and four sizes on a marker (*A*1, *A*2, *A*3, *A*4) and the length of the marker for one, two, three and four sizes arranged on it (*L*1, *L*2, *L*3, *L*4).

The criteria to establish which arrangement is the best are as follows:

- Coefficient of utility of fabric, which should be maximum;
- Estimated total length of the fabric, which should be minimum;
- Number of layers, which should be as few as possible;

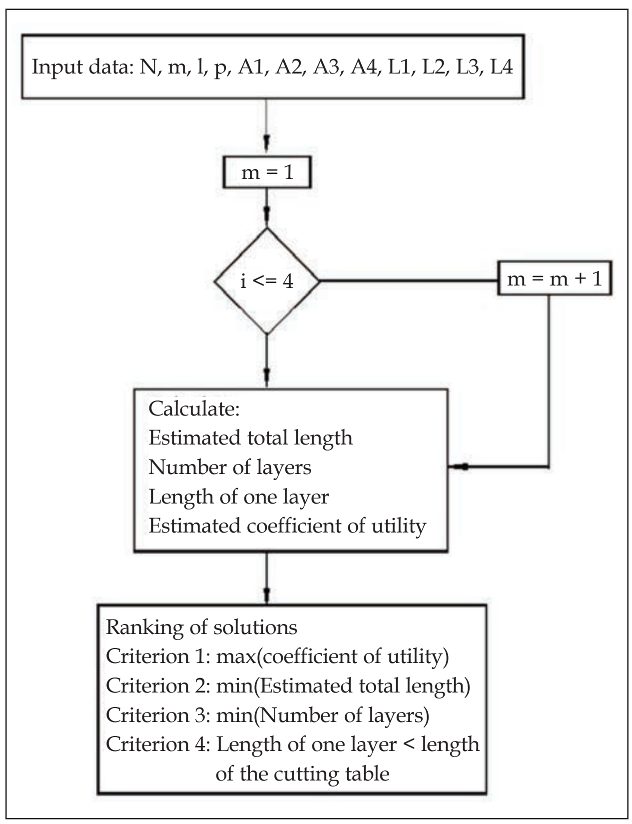


Fig. 1. Logical scheme on which the program is based on

- Length of the marker, which should be less than the length of the cutting table.

No matter what the product is, the planning of cutting needs to know the patterns and the characteristics of the fabric (such as width and grainline). The patterns are generated by the designer of the model and are provided in different electronic formats, compatible with general CAD software and specific software used in the garment industry.

As a rule, the sum of the patterns' areas represents the useful area of the fabric. The ratio between the useful area and the total area of the fabric is called the utility coefficient:

$$C = \frac{\sum \text{Area of patterns}}{\text{Total area of fabric}} \cdot 100\ [\%] \qquad (1)$$

The utility coefficient may be computed for one marker or for the whole area of the fabric, which is the final parameter of interest for the cutting planner.

If all patterns are generated and the number of multiplications is known, it is the task of the human operator to plan the cutting. They encounter the problem of deciding which patterns should be assigned to one marker because there are a lot of combinations possible. There must be stated a decision criterion, which is proposed to be the utility coefficient of fabric.

In the case of unique pieces or a small number of pieces in each size, there are few solutions for combining patterns in arrangements on the marker or even only one if the piece is unique. In this case, the utility coefficient depends mainly on the shape of the patterns (long or compact), grainline and colours or geometry of the patterned fabric. The utility coefficient is expected to be small. However, the waste, in absolute value, is not important.

In the case of a large series of production, which implies the assembling of hundreds or thousands of products in the same model, the utility coefficient becomes very important because the waste can be economically and environmentally unacceptable. The arrangement of patterns must be optimized so that the fabric is used most efficiently and the total waste is minimized. For this purpose, a software application was written as VBA. Figure 2 shows the interface of the program, called "Planning of production" consisting of four frames with image and text controls and a series of five command buttons.

The frames "Model" and "Pattern" allow the operator to load an image of the model and the image of a generic pattern.

The frame "Input data" contains label and text controls for 12 parameters, which must be entered by the user. The calculus algorithm considers the following data:

- Total number of pieces (*N*) – imposed in an order;
- Number of sizes on a marker (*m*) – at the choice of the user (*m* = 1, 2, 3 or 4 in the algorithm). The number *m* was limited to four for practical reasons. The length of the cutting table determines the maximum length of the marker (the length of the cutting table varies depending on the company). The program and the simulations were used for a company where the cutting table is seven meters in length. Four sizes on a marker use up to 4…6 meters in length, depending on the model. An order usually

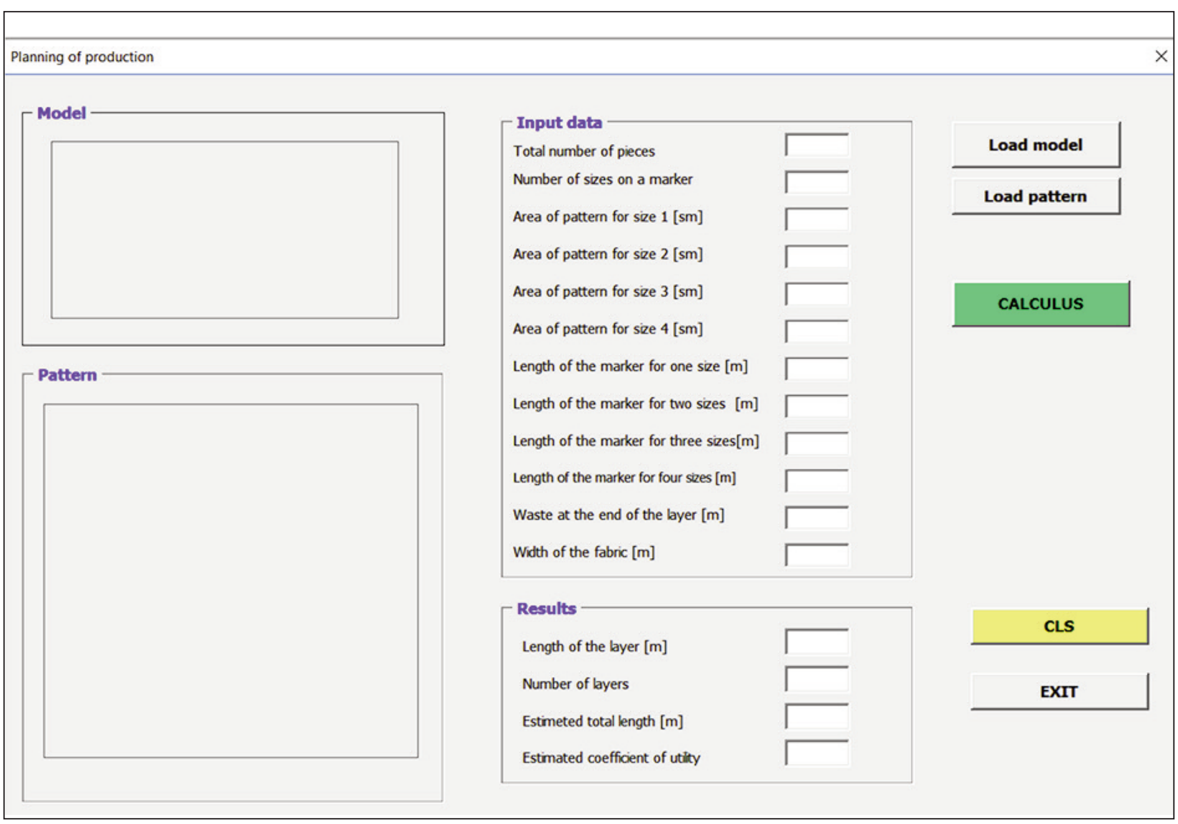


Fig. 2. Graphical user interface of the program

contains 8, 10 or more sizes, which should be organized into smaller groups;

- Area of the pattern for sizes 1, 2, 3, 4 ($A1…A4$) and Length of the marker for 1, 2, 3 or 4 sizes on one marker ($L1…L4$). These parameters can be obtained within any CAD application for garment design, by simulating one piece of each size;
- Waste at the end of the layer (p). The length of a layer can be less or equal to the length of the table. At the beginning and end of the layer, a short amount of fabric must be foreseen. The total extra fabric is denoted p;
- Width of the fabric (l). This parameter may be smaller than the actual width of the fabric if necessary, depending on its margins manufacturing.

The frame "Results" displays four numerical results:

- Length of the layer (L_{layer});
- Number of layers (n);
- Estimated total length (L);
- Estimated coefficient of utility (c).

The command button "Calculus" runs the algorithm, consisting of the following steps:

$$n = \frac{N}{m}, \quad (2)$$

$$L = N \cdot L1, \text{ if } m = 1, \quad (3)$$

$$L = N \cdot \frac{L2}{2}, \text{ if } m = 2, \quad (4)$$

$$L = N \cdot \frac{L3}{3}, \text{ if } m = 3, \quad (5)$$

$$L = N \cdot \frac{L4}{4}, \text{ if } m = 4, \quad (6)$$

$$L_{layer} = \frac{L}{n}, \quad (7)$$

$$c = 1/(L \cdot l) \cdot n \cdot \left(\sum_{i=1}^{4} A_i - p \cdot l\right) \cdot 100 \quad (8)$$

The command button "CLS" erases data from all text controls and the command button "Exit" closes the program.

RESULTS AND DISCUSSION

The program "Planning of production" was used to generate the optimal cutting plan for different products. The preliminary data "Area of patterns" and "Length of the marker" for one, two, three and four sizes were generated with Gemini CAD [26], a professional software for arranging patterns on the marker.

The product used to illustrate the use of the program is a coat. For numerical simulation we consider it to be the object of an order of 200 pieces in four sizes (38, 40, 42, 44). The image of the product and the input data used in simulations is given in table 1.

The simulations were run for m = 1, 2, 3 and 4, at different combinations of two and three sizes. The results of the simulations are synthesized in table 2.

The numbers in table 2 allow the following observations:

- The utility coefficient of fabric varies between 57% and 78%, depending on the number of sizes assigned to one marker.

The final choice for the cutting plan is, thus, m = 2. It ensures the highest coefficient of utility, at a minimum consumption of fabric. 78% of 200 meters in length are useful. The waste is only 71 meters. The worst solution is m = 1, with a waste of 95 meters from a total length of 220 meters. The optimization saves 24 meters of fabric and improves the productivity of cutting because the number of layers is half reduced. The study's findings indicate that the proposed software is an effective tool for optimizing cutting planning in the apparel industry. The industry's emphasis on waste reduction is consistent with the increasing focus on sustainability and resource conservation using advanced digitization and technology [27, 28]. The simulations run for different products lead to the conclusion that the coefficient of utility can be improved by (10…15)%. However, there is a general remark to notice: the coefficient of utility is smaller for long patterns (such as long coats, dresses, and pants) and higher for compact ones (such as shirts and short coats).

Table 1

INPUT DATA (PRODUCT COAT)

ID	Parameter	Numerical data
1	Total number of pieces	200
2	Number of sizes on a marker	1…4
3	Area of the pattern for size 1 (38)	1.16
4	Area of the pattern for size 2 (40)	1.20
5	Area of the pattern for size 3 (42)	1.32
6	Area of the pattern for size 4 (44)	1.49
7	Length of the marker for 1 size on one marker	1.10
8	Length of the marker for 2 sizes on one marker	2.0
9	Length of the marker for 3 sizes on one marker	3.45
10	Length of the marker for 4 sizes on one marker	4.28
11	Waste at the end of the layer	0.06
12	Width of the fabric	1.60

Table 2

RESULTS OF THE SIMULATIONS FOR M = 1, 2, 3, 4 (PRODUCT COAT)				
Followed parameters	**m=1**	**m=2**	**m=3**	**m=4**
Length of the layer (m)	1.10	2.00	3.45	4.28
Number of layers	200	100	67	50
Estimated total length (m)	220	200	230	214
Estimated coefficient of utility (%)	56.82	77.81	69.02	73.16
Total necessary area (m^2)	352	320	368	342.4
Wasted area (m^2)	151.99	71.01	114.01	91.90

EXPERIMENTAL STUDY

The theoretical approach was validated with an experimental program, developed in an assembling company.

The actual coefficient of utility of the fabric was computed with the following data:

- Total weight of the cut pieces of the product:

$$W_{\text{cut products}} = \sum_{i=1}^{k} n_i \cdot w_i \tag{9}$$

with n_i = number of products in size I; w_i = weight of a products in size I; i = 1…k (numer of sizes).

Practically, several products of each size were weighted and for each size, the mean value was introduced in equation 9.

- Total weight of the available fabric:

$$W_{\text{available fabric}} = \sum_{j=1}^{m} L_j \cdot w_L \tag{10}$$

with L_j = length of fabric in roll j; w_L = weight per meter for the fabric; j = 1…m (number of rolls).

The utility coefficient becomes:

$$C_u = \frac{W_{\text{cut products}}}{W_{\text{available fabric}}} \tag{11}$$

Experimental data are presented below for two products: Dress (table 3) and Short coat (table 5).

The order for the product dress comprises sizes 34 to 50 in different numbers and four colours, in a total count of 2046 products.

The simulation with the program “Planning of production” provided the optimum solution for two sizes on a marker, with a theoretical coefficient of utility 0.77. Table 4 displays the results of the program for the product dress in the colour light green, required in 492 copies (first line in table 3). The best arrangement results with the association of sizes as shown in table 4. As the required number in sizes is different,

Table 3

LENGTH AND WEIGHT OF THE AVAILABLE FABRIC (DRESS)			
Colour	**Number of products**	**Available length (m)**	**Weight (kg)**
	492	1595	268.27
	630	1435	241.36
	467	1640	275.84
	457	2258	379.78
Total	2046	6928	1165.24

Table 4

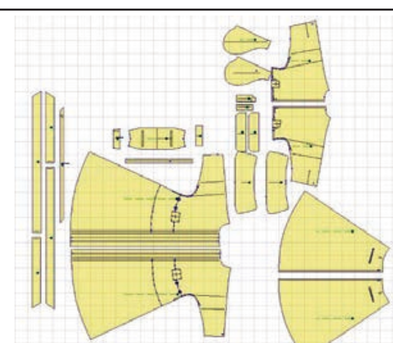
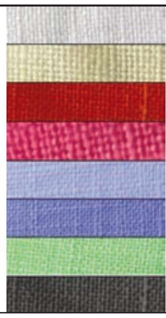
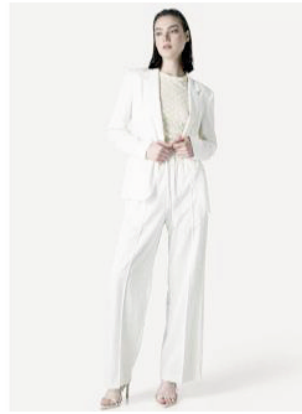
SUMMARY OF PLANNING THE CUTTING FOR 492 PRODUCTS DRESS IN COLOR GREEN					
Associated sizes	**Products**	**L_{total} (m)**	**L_{waste} (m)**	**Cu**	**Generic pattern of the dress**
36–48	24/size	102	23	77.4	
40–46	58/size	232	53	77.0	
40–44	88/size	366	85	76.8	
42	104	424	96	77.3	
Remaining Products on supplementary layers	48	108	27	75.4	
Total	492	1232	284	77	

Table 5

LENGTH AND WEIGHT OF THE AVAILABLE FABRIC (SHORT COAT)			
Colour	**Number of products**	**Available length (m)**	**Weight (kg)**
	73	137.24	28.59
	37	69.50	14.48
	304	547.26	114.01
	33	62.34	12.99
	88	165.44	34.47
	23	43.24	9.01
	190	357.20	74.42
	22	41.36	8.62
Total	770	1423.57	296.58



there are supplementary layers for the rest of the 48 pieces.

Before the cutting, the rolls of fabric were counted, and the length and weight were computed (table 3). The total weight of the 2046 products is 879.8 kg, resulting in an actual coefficient of utility C_u = 0.754.

The order for short coats, in sizes from 34 to 52 and 8 colours, counts a total of 770 products.

The available fabric is characterized by parameters in table 5.

The simulations provided an optimum solution of four sizes on a marker, with an estimated coefficient of utility 0.89.

The total weight of the cut pieces is 259.5 kg, resulting in a coefficient of utility C_u = 0.87.

The experimental results for both products validate the theoretical model.

CONCLUSIONS

Briefly summarizing, the cutting plan optimization, using simulations on original software, provided consumption of fabric and waste for different arrangements of the patterns on the marker. The simulations considered a maximum number of four sizes on a marker, as a reasonable number suited for the most frequently used cutting tables. The hierarchy of the solutions was based on four criteria ranked by importance: coefficient of utility, total length of the fabric, number of layers, and length of the marker.

The simulations provided numerical data for more solutions, to which the coefficient of utility of fabric is substantially variable, and an optimum arrangement of patterns on the marker can be chosen.

The program was used for several products of a garment assembling company, and the actual coefficient of utility was computed with measured data. The results validated the theoretical approach, as the difference between the real and theoretical coefficients is less than 2%.

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Determinants affecting the current state and perspectives of development of textile and clothing industry clusters within the European Union

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ABSTRACT – REZUMAT

Determinants affecting the current state and perspectives of development of textile and clothing industry clusters within the European Union

The textile and clothing industry is one of the oldest industries ever, as the need for clothing is as old as human existence itself. Of course, the challenges and problems it faces are connected with this, currently primarily the environmental burden, the need for digitization, low wages for workers as well as the protection of brands and the development of the grey economy. With its positions, the European Union declares its interest in solving these issues. Many traditional companies are undergoing changes and there is a natural need for innovation, thus the textile and clothing industry is interfering with the creative industry. The barriers to innovation in this area are frequently small and medium-sized enterprises, which cannot solve many things and be competitive compared to large enterprises, but their flexibility and quick response to the changing needs of customers and the market give them advantages compared to the big ones. The possibilities of how smaller businesses can succeed and compete even in the long term are through clusters, which will provide them with the necessary scope, strength, and research, but at the same time keep them independent. In our contribution, we tried to find out the perspective of the development of textile and clothing industry clusters in Europe given the existing market situation and consumer expectations.

Keywords: *creative industry, clusters, the European Union, localization coefficient, innovation*

Factori determinanți care afectează starea actuală și perspectivele de dezvoltare a clusterelor din industria textilă și de îmbrăcăminte în cadrul Uniunii Europene

Industria textilă și de îmbrăcăminte este una dintre cele mai vechi industrii, deoarece nevoia de îmbrăcăminte este la fel de veche ca existența umană. Desigur, provocările și problemele cu care se confruntă sunt legate de aceasta, în prezent în primul rând fiind impactul asupra mediului, nevoia de digitalizare, salariile mici pentru lucrători, precum și protecția brandurilor și dezvoltarea economiei gri. Prin pozițiile sale, Uniunea Europeană își declară clar interesul pentru rezolvarea acestor probleme. Multe companii tradiționale trec prin schimbări și există o nevoie firească de inovare, astfel că industria textilă și de îmbrăcăminte interferează cu industria creativă. Barierele inovării în acest domeniu sunt adesea întreprinderile mici și mijlocii, care nu pot rezolva multe aspecte și nu pot fi competitive în comparație cu întreprinderile mari, dar flexibilitatea și răspunsul rapid la nevoile de schimbare ale clienților și ale pieței le conferă avantaje față de întreprinderile mari. Posibilitățile prin care întreprinderile mai mici pot avea succes și concura chiar și pe termen lung sunt prin intermediul clusterelor, care le vor oferi amploarea, puterea, cercetarea necesară, dar în același timp le vor menține independente. Prin contribuția noastră, am încercat să aflăm perspectiva dezvoltării clusterelor din industria textilă și de îmbrăcăminte din Europa, având în vedere situația existentă pe piață și așteptările consumatorilor.

Cuvinte-cheie*: industria creativă, clustere, Uniunea Europeană, coeficient de localizare, inovare*

INTRODUCTION

The field of textile and clothing production is an important industry in all countries of the world because every country is at least in the position of a consumer from this point of view. The European Union pays considerable attention to this sector, as almost 60% of production comes from countries outside its territory. As part of a package of measures within the framework of the circular economy, in March 2022 it adopted a comprehensive EU Strategy for textiles, which is focused on sustainability, circularity (circulation), competitiveness and innovation [1]. It is primarily oriented on the creation of eco-design, which will ensure the recycling of materials, the prevention of the use of harmful and dangerous elements in the production of textiles and the strengthening of businesses that will offer consumers sustainable textiles and their recycling. Of course, the textile ecosystem is one of the 14 industrial ecosystems that the European Commission has identified as important for the creation of the single market, after the period of the Covid 19 pandemic [2].

The transition towards a circular economy offers an opportunity to reduce Europe's environmental footprint through measures of diminishing raw material consumption and reducing waste generation [3, 4]. The textile ecosystem has a strong regional character. Traditional producers from Western countries such as Italy, France, Germany or Spain have their headquarters in these countries. In Central and Eastern Europe, many producers benefit primarily from high labour productivity, and many Western European companies also have branches in these countries (figure 1).

Companies in the developed markets prefer the manufacturing of their products in the developing markets for cost-saving [5]. This creates a kind of assumption of localization and cooperation, which is necessary for the emergence of regional specialization and the creation of clusters and industrial groupings. More than 81% of workers in textile production and 75% of workers in trade are women, of which approximately 30–40% are low-skilled and 50-60% are considered medium-skilled workers. This fact is again a prerequisite for local specialization since such workers are more "attached" to the locality.

The European textile and clothing industry has traditionally been regionally grouped, usually under the influence of available raw materials, processing aids as well as human resources or relevant end markets [6]. Production in the field of textiles, as can be seen from table 1, is different in different countries. Every country has at least a minimum of its producers due to the specific, regionally and culturally determined needs of the population. Of course, many countries are not primarily focused on textile production (e.g. Malta, Cyprus or Estonia), but table 1 shows that many are dominated by several sectors and are traditionally known for their textile production (born Italy, France). Awareness of this fact, production that is similar or complementary in several countries, already provides the initial prerequisite for cooperation and the creation of cooperative partnerships and clusters.

In these countries, production has historically been organized around clusters and industrial areas where know-how is passed down from generation to generation and where the co-location of firms, suppliers and users creates a fertile environment for innovation and productivity. The entire regional community is involved in these activities, often through family businesses. This is at the same time an added value, because the knowledge remains in that given place, and at the same time it is also a responsibility for the community, i.e. local community. This leads to a natural grouping of activities and the development of regions, i.e. to the formation of clusters.

Clusters are a term [7] that first appeared in the literature at the beginning of the last century [8], although

Table 1

TEXTILE AND CLOTHING INDUSTRY IN INDIVIDUAL COUNTRIES OF THE EU

Country	Number of employees	Specialization
Belgium	14190	Artificial fibres and home textile
Bulgaria	11823	Yarn, home textile
Czech Republic	22850	Textile clothing and accessories and home textile
Croatia	3662	Luggage, handbags, saddlery, harnesses
Cyprus	535	Leather and clothing
Denmark	3361	Fabrics, yarn, artificial fibres
Estonia	1058	Production of machines for textile and clothing
Finland	5650	Sustainable fashion and materials production
France	40392	Retail, leather products, accessories
Greece	7544	Footwear and fur products
Netherland	13010	Home textiles, artificial fibres
Ireland	1982	Work clothes
Lithuania	9541	Fabric and clothing production, eco production
Latvia	3790	Linen, hemp, underwear
Luxembourg	748	Sustainable fashion, eco production
Hungary	8880	Completion of production
Malta	269	Sustainable fashion, eco production
Germany	80174	Home textile
Poland	59337	More subsectors
Portugal	45514	Textile production, acrylic
Austria	7820	Artificial fibres
Romania	27031	Footwear, yarn and fur production
Slovakia	6415	Artificial fibres
Slovenia	3150	Yarn, product completion
Spain	49312	Sustainable fashion, eco production
Sweden	1840	Sustainable fashion, eco production
Italy	108086	All subsectors, leather and furs, fabrics, artificial fibres

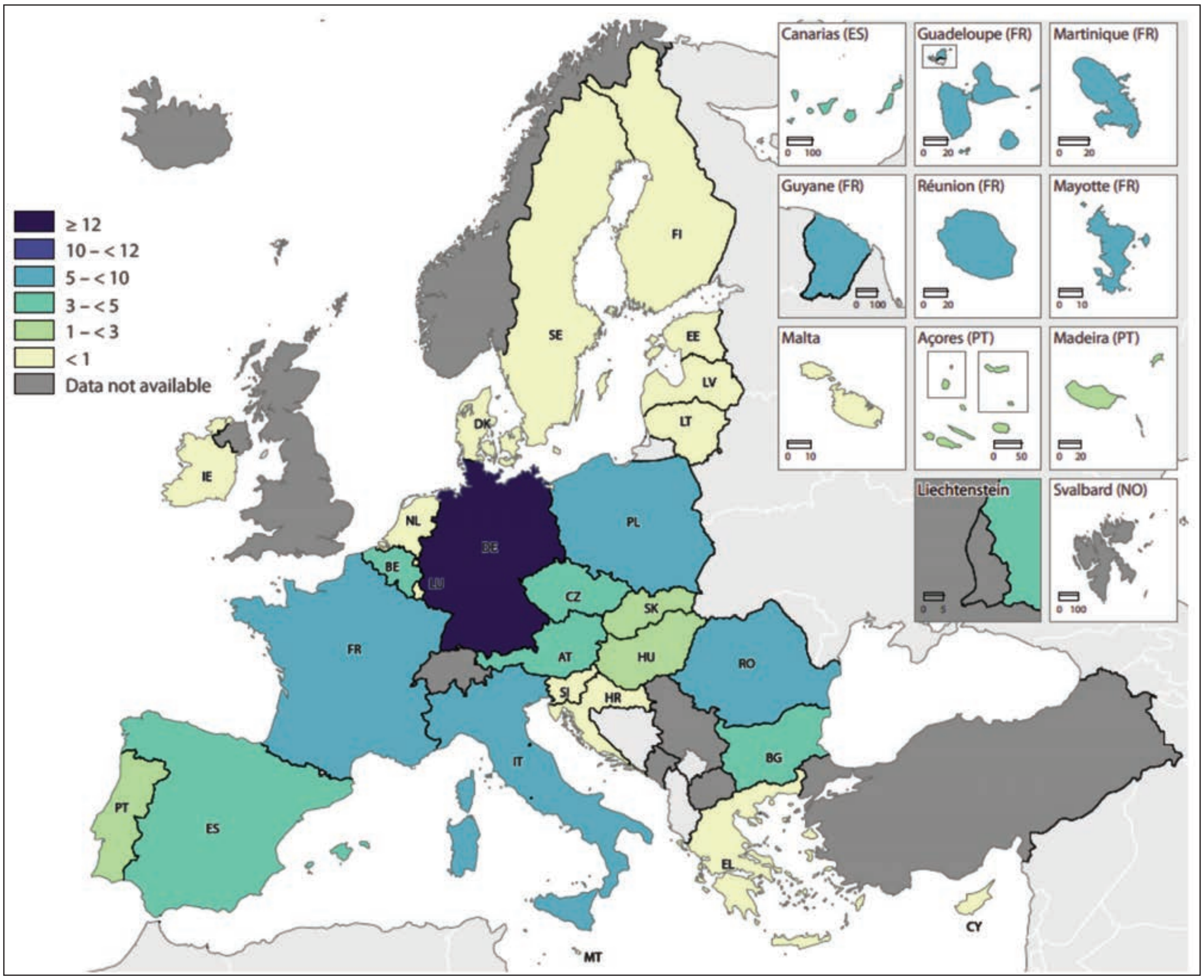

Fig. 1. Number of textile and clothing clusters in EU countries

the creation of natural groupings of companies and the benefits of such connections were recorded long before [9]. The European Cluster Observatory measures and maps the size, specialization, focus and performance of clusters. An estimated 2,950 clusters operate across Europe in 51 sectors, providing 1 in 4 jobs (61.8 million jobs in total) [10]. Large regional differences can be seen between the clusters, the top 200 clusters show productivity above 140% of the average [11].

Of course, the clusters in Western Europe have a somewhat longer history, many authors consider them to be more efficient and therefore better functioning than the clusters in the Eastern part of Europe, this fact puts them in the position of the socalled spill-overs in the field of knowledge, which can be seen in the textile and clothing industry. Conversely, clusters within Eastern Europe can attract foreign investors precisely because of low costs. Western European clusters are also considered initiators of innovation and foreign cooperation. As soon as a large textile company introduces an innovative product or an innovation in the process, this spill-over effect very quickly affects small companies especially in the clusters of Eastern Europe [12].

In the textile and clothing industry within the European Union, there are currently 67 clusters operating primarily in countries traditionally associated with the textile and clothing industry, such as Germany, Italy, France, Romania, but also Poland, Belgium, Bulgaria, the Czech Republic, Austria, Spain, Portugal, Hungary and Slovakia [8]. As we can see in figure 1, the majority of these clusters could be observed in Germany (15), Italy (9), Romania (6), France (6) or Poland (5). What seems to be curious, is that more than half of EU countries (14 from 27) have no textile or clothing type of cluster, although there is production, employment, education (in universities) and enterprises in this area that could lead to the concentration in this area of activity.

METHODOLOGY

This research has been done to set determinants which have an impact on the textile and clothing industry within the area of EU counties and which could be seen as a precondition of enhanced competitiveness thanks to the creation of clusters in this area of activity. When processing the contribution, we used available data from statistical databases, primarily Eurostat, ILO, OECD and regional data. For the evaluation, we used both data comparison and correlation analysis in which we compared the sensitivity of data such as the number of companies operating in the textile industry (especially the share of small and medium-sized companies in individual countries), the number of patents and innovations in the monitored period, the number of universities and of research workplaces in the field of the clothing industry and design to the number of existing clusters in this area. For individual countries, we also calculated the localization coefficient as a prerequisite for specialization in the researched area, which we subsequently subjected to a sensitivity analysis within the monitored data.

RESULTS

The localization coefficient (1), even though it is attributed to a non-systematic approach, is one of the most used and simplest tools for determining the potential of a region for the formation of a cluster of a certain industry. The localization coefficient (*LQ*) expresses how many times the sector's share of employment in the region is higher than the national average [12]:

$$LQ = (x/X) / (y/Y) \qquad (1)$$

where *LQ* is employment localization coefficient in the region; *x* – number of employees working in the industry in the given region; *X* – total number of employees in the region; *y* – number of employees working in the given industry in the country; *Y* – total number of employees in the country.

If the *LQ* is greater than one, it means that the industry in question is overrepresented in the region. Coefficients of localization exceeding the value of 1.2 are subsequently perceived as initial evidence of regional specialization in a given industry [13].

For the successful operation of the cluster, we consider it essential that it includes not only the companies themselves but also representatives of the local government and universities or research institutes. This so-called concentration [14, 15] brings to the cluster the necessary prerequisite for development (through local self-government), innovation (secured by research) and the necessary cooperation as well as competition (through the enterprises themselves). The influence of a university on the development of a region depends on many factors, including the focus and strategy of the university itself. The influence of universities on the development of regions and the business environment can be found in the works of several authors such as Adams [16], Stankeviciute [17], Shattock [18], Rehák [19], Sapsed [20], Hánová [21] and Marshal [14]. Universities generally find their application in education, research and development and services to society, which bring skills, and innovation to the region and influence the culture and cohesion of the community, including environmental sustainability [22]. The mere existence of universities in a locality is not a guarantee of effective stimulation of the creation and dynamics of an innovative cluster or regional development. However, its presence can play a significant role in the development of the cluster. At the same time, local businesses around the university cannot wait for their role as an "innovation engine" that will lead to the growth and strengthening of their region. Innovation is the key to success for textile companies, just as in another economic fields [23].

From the results we have presented in table 2, it is possible to determine the potential of the regions of the European Union, in terms of countries (member states), for the creation of clusters in the field of textile and clothing industry. At first glance, it can be seen that the LQ is very high in Portugal and Lithuania, where it reaches very high values. Significant specialization, i.e. this sector is also highly represented in other countries such as Italy, the Czech Republic, Bulgaria, Latvia, Poland, Romania and Slovenia. Lithuania, Latvia and Slovenia are countries with no clusters, now. This is the reason why we have included LQ in the analysis of sensitivity, too.

Based on the subsequently performed sensitivity analysis (table 3), we found that the number of innovations and patents has the highest impact (very high correlation) on the existing clusters. The number of workers in the textile industry has only three hundredths less influence. A moderately high correlation can be seen between the number of enterprises in the textile industry and the number of universities and research institutes in the field of textiles and design. From the point of view of innovation, a moderately significant correlation can be seen in the number of universities and also in the number of companies in the textile industry. Correlation analysis also confirmed that there is a high dependence between the total number of enterprises in the textile industry and the number of small and medium-sized enterprises, that SMEs are employers in this area, their share in the formation of clusters is significant, and a moderate correlation was also manifested in the number of research workplaces and innovations in this area. The localization coefficient and its sensitivity, within individual countries, on the other hand, showed only a very low correlation with the state of existing clusters and the number of companies in the textile industry, a somewhat larger but still low correlation is only manifested in the number of workers in the textile industry, and it starts to take on a negative value in patents and innovations (although very low).

CONCLUSIONS

The textile industry constitutes a significant sector of the economy of many countries due to its participation in the GDP and the generation of jobs [24]. In the European textile and clothing industry 99% of enterprises are small or medium (SMEs) [25]. Compared to large enterprises, SMEs have very specific environmental threats, such as limited material, financial, informational, human and managerial resources, lower negotiation power, higher interest rates available etc. Even though they are permanently ready to

Table 2

TEXTILE AND CLOTHING INDUSTRY INDICATORS							
Country	**No. of enterprises**	**No. of enterprises in TI**	**No. of SME in TI**	**Innovations, patents**	**No. of universities and research institutions in TI and design**	**No. of clusters**	**LQ**
Belgium	13027	1024	1016	235	2	4	1.08
Bulgaria	20136	712	707	8	6	4	1.54
Czech Republic	20271	2202	2186	192	5	3	1.76
Croatia	3549	660	559	4	2	0	0.87
Cyprus	1949	92	92	2	6	0	0.32
Denmark	4770	325	325	111	1	0	0.44
Estonia	1573	346	343	5	4	0	0.59
Finland	3781	1228	1228	66	9	0	0.82
France	65517	8970	8953	611	13	6	0.52
Greece	28520	1500	1500	9	2	0	0.66
Netherland	22223	2873	2865	219	0	0	0.54
Ireland	4247	466	466	18	1	0	0.30
Lithuania	6770	1241	1233	2	4	0	2.58
Latvia	3559	547	546	4	2	0	1.60
Luxembourg	606	15	14	5	1	0	0.91
Hungary	14163	1498	1494	10	2	1	0.73
Malta	556	0	0	2	2	0	0.38
Germany	47871	4707	4657	2931	12	15	0.74
Poland	59101	6794	6768	177	2	5	1.31
Portugal	32140	3523	3499	54	9	2	3.52
Austria	6318	786	783	187	5	3	0.67
Romania	18448	1727	1707	44	5	6	1.33
Slovakia	6726	1810	1807	15	3	1	0.93
Slovenia	2318	334	332	44	3	0	1.21
Spain	90752	6400	6388	324	13	3	0.85
Sweden	11800	1882	1882	173	12	0	0.13
Italy	163016	15790	12630	1240	10	9	1.73
Total	**655886**	**67452**	**63980**	**6692**	**136**	**-**	**-**

Table 3

TEXTILE AND CLOTHING INDUSTRY INDICATORS							
Indicator	**No. of enterprises**	**No. of enterprises in TI**	**No. of SME in TI**	**Innovations, patents**	**No. of universities and research institutions in TI and design**	**No. of clusters**	**LQ**
No. of enterprises	1.00	0.90	0.72	0.56	0.84	0.89	0.33
No. of enterprises in TI	0.90	1.00	0.51	0.55	064	0.99	0.20
No. of SME in TI	0.72	0.51	1.00	0.52	0.88	0.52	–0.04
Innovations, patents	0.56	0.55	0.52	1.00	0.56	0.58	0.10
No. of universities and research institu-tions in TI and design	0.84	0.64	0.88	0.56	1.00	0.65	0.13
No. of clusters	0.89	0.99	0.52	0.58	0.65	1.00	0.19
LQ	0.33	0.20	–0.04	0.10	0.13	0.19	1.00

change to grow, usually SMEs have little information about the way to approach change effectively [26]. A cluster is a means that, in addition to strengthening the position of small and medium-sized enterprises, contributes to the growth of the specialization of the region or municipality, and encourages governments to invest in the industry and the respective region at the same time. This naturally results in such a positive effect as the development of regions and municipalities. Clusters are thus unquestionably considered an important microeconomic factor by many experts in theory and practice. A prerequisite for the creation of clusters is also the fact that, unlike large ones, small and medium-sized enterprises are not able to use, for example, economies of scale, they do not have sufficient capacities and resources for research, education of their employees, obtaining information, etc. For that reason, it is appropriate for them to create clusters as a potential for their development within the region [27]. The adequacy and possible use of regions for the creation and existence of clusters is the subject of many studies and analyses. As part of our study, we focused on examining the textile and clothing industry. As part of the localization coefficient, which can identify the region's potential based on a comparison of employment within the relevant field, we determined the coefficient itself for the respective country within the EU. The limit in our investigation is the fact that we considered individual member countries as regions, while regional specialization would be appropriate within a different regional division (need for natural division). In many cases, it makes sense to create clusters by connecting several sectors that can support and influence each other. There are several industries/sectors in the textile industry (automotive, housing, etc.) This is the reason why, in our opinion, further research in this area is particularly necessary.

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Sustainability and environmental costs in the textile industry: a case study

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ABSTRACT – REZUMAT

Sustainability and environmental costs in the textile industry: a case study

The impact of greenhouse gas and carbon emissions on climate change and more frequent natural disasters in recent years have increased people's and government's environmental awareness. The enactment of environmental legislation and new standards have resulted in some additional environmental costs for companies. Every additional cost is very important for companies operating under intense competitive pressure. Companies operating in the textile sector undertake the costs of prevention, use and damage at every stage of their production. In this study, the importance of the textile sector in Türkiye in terms of the country's economy has been revealed and the environmental costs of textile enterprises have been examined. The study aims to reveal the environmental costs for yarn production, yarn dyeing process, weaving-confection processes and dyeing-finishing processes separately and to calculate the share of these costs in total operating expenses. According to the results of the study, it has been determined that the share of environmental costs in total expenses in the textile company is 3.1%. It has been observed that the share of environmental costs in total expenses varies between 0.5% and 6% at different production stages.

Keywords: *environmental costs, textile industry, environmental accounting, sustainability, cost analysis*

Sustenabilitatea și costurile de mediu în industria textilă: un studiu de caz

Impactul gazelor cu efect de seră și al emisiilor de carbon asupra schimbărilor climatice și a dezastrelor naturale mai frecvente din ultimii ani au sporit gradul de conștientizare al populației și al guvernelor în materie de mediu. Adoptarea legislației de mediu și introducerea de noi standarde au dus la unele costuri de mediu suplimentare pentru companii. Pentru companiile care operează sub presiune competitivă intensă, fiecare cost suplimentar este foarte important. Companiile care operează în sectorul textil își asumă costurile de prevenire, utilizare și deteriorare în fiecare etapă a producției lor. În acest studiu a fost prezentată importanța sectorului textil din Turcia în economia țării și au fost examinate costurile de mediu în întreprinderile textile. Scopul studiului este de a prezenta separat costurile de mediu pentru producția de fire, procesul de vopsire a firului, procesele de țesere-asamblare și procesele de vopsire-finisare și de a calcula ponderea acestor costuri în cheltuielile totale de exploatare. Conform rezultatelor studiului, s-a stabilit că ponderea costurilor de mediu în totalul cheltuielilor în întreprinderile textile este de 3,1%. S-a observat că ponderea costurilor de mediu în totalul cheltuielilor variază între 0,5% și 6% în diferite etape de producție.

Cuvinte-cheie*: costuri de mediu, industria textilă, răspundere faţă de mediu, sustenabilitate, analiza costurilor*

INTRODUCTION

The Turkish textile industry has been successfully fulfilling its role as the locomotive of the country's development for many years, with the employment it provides and its high export potential. With its 3.4% share in global textile exports, Türkiye is among the top five textile exporting countries in the world. Türkiye's textile exports in 2021 are around 13 billion dollars. By the end of 2021, Türkiye will be the world's fourth-largest knitted fabric supplier, fourth-largest home textile supplier, fourth-largest denim fabric supplier, fifth-largest yarn supplier and fifth-largest woven fabric supplier. By 2022, Türkiye will be the EU's second-largest supplier of textiles and raw materials. The EU imports 15.2% of its total textiles and raw materials from Türkiye. Türkiye is the EU's first-largest knitted fabric supplier, second-largest woven fabric supplier, and third-largest apparel and apparel supplier [1].

In addition to its role in job creation, the textile industry also causes worldwide pollution. Industrial estimates show that more than 35% of the chemicals released in the environment are the result of various textile processing and dyeing processes, and the consumption of freshwater by the textile industry is approximately three trillion gallons worldwide and is used to produce 60 billion kilograms of fabric [2]. Problems in transportation and packaging, especially harmful chemicals used in the textile industry, high water consumption and related water pollution, high energy consumption in production processes and associated air emissions, and waste generation are

the biggest obstacles to environmental sustainability [3].
A non-profit “Textile Stock Exchange” was established in 2002 to increase sustainability in the textile value chain all over the world. In 2012, the concept of “Global Recycling Standard”, which covers the recycling of waste, emerged. In addition, starting from the 1990s, it has been carrying out sustainability activities in many global textile markets such as Patagonia, Levi's, H&M, Nike, Adidas and Esprit [3].
Sustainability activities are a current field that is discussed in the literature and is the subject of many studies in different sectors. There are also important studies on sustainability in the textile industry. Haque et al. (2021), Hayat et al. (2020), Abbas et al. (2020), Shahi et al. (2021), and Tebaldi et al. (2022) examined sustainability activities in the textile sector in different countries in their study [4–8]. However, there are not enough studies in the literature that include a detailed analysis of environmental costs for the textile industry. In this study, sustainability and environmental costs, which are the subject of current discussions, were examined specifically for textile enterprises.
The study aimed to determine the environmental costs of different enterprises of a textile company operating in Türkiye. In this regard, firstly the issue of sustainability in the textile sector was discussed and then environmental costs were explained conceptually. In the last section, environmental costs for yarn, yarn dyeing, weaving-apparel and dyeing-finishing enterprises are analysed in detail.

SUSTAINABILITY IN THE TEXTILE INDUSTRY

Mankind has to produce to survive. With the development of globalization and industry, production has increased, this has affected all living things in the ecosystem and has led to the rapid depletion of natural resources. The increasing world population, scarce resources, and therefore the threat to future generations' lives have pushed scientists to seek solutions. The concept of sustainability emerged as a response to these problems [9, 10].
There are many definitions of sustainability. The definition by the World Commission on Environment and Development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [11]. In another definition, sustainability is to limit the use of non-renewable resources by the present generation and to keep the negative effects on the ecosystem at a level that does not exceed the capacity of the system to transfer the diversity and non-renewable resources in its ecosystem to future generations [3].
Sustainability, which is necessarily one of the main problems of the twenty-first century, is generally handled together with corporate social responsibility, informed purchasing decisions and the green orientation that has emerged in some companies [12].
Sustainability has three dimensions:

Ecological (environmental) dimension of sustainability: Environmental sustainability is to ensure the continuity of natural resources and to transfer them to future generations, to use non-toxic and recyclable resources that do not harm the physical environment. In the ecology dimension, sustainability is examined in two stages:
- Production ecology; selection of textile raw materials, chemicals and processes with an environmentally friendly approach, use of treatment methods at every necessary stage;
- Waste ecology; It is the conversion or recycling of wastes such as water and textile products, which occur after production, into products that are harmless to the environment.

Economic (labour force) dimension of sustainability: In the economic dimension, sustainability is the protection of life and the environment and ensuring economic growth. The question to be asked in terms of economy is how development can be achieved without compromising the ability of future generations to meet their own needs. Ensuring economic sustainability in the textile sector is possible by using raw materials, energy and manpower in production processes without wasting them.
Social (equality) dimension of sustainability: In the social dimension of sustainable development, it is aimed to increase education and health standards, maintain cultural diversity, respect human rights and reach living standards in which basic human rights are implemented [13, 14]. Creating a working environment based on the fundamental rights and health of the workforce in the textile industry is the first important step to be taken for social sustainability. In addition, production processes, products and designs that increase the living standards of the whole society and prioritize their health contribute to social sustainability.

Recycling

To ensure sustainability, enterprises need to reintroduce the waste they cause in their activities to the economy.
Recycling in the textile industry is the reuse or reprocessing of used clothes, fibrous materials and textile waste from the production process. Recycling textile waste is not only an important way to solve many environmental problems but also a tool of socioeconomic and environmental sustainability [15].
Countries are increasingly focusing on commercial waste and producer responsibility to meet increasing recycling, reuse, and prevention targets. Directive 2008/98/EC in Europe; defines the basic concepts and definitions related to waste management such as waste definitions, recycling and recovery. It explains when waste ceases to be waste and becomes a secondary raw material and how to distinguish between waste and by-products. The regulation reveals some basic waste management principles, such as waste must be managed without endangering human health and harming the environment, especially without endangering water, air, soil, plants or animals, without

causing disturbance through noise or odours, and without adversely affecting rural areas or areas of special interest.

Waste legislation and policy of EU Member States implement the “waste management hierarchy”. Accordingly, the priority of waste is to prevent and reduce the amount of waste at the production stage. Secondly, efforts should be made to recover waste through reuse, recycling and energy production. As a last resort, the waste is destroyed or stored safely without harming the environment. In other words, first of all, the aim should be to prevent waste, if it cannot be prevented, it should be reused or recycled, and if neither can be done, waste should be destroyed [16].

Carbon footprint

Carbon footprint has become a widely used term and concept in public debates about responsibility and mitigation action against the global climate change threat. A carbon footprint is a measure of the specific total amount of carbon dioxide emissions that result directly or indirectly from an activity or accumulate over the life stages of a product [17].

Although the impact of sustainable textile production on global warming has not come to the fore until today, the output of atmospheric pollutants is also high due to the wide scope and supply chain of the sector and the production. For example, although a fabric does not seem to pollute the environment, most of the production processes result in greenhouse gas emissions, CO_2 and methane (CH_4) gases, etc., and negative environmental effects bring along the sustainability problem in the textile industry. To reduce the carbon footprint against the global climate change threat, the use of renewable energy sources can be preferred instead of obtaining energy from fossil fuels in production. In addition, the reuse of expired fabrics as raw materials, regular maintenance of the machines used in the enterprise, insulating hot water tanks and the use of energy-saving lighting elements will contribute to the reduction of carbon footprint. In recent years, when zero waste management has gained importance, sustainability in production can be achieved by targeting a “zero carbon footprint” in the textile industry [18].

Corporate Sustainability is the adaptation of economic, environmental and social factors to company activities and decision mechanisms, together with corporate governance principles, and the management of risks that may arise from these issues, to create long-term value in companies. Borsa Istanbul, where publicly traded companies in Türkiye are dealt with, has a sustainability index along with many different indices. The purpose of the BIST Sustainability Index is to create an index that will include companies that are traded on Borsa Istanbul and have a high level of corporate sustainability performance and to increase understanding, knowledge and practices on sustainability in Türkiye and especially among Borsa İstanbul companies. Companies that want to be included in this index must meet the environmental, corporate governance and social criteria determined by Borsa Istanbul. Environmental criteria include companies' environmental policy, environmental management systems, biodiversity policy and climate change management. As of 2023, there are 73 companies in the BIST Sustainability Index, and only one of these companies, Kordsa Teknik Tekstil Anonim Şirketi, operates in the textile sector [19].

ENVIRONMENTAL LEGISLATION AND ENVIRONMENTAL STANDARDS

The rapid industrialization in Türkiye in the last twenty years has led to an increase in environmental problems and legal and institutional arrangements on the environment. The highest legal norm that determines the limits of rights and requirements on the environment is the 1982 Constitution. The third article of the Environmental Law No. 2872 enacted in 1983 contains general principles regarding the protection, improvement and prevention of pollution of the environment. The Environmental Impact Assessment Regulation (EIA), one of the most important and effective instruments of environmental law, which was first issued in 1993 and was last updated in 2019, emerges as an important process in which environmental activities are supervised and coordinated in the process from the start of a project to its completion. EIA is a tool used by the upper decision mechanisms to prevent and reduce all the positive and negative effects that may be experienced in the future, starting from the implementation phase of the project, and to make decisions appropriate for the environment, before the implementation decision is made for a planned project [20].

In addition to the environmental law and EIA regulation, textile enterprises operating in Türkiye have to consider the EU council proposal of 17 June 1992 on the textile and clothing industry and the council directive 96/61/EC on textile production issued on 24 September 1996.

Environmental management systems

Setting standards to prevent environmental problems is an important environmental policy tool used by the state to prevent and control environmental problems. It is aimed to minimize the damage to the environment by determining the limited amounts of pollution and dangerous dimensions of environmental factors such as air, water, soil and noise. The most important ones among such standards are ISO 14001 Environmental Management System Standard, BS 7750 Environmental Management System Standard and Eco-Management and Audit System (EMAS) standards. The ISO 14001 Standard, which is the most accepted among these standards, was developed by the International Standards Organization (ISO) and published in August 1996. ISO14001 is the only audited and certified standard of the ISO 14000 Series. In addition to these standards, OEKO-TEX Standard 100 is an international and independent certification system. OEKO-TEX Standard 100 also provides significant advantages for manufacturing and exporting textile companies. Textile companies that have the OEKO-TEX Standard 100 certificate thus eliminate international trade barriers, increase the export and import share of textile products, and make an important contribution to the environment and vitality by ensuring environmentally friendly and human health-friendly production [21].

Considering human and environmental health, it is seen that the production and use of organic textile products have increased in recent years. The most well-known of the standards certifying that textile products are organic is the Global Organic Textile Standard (GOTS). According to GOTS criteria, fibres, yarns, fabrics, accessories, chemicals, dyestuffs, etc. that may harm human and environmental health cannot be used in the production of organic textile products [22]. For this reason, GOTS certification has an important place in the textile industry in terms of environmental and human health.

Environmental costs

Environmental costs include the costs of interventions that a business takes to prevent, reduce or repair environmental damage caused by its activities. Environmental costs can be grouped into three main groups: reduction costs, usage costs and loss costs. Reduction costs; These are the costs incurred by enterprises to protect the environment, prevent environmental problems, and minimize the damage to the environment. Usage costs; It covers expenses arising from the use of environmental natural resources. Accordingly, it is necessary to determine the costs of wear, abrasion, etc. resulting from the use of environmental resources. Loss costs are; It consists of the costs that the environmental pollution or environmental damage caused by the activities of the enterprises will impose on the enterprises [23]. Loss costs are included in the costs of penalties and compensation for complaints and lawsuits filed as a result of air, water, soil, and noise pollution. Reduction, use and loss costs for enterprises can be counted as follows:

- Reduction (Prevention) Costs: process control, environmental planning, emission measurement, recycling designs, environmental reports, environmental audit etc.
- Usage Costs: air, water, soil costs, noise costs, energy costs etc.
- Loss Costs: penalties and compensations, environmental clean-up, waste disposal, etc.

MATERIAL METHOD

This study focuses on explaining the analysis of environmental costs in textile companies. In the analysis part of the study, a company operating in the textile sector in the Denizli province of Türkiye was examined. This company has yarn, yarn dyeing, weaving-apparel and dyeing-finishing enterprises located in four different locations. Environmental costs in these enterprises were determined on a unit basis and their share in the general expenses of the company was calculated. The data were obtained through face-to-face interviews with company officials and examining the annual financial statements for 2022. Financial reports were examined using the content analysis method All costs are determined annually and calculated in Euros.

RESULTS AND DISCUSSION

In this section, first of all, the results of the analysis of the environmental costs of four different enterprises belonging to the textile company are shown separately. Then, the total environmental costs of the company were calculated by summing the costs of all enterprises.

The results of the four enterprises owned by the company are presented below.

a) Yarn Enterprise: Yarn production is carried out by opening and embossing the fibre, cleaning, blending, combing and separating the short fibres and neps into slivers, drawing them to the desired yarn count, and twisting. Environmental costs in yarn production processes generally consist of energy management costs and waste management costs.

The environmental costs of the yarn enterprise are shown in table 1. When table 1 is examined, it is seen

Table 1

ENVIRONMENTAL COSTS OF THE YARN ENTERPRISE

Costs	Annual amounts (€)
Prevention costs	**20,219**
Fee paid to educators for Environmental education	708
Equipment used by workers (mask etc.)	9,100
Additional overtime fees paid to workers for training	10,000
Led bulb project for electricity saving (Economic life 5 years)	2,054 / 5 year = 411
Loss costs	**3,875**
Waste disposal cost	3,875
Total environmental costs (annual)	**24,094**
Total enterprise expenses	**4,500,000**
Share of environmental costs in total expenses	**0.54%**

Table 2

ENVIRONMENTAL COSTS OF YARN DYEING ENTERPRISE	
Costs	**Annual amounts (€)**
Prevention costs	**2,080**
Environmental engineer consulting fee	820
Oeko-Tex certification fee	1,055
Chimney filtering system cost (maintenance + filter)	205
Usage costs	**14,602**
Wastewater cost	14,500
Natural gas boiler maintenance cost	102
Recycling recovery	**2,286**
Sales of waste	2,286
Total environmental costs (Prevention costs + Usage costs – Recycling recovery)	**14,396**
Total enterprise expenses	**1,278,315**
Share of environmental costs in total expenses	**1.13%**

that environmental costs, prevention costs and damage costs are realized in the yarn enterprise, but it is determined that there are no usage costs. During the interview with the enterprise manager, it was stated that the protective equipment was used for the occupational health and safety of the employees. In addition, environmental training was provided to the employees outside of working hours and overtime wages were paid to the workers. At the same time, old type bulbs have been replaced with LED bulbs to save electricity. Another striking point is that the enterprise cannot gain from recycling and waste, on the contrary, it bears costs for their disposal.

As can be seen in table 1, the share of environmental costs in total expenses in yarn enterprise is approximately 0.5%, which is quite low.

b) Yarn Dyeing Enterprise: When coloured yarn is used in weaving and knitting enterprises, raw yarns are dyed according to the desired colour and properties in yarn dyeing enterprises. Yarn dyeing enterprises are one of the enterprises where most chemicals are used in the textile sector.

Environmental costs of yarn dyeing enterprise are shown in table 2. When table 2 is examined, in the yarn dyeing enterprise, it was observed that the environmental costs, prevention costs and usage costs were realized, and it was determined that there were no damage costs. As prevention costs, the business incurred environmental engineering consultancy fees, certification fees and chimney filtering costs. In addition, there are wastewater costs and natural gas boiler maintenance costs as usage costs. It has been observed that recycling is achieved through the sale of waste.

As can be seen in table 2, the share of environmental costs in total expenses in the yarn dyeing enterprise is approximately 1% and is quite low.

c) Weaving-Apparel Enterprise: Since weaving and apparel are located in the same building and some cost items are combined in the integrated company where we work, environmental cost calculations are also combined. It is the enterprise where the fabrics are woven and the apparel processes are carried out according to the desired specifications.

The environmental costs of the Weaving-Apparel enterprise are shown in table 3. When table 3 is examined, in the weaving and apparel enterprise, it was observed that the environmental costs, prevention costs and usage costs were realized, and it was determined that there were no damage costs. Prevention costs include equipment costs, depreciation costs, water treatment expenses and training costs. It has been observed that recycling gains are obtained by the sale of waste.

As can be seen in table 3, the share of environmental costs in total expenses in the weaving-apparel enterprise is approximately 6% and is higher than other enterprises. This is due to the newly installed solar energy system in the enterprise.

d) Dyeing Finishing Enterprise: These are the enterprises where the fabrics are dyed according to the desired properties. One of the departments where chemicals are used the most is dyeing finishing enterprises.

The environmental costs of the dyeing finishing enterprises are shown in table 4. When table 4 is examined, in the dyeing finishing enterprise, it has been observed that environmental costs, prevention costs, usage costs, and damage costs are realized. Prevention costs include inspection, certification, filtering and training fees. It has been observed that recycling is achieved through the sale of waste.

As seen in table 4, the share of environmental costs in total expenses in the dyeing finishing enterprises is approximately 2%.

In table 5, the total environmental costs of the company are shown in terms of cost types. These costs are calculated by bringing together the environmental costs of four different enterprises (yarn, yarn dyeing, weaving-apparel and dyeing-finishing enterprises).

Table 3

ENVIRONMENTAL COSTS OF THE YARN ENTERPRISE	
Costs	**Annual amounts (€)**
Prevention costs	**79,572**
Equipment used by workers	16,000
Ventilation-air conditioning system (annual depreciation fee)	57,000
Water treatment expense	5,510
Fees paid for Environmental education	1,062
Usage costs	**340,000**
Solar energy system (annual depreciation fee)	340,000
Recycling recovery	**26,728**
Sales of waste (textile waste + electrical waste)	26,728
Total environmental costs (Prevention costs + Usage costs – Recycling recovery)	**392,844**
Total enterprise expenses	**6,129,179**
Share of environmental costs in total expenses	**6.4%**

Table 4

ENVIRONMENTAL COSTS OF THE DYEING FINISHING ENTERPRISE	
Costs	**Annual amounts (€)**
Prevention costs	**45,766**
Ministry of Environment inspection fees	1,800
Chimney filtering cost	3,000
Oeko-Tex certification fee	8,500
Fees paid for Environmental education	1,800
Equipment used by workers	12,000
Heat recovery project – equipment – well costs (annual depreciation cost)	18,666
Cost of using	**94,200**
Wastewater cost	91,200
Ventilation-air conditioning system (annual depreciation fee)	3,000
Loss costs	**7,100**
Emission measurement cost	3,500
Chimney ash disposal cost	3,600
Recycling recovery	**2,500**
Sales of waste (textile waste + electrical waste)	2,500
Total environmental costs (Prevention costs + Usage costs – Recycling recovery)	**144,566**
Total enterprise expenses	**6,692,870**
Share of environmental costs in total expenses	**2.16%**

Table 5

TOTAL ENVIRONMENTAL COSTS OF THE TEXTILE COMPANY	
Costs	**Annual amounts (€)**
Prevention costs	147,637
Cost of using	448,802
Loss costs	10,975
Recycling recovery	(31,514)
Total environmental costs (Prevention costs + Usage costs – Recycling recovery)	575,900
Total company expenses	18,600,364
Share of environmental costs in total expenses	3.1%

As can be seen in table 5, the share of environmental costs in total operating expenses is 3.1%. Usage costs take the biggest share among environmental costs. The lowest cost is loss costs. The company should focus on reducing overall environmental costs by increasing the required recycling recovery.

CONCLUSION

The textile sector, which is an important sector of the Turkish economy, provides significant contributions to the sector and the country's economy with its production and export potential. Due to its production structure, the sector creates air, water, soil, and noise pollution. Enterprises operating in the sector bear environmental costs to protect the environment through corporate social responsibility and legal regulations. In addition, the increase in people's environmental awareness has led to more preference for enterprises that produce organic products and produce by environmental regulations and environmental standards.

Environmental laws introduced for sustainable economic growth have brought additional costs to enterprises along with new responsibilities. In an increasingly competitive environment, enterprises need to carefully review all their costs to survive. In this context, enterprises have to determine the environmental costs and calculate their share of the total expenses. Contributing to the business, especially in making managerial decisions and reusing the waste generated after production, increases the importance of environmental finances. The environmental costs in the Turkish textile industry consist of the training fees spent for environmental education, the equipment fees used by the workers, the environmental management certification and inspection systems fees, the chimney filtering system costs, the wastewater cost, the boiler maintenance costs, the ventilation-air conditioning system costs. Recycling gains are also obtained by the sale of waste. In this study, the analysis of the environmental costs of textile companies operating in Denizli province was made. As a result of the application, it has been revealed what the environmental costs consist of and it has been determined that the share of the total operating expenses is between 0.5% and 6% at different production stages.

Although the textile sector is an important sector for economies, it causes environmental pollution all over the world. The chemicals used in the industry negatively affect the entire environment, especially air and water. Additionally, water consumption used in production significantly reduces clean water resources. In this sector, which produces clothes, accessories, and home textile products from the essential needs of people; raw materials and auxiliary materials are of natural origin; reducing pesticides (chemical pesticides, pesticides) used in fibre production or choosing fibres with the least pesticide need; reducing the use of chemicals considerably, including recycling products in production, providing longer product life, enabling recycling in the production-consumption stages, and even establishing a production system that does not cause any waste generation is important for our world both ecologically and economically [13]. The use of natural fibres for human health in the textile sector and the increase of organic production lines will also contribute to the protection of the environment. Recycling of wastes to the economy by recycling will prevent loss costs and create new resources for the enterprise. Besides, the use of sustainability-based ecological materials and designs while determining the production policies of companies is effective in reducing environmental costs.

In addition to minimizing these environmental costs in the production process, taking measures to transform the waste generated after the use of textile products in a way that causes the least damage to the environment is another important point in terms of sustainability.

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

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ABSTRACT – REZUMAT

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

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

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

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

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

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

INTRODUCTION

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

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

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

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

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

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

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

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

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

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

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

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

The literature suggests that this material demonstrates exceptional performance in terms of its water-repellency and resistance to dust [53].

Hydroxyl radicals formed in the redox reactions of titanium dioxide (TiO_2) nanoparticles affect their antimicrobial activity. The particles form hydroxyl radicals by interacting with ultraviolet light at the appropriate wavelength. These radicals inactivate microorganisms by oxidizing organic compounds in the structure of microorganisms [54, 55]. In the literature, the observation of the antimicrobial ability of titanium and the conclusion that it has excellent antimicrobial activity in improving cell compatibility can prevent microbial adhesion due to its photocatalytic activity [56, 57]. When TiO_2 is excited by photons, minimum energy, electron/hole (e–/h+) pairs equal to its bandgap, are produced, providing powerful redox reactions to kill germ cells [58]. The introduction of doping agents has the potential to reduce the band gap of TiO_2 and enhance the separation of charges within the material. Consequently, this can lead to an improved antibacterial effect when TiO_2 is excited by light [58, 59]. However, it is important to note that this effect is not observed in the absence of light, hence restricting its applicability in the field of biomedicine [60, 61]. Furthermore, antimicrobial strategies targeting germ membrane functions are promising in treating persistent infections [62–64]. Biomaterials are biocompatible materials that do not interfere with the regular changes of the surrounding tissues and do not cause unwanted reactions (inflammation, coagulation, etc.) in the tissue [65]. Biocompatibility can be defined as compatibility with the body. Therefore, it is seen that bioceramic materials added to textile products affect thermal properties, do not cause problems in terms of comfort and reduce the temperature difference between the body and the garment [66]. Non-specific mechanisms of action enable NPs to operate in pathways that are beyond the reach of antibiotics. Furthermore, it should be noted that the primary processes responsible for antibiotic resistance are not directly associated with nanoparticles. These mechanisms do not necessarily require the penetration of nanoparticles [36].

The antibacterial and strength results obtained from the nanoparticle materials used in this study are shared below. These are also distinguished to those in the literature where cotton, linen and bamboo surfaces which were also evaluated together, and their mechanical and antibacterial results were examined. *E. Coli* cells are longer than *S. Aureus* cells and can come into contact with a larger number of spherical particles, cell wall components have different pathways for the absorption of NPs [31, 36, 67]. This situation causes differences between the methods applied and the results obtained, and structures that are resistant to *E. Coli* may not show the same sensitivity against *S. Aureus* [68]. In this study, cotton, bamboo and linen untreated raw surfaces were treated with three different chemicals and then compared, which is important in terms of finding and evaluating all three together in the literature.

MATERIALS AND METHODS

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

Bioceramic nanoparticles and coating chemicals

Within the scope of the study, three different nanoparticles were used. Sigma-Aldrich supplied nanoparticles. The recipe and chemicals for the preparation of the coating paste, the properties of the particles used and the viscosity values of the prepared coating paste are given in table 2. Coating chemicals were obtained from Rudolf Duraner.

The chemicals used in the preparation of the coating paste were mixed with a Janke Kurkel brand mixing device. The viscosity values of the prepared coating paste were measured with a Brookfield DV-E Viscometer at 50 rpm using a Sp6 tip.

Application of the coating process

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

Table 1

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

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

Table 2

PURITY OF NANOPARTICLES, PARTICLE SIZES AND VISCOSITY VALUES OF THE PREPARED COATING SOLUTION AND FORMULA

Nanoparticle type	Degree of purity (%)	Particle size (nm)	Viscosity (cP)	Formula			
				Material	Ratio	Material	Ratio
Titanium Dioxide (TiO_2)	99.9	17	7020	Anionic Binder Acrylate (AC 111)	20%	Anionic crosslinker/fixing agent(RUCO-COAT FX 8011)	1.5%
Silicon Dioxide (SiO_2)	98.5	55-75	11600	Dispergator (AD 719)	0.5%	Distilled Water	75.5%
Zinc Oxide (ZnO)	99.5	30-50	4800	Anionic Thickener (RUCO-COAT TH 5020)	1.5%	Nanoparticles	1%

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

Measurements and analysis

Evaluation of FT-IR measurements

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

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

Antimicrobial activity analysis

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

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

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

Mechanical properties

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

RESULTS AND DISCUSSION

Evaluation of FT-IR measurements

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

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

Evaluation of EDS measurements

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

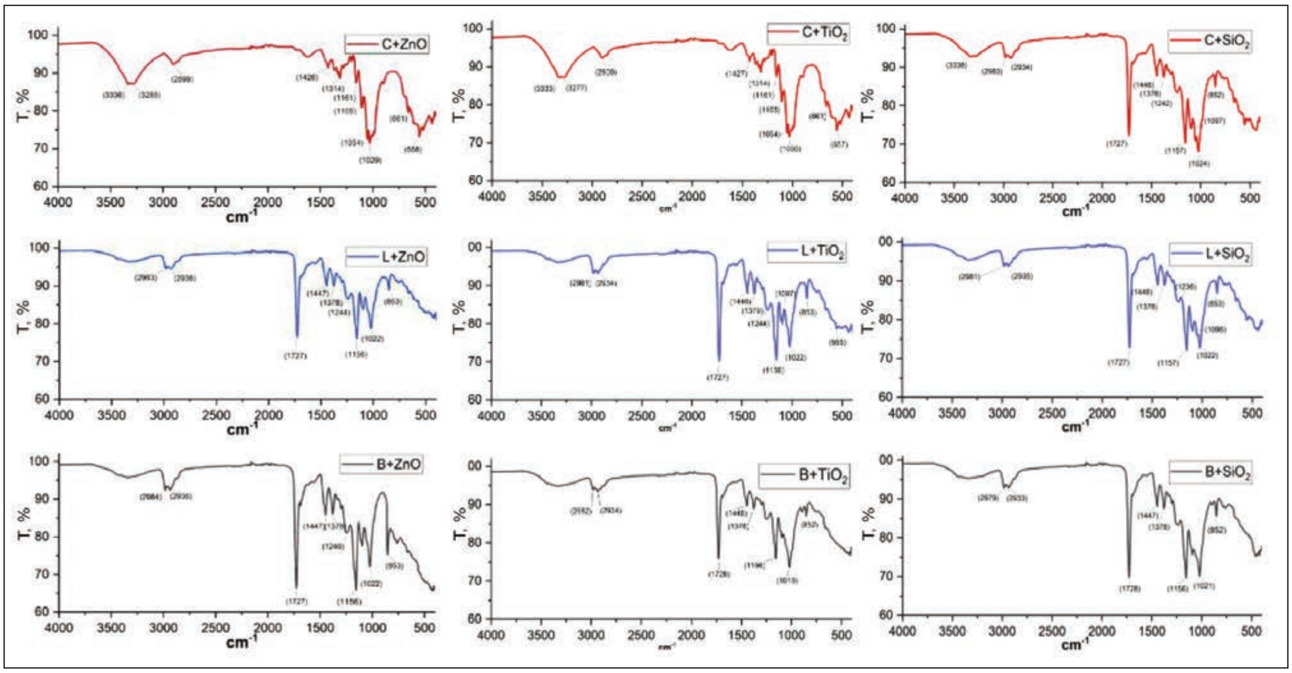


Fig. 1. FT-IR analysis results of cotton, linen and bamboo surfaces coated with coating paste

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

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

Evaluation of SEM images

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

Evaluation of antimicrobial activity

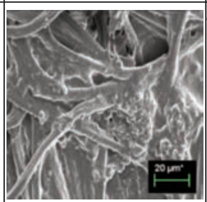
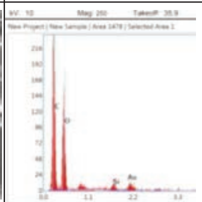
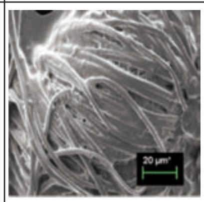
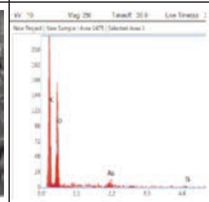
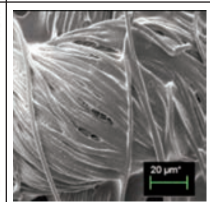
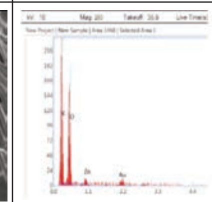
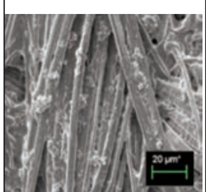
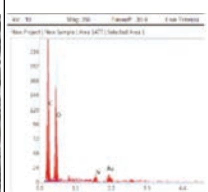
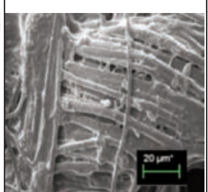
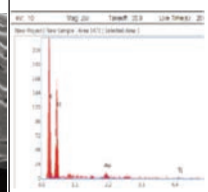
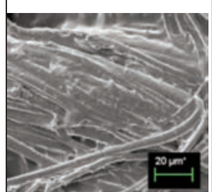
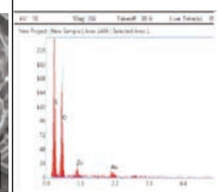
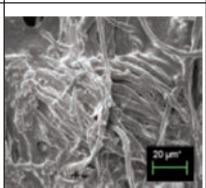
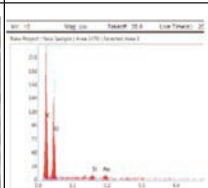
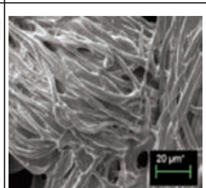
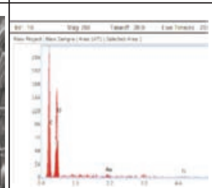
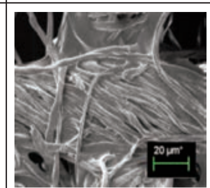
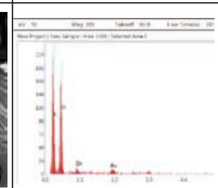
The percentage reduction of gram-positive and gram-negative bacteria of ZnO, TiO_2 and SiO_2 nanoparticle-coated cotton, linen and bamboo fabrics is presented as %R. In the application made by the AATCC 100 standard, textile samples are immersed in diluted bacterial solutions (Initial) and then dripped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

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

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

Table 3

SEM, EDS ANALYSIS RESULTS AND ELEMENT DISTRIBUTIONS OF COATING SURFACES

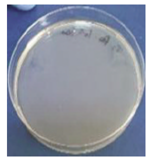
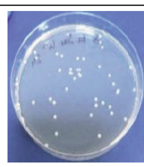
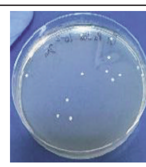
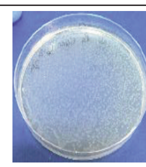
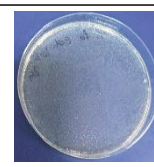
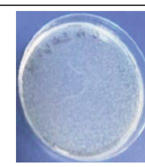
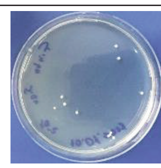
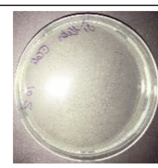
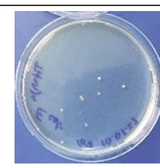
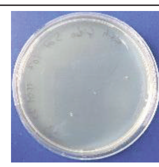
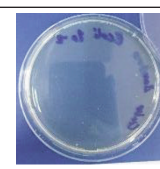
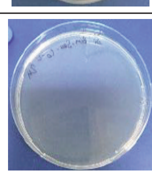
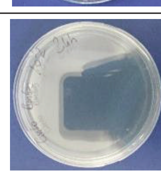
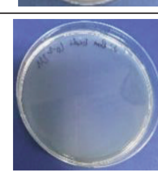
M	1a	1b	2a	2b	3a	3b
	SEM	EDS	SEM	EDS	SEM	EDS
	SiO_2	SiO_2	TiO_2	TiO_2	ZnO	ZnO
Bamboo						
EDS	-	Wt%	-	Wt%	-	Wt%
	C	60.79	C	66.41	C	57.96
	O	36.99	O	30.69	O	40.49
	SiO_2	1.42	TiO_2	2.18	ZnO	0.99
Linen						
EDS		Wt%		Wt%		Wt%
	C	60.09	C	66.04	C	60.4
	O	37.76	O	31.12	O	37.41
	SiO_2	1.28	TiO_2	2.19	ZnO	1.46
Cotton						
EDS		Wt%		Wt%		Wt%
	C	59.31	C	61.66	C	56.67
	O	38.74	O	35.79	O	14.51
	SiO_2	1.36	TiO_2	2.1	ZnO	1.05

Mechanical Tests

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

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

Table 4

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

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

CONCLUSIONS

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

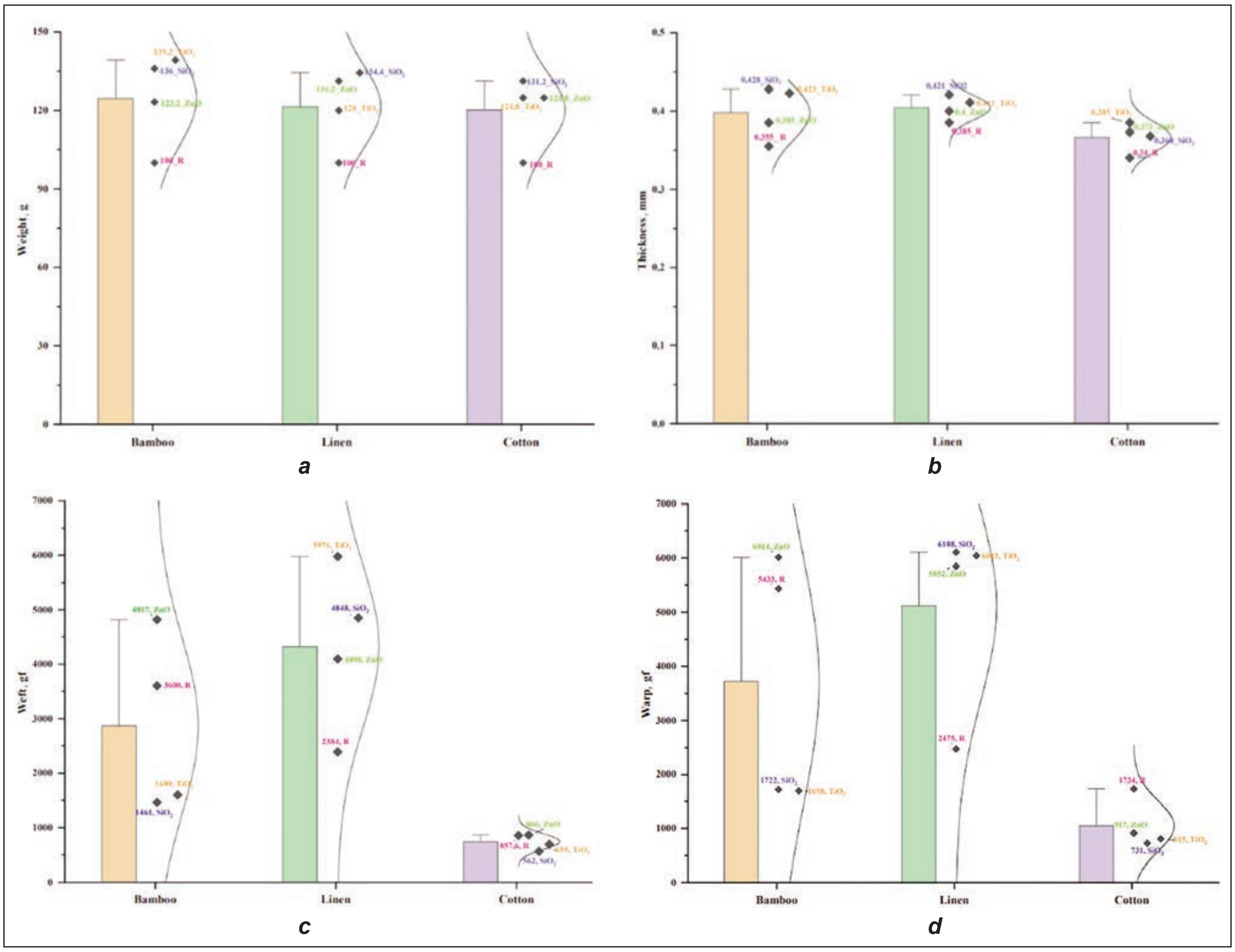


Fig. 2. Graphical changes on the woven surfaces: *a* – weight; *b* – thickness; *c* – strength on weft direction; *d* – strength on warp direction

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

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

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

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

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

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

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Investigating the post-pandemic textile market: the stake of private labels in customer loyalty

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ABSTRACT – REZUMAT

Investigating the post-pandemic textile market: the stake of private labels in customer loyalty

The textile market is a global production, processing, and distribution industry. It includes various products, from natural fibres like cotton and wool to synthetic fibres like polyester and nylon. The textile market has faced several challenges recently, including rising production costs, increasing competition from overseas producers, and declining consumer demand. This empirical study examines the relationship between private labels offered in organised retail apparel stores in Belagavi, North Karnataka, India, and certain factors such as customer satisfaction, trust, and Loyalty. This study explores the role played by trust as a mediator between customer satisfaction and Loyalty to brands in the textile industry. The data were collected from 460 respondents using convenience sampling with a structured questionnaire. The results show that Satisfaction (B=0.0782, p=0.611) and Trust (B=0.8678, p<0.001) show significant positive unstandardised coefficients in the regression model predicting Loyalty. There is a mediated but indirect influence of customer trust on customer satisfaction and Loyalty generated by Satisfaction in the study area. By weaving together Satisfaction and trust, textile retailers can forge stronger customer bonds, enhance Loyalty, and gain a competitive edge in the Belagavi market. This approach paves the way for sustainable growth and success in the dynamic textile landscape.

Keywords: *private label textiles, customer satisfaction, customer trust, brand loyalty, textile market, pandemic, purchase intentions, e-commerce, textile, fashion, fabric, apparel*

Investigarea pieței din domeniul textil în contextul post-pandemic: miza mărcilor private în loialitatea clienților

Piața produselor textile este o industrie globală de producție, procesare și distribuție. Aceasta include diverse produse, de la fibre naturale precum bumbacul și lâna până la fibre sintetice precum poliesterul și nailonul. Piața produselor textile s-a confruntat recent cu mai multe provocări, inclusiv cu creșterea costurilor de producție, creșterea concurenței din partea producătorilor internaționali și scăderea cererii consumatorilor. Acest studiu empiric examinează relația dintre mărcile private oferite în magazinele de îmbrăcăminte organizate în contextul comerțului cu amănuntul din Belagavi, North Karnataka, India și anumiți factori de influență precum satisfacția clienților, încrederea și loialitatea. Acest studiu explorează rolul jucat de încredere ca mediator între satisfacția clienților și loialitatea față de mărcile din industria textilă. Datele au fost colectate de la 460 de respondenți utilizând eșantionarea de conveniență pe baza unui chestionar structurat. Rezultatele arată că Satisfacția (B=0,0782, p=0,611) și Încrederea (B=0,8678, p<0,001) prezintă coeficienți nestandardizați pozitivi semnificativi în modelul de regresie care prezice loialitatea. Există o influență mediată, dar indirectă, a încrederii clienților asupra satisfacției clienților și loialității generate de satisfacția în zona de studiu. Îmbinând satisfacția și încrederea, comercianții cu amănuntul din industria textilă pot crea legături mai puternice cu clienții, pot spori loialitatea și pot obține un avantaj competitiv pe piața Belagavi din India. Această abordare deschide calea pentru o creștere durabilă și succes în peisajul dinamic al industriei textile.

Cuvinte-cheie*: marca privată din domeniul textil, satisfacția clienților, încrederea clienților, loialitatea mărcii, piața de textile, pandemie, intenții de cumpărare, comerț electronic, textile, modă, țesături, îmbrăcăminte*

INTRODUCTION

The phenomenal growth of e-commerce and organised retailers exerted pressure on small and medium apparel retailers in India. With constraints of capital, space, and marketing capabilities, these retailers need help to move further. It became imperative for these retailers to enhance margins by adopting private-label strategies. However, building private labels requires customer satisfaction, trust, and Loyalty. The COVID-19 pandemic boosted online retail sales in India at unprecedented speed, with awareness of the ingenuity and business/financial analytics element involved in developing one's private label. The retail apparel industry has witnessed the rise of private labels. Still, the rationale behind their addition to companies' portfolios has not been extensively examined or explored in scholarly or industry literature [1, 2]. The rise of private label brands in India equals the growing proportion of organized retailing

[3]. Retailers are creating suitable private labels to build customer loyalty and brand tactics to inspire positive opinions of their store's private label brands [4]. India is one of the few nations that control the entire supply chain nearby, from various fibres to a sizable market. It can provide clients with packaged goods that include various fibre types, different count sizes, fabrics with varying weights and weaves, and a selection of finishes. The multiple textile traditions and cost-based benefits only highlight this benefit [5]. To give academics and retailers a perspective on how theories on buying processes relate to practice, the components of the fashion retail buying role have been compiled into a framework [6]. At this crossroads, private-label apparel retailers are eyeing viable options to augment customer satisfaction and trust in building customer loyalty.

Customer loyalty

Modern consumers quickly gauge a brand's impact on their Loyalty by how satisfied and trusted they feel about it. Customer loyalty is attained by a company based on its customer satisfaction [7–9]. Customer loyalty to buy intention is highly correlated with consumer satisfaction [10]. A brand's ability to satisfy customers will affect how loyal consumers are to it. Further, Loyalty assists the business in keeping its clients, acting as a barrier to switching behaviour [11]. Satisfaction of customers towards private label brands based on price, quality & promotion has a great deal in developing customer loyalty towards private label brands in the apparel segment [12]. Customer attitudes are shaped by brand loyalty, which influences and leads to their intention to buy [13]. Emotional ties to businesses are necessary for customer loyalty to encourage repeat business [14]. Using brand loyalty as a barrier to brand switching may be due to consumers' repeated behaviours, which may be based on inertia and cause resistance to brand switching [11]. Behavioural Loyalty demonstrates the actual reliance on recurrent purchase behaviour. In contrast, attitude loyalty illustrates how a customer's psychology will function in recommending brands to others [15, 16].

Customer Trust and Satisfaction

Numerous studies across industries highlight the critical role of brand trust, Satisfaction, and Loyalty in driving customer relationships. From traditional retailers like coffee shops to cutting-edge Malaysian companies [17], customers who trust and feel satisfied with brands exhibit greater Loyalty, often manifested in repeat purchases and increased spending [18]. Further underlines the mediating role of Satisfaction and trust in building brand loyalty, even in contexts like insurance [19–22], found that Satisfaction with private-label fashion directly influences repurchase intentions, solidifying the link between Satisfaction and Loyalty. Brand experience, Satisfaction, trust, and Loyalty are independent factors affecting customer loyalty; the overall takeaway remains clear: fostering trust, Satisfaction, and Loyalty is paramount for brands seeking long-term customer relationships and sustained success [23]. Client loyalty is affected by client delight. Dependability, fulfilment, and ethical behaviour all contribute to belief. Higher levels of client fulfilment boost devotion and faith. A relationship exists between moral behaviour, fulfilment, belief, and dependability [24].

LITERATURE REVIEW:

Bibliometric analysis using the VosViewer software

Bibliometric analysis is a quantitative technique for measuring published research [25]. It tracks the development in the field, identifies the trends, and assesses the impact of individual researchers. A co-occurrence analysis of private label research using VosViewer and Scopus data in a CSV file revealed three key clusters as shown in figure 1: (1) store brands creating value for customers and stronger store loyalty; (2) national brand equity fuels purchase

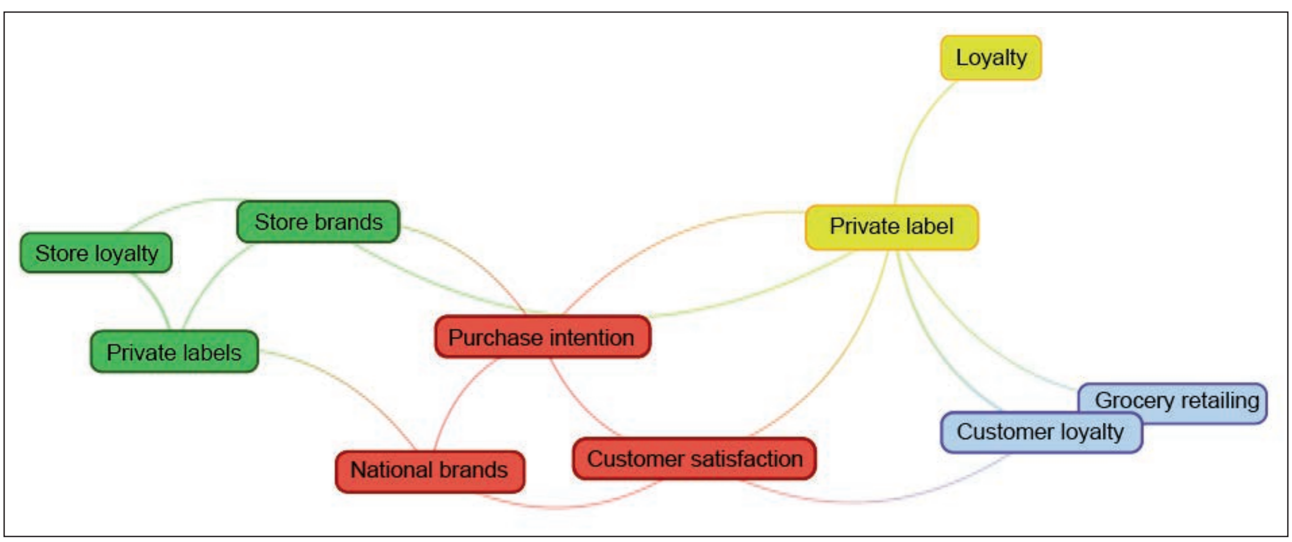

Fig. 1. Co-occurrence analysis

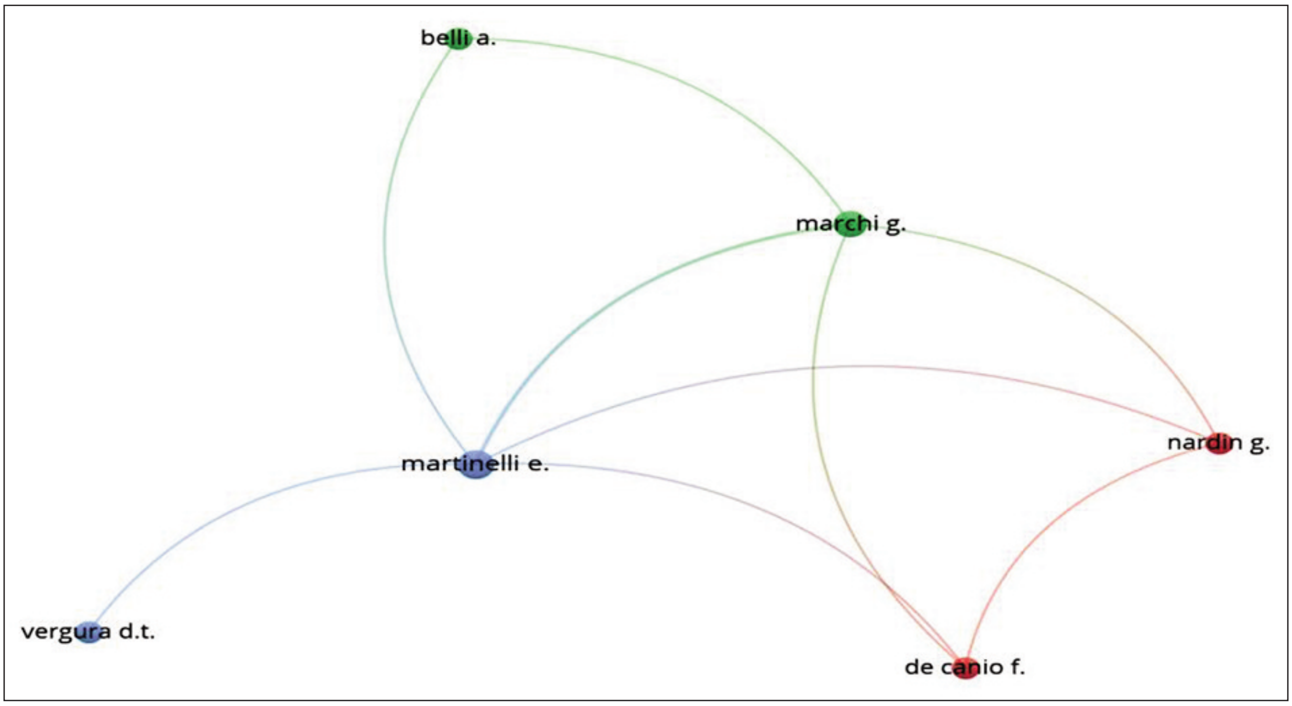

Fig. 2. Co-authorship analysis

intentions leading to customer satisfaction; and (3) retailers significantly impacted customer purchases during the COVID-19 pandemic, though this cluster was weaker. This emphasizes the importance of store and national brands in influencing customer behaviour, highlighting the role of value, equity, and purchase intentions in driving Loyalty and Satisfaction amidst shifting retail landscapes [25].

Researchers also conducted Co-authorship analysis using VosViewer. This method tracks the number of times two or more authors collaborate on publications. This is used to identify research networks and follow the development of new research areas. Figure 2 shows that Martinelli and Vergura authored papers on private labels and customer loyalty [26]. They also worked on sustainability and premium store brands. Similarly, Nordin and Martinelli worked together on the fear of COVID-19 and its effect on private labels and Loyalty [26]. In another exciting research, vegetarian private labels influence purchase intentions and Loyalty [26].

Store loyalty and private labels

Store brands enhance customer footfall to the store. These brands, with price flexibility, gained customer attention towards the store. Further, store loyalty due to private labels depends on households' usage, store branding strategies, and the metrics a retailer adopts [27]. In certain instances, it was observed that private-label Loyalty has increased store loyalty [28]. Additionally, price acted as a significant variable in constructing store loyalty. It is also observed that higher-priced customers exhibited less store loyalty [29]. However, it was also argued that during COVID-19, customers purchased private labels due to lower prices [30].

Contrary to this argument, it was observed that store experience and customer satisfaction during COVID-19 enhanced customer loyalty [31]. In addition, customers' variety-seeking buying behaviour significantly influences buying private labels. Satisfied private-label customers with variety-seeking behaviour tended to exhibit better customer loyalty [32]. A few retailers offering non-traditional products and services observed that attitudinal Loyalty significantly creates customer loyalty [33]. Private labels with sustainability and social concerns gained more customer loyalty than their counterparts [34].

National brands versus private labels

National brands were hit harder during the COVID-19. Private labels, due to their value propositions, gained prominence. Store brands offer higher margins than national brands [35–38]. In the post-COVID-19 days, national brands still need to regain their lost position. However, in certain instances, it was observed that the non-availability of certain brands in the store led to customer churn [39, 40].

Customer satisfaction and private labels

Satisfaction is critical in building confidence with M-commerce clients [41]. Price, quality, and the worth of private brands affect customer satisfaction [26, 42]. A well-executed private-label approach increases consumer happiness and develops customer loyalty [43]. Identifying customer happiness and trust is crucial in analysing a website's influence on customers in online retail. Building trust requires a positive impact on Satisfaction, highlighting the interdependence of these factors and stating that retailer satisfaction and trust are critical to gaining Loyalty from store initiatives in private labels [44].

Emphasize further how crucial product quality, related Satisfaction, and trust are to businesses hoping to win over repeat business [45]. Developing trust is essential to increasing customer satisfaction because it plays a crucial part in the process [46].

Research Gap

Researchers used the keywords private labels, store loyalty, private label loyalty, trust, and Satisfaction to identify research articles in the post-pandemic era based on papers found that more highlighted the relationship between store brand image and Loyalty but not on satisfaction and trust post-pandemic days [47]. Customers' Loyalty, including trust and other variables, did not consider Satisfaction and image and did not consider the impact of customer satisfaction on post-pandemic customer loyalty [48]. Customer trust and Satisfaction were considered for customer loyalty and living void space on customer satisfaction [49].

Research Gap validation through web content

The research gap identified via published articles needed to be more substantial. Thus, researchers validated the gap through web articles. The analysis depicts the absence of private labels in the study area. By considering just essential characteristics, they could determine which keywords were popular. The words were more prevalent on Loyalty, Satisfaction, and trust, but private labels looked to be concentrated in the research.

Objective

The research objectives were developed to investigate the impact of private labels on assessing customer loyalty in the apparel industry in the post-pandemic period. The deduced objectives include:

1. To examine the effect of consumer loyalty on Satisfaction.
2. To explore the correlation between consumer satisfaction and customer trust.
3. To examine the mediating role of trust in the association between customer satisfaction and brand loyalty.

Hypothesis:

Ha1: There is a positive linear relationship between customer satisfaction and the generation of Loyalty for private labels.

Ha2: There is a positive linear relationship between customer satisfaction and the generated trust for private labels.

Ha3: Trust mediates the association between the customer's Satisfaction and customer Loyalty.

Theoretical Model of the research

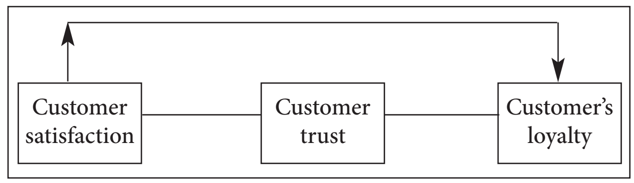

Fig. 3. Theoretical model of the research for apparel

This framework in figure 3 emphasizes the relationship between store loyalty, private labels, and customer satisfaction, acknowledging the impact of price, variety seeking, sustainability, and the pandemic. Further research will explore these relationships in greater depth, contributing to understanding consumer behaviour and Loyalty in the context of private labels for textile brands [54, 55].

METHODOLOGY

A descriptive research design was selected based on the survey requirements. The study examined how customer satisfaction generated trust and Loyalty on private label textiles in Belagavi city of Karnataka state in India. Researchers thoroughly investigated existing literature to identify research gaps and variables. This process enabled researchers to prepare the questionnaire instrument for the research. The

Table 1

RESEARCH GAP ANALYSIS			
Paper title	**Authors**	**Outcomes measured**	**Research Gap identified**
The Influence of Brand Element Criteria and Brand Image of Private Label Products on Store Image and Customer Loyalty Implications: Study of Modern Retailers During COVID-19 Pandemic	Annas [50]	• Store Image • Customer Loyalty	Trust and satisfaction variables were not measured
Customer Loyalty to Modern Retail Channel: A Study in The Context of the COVID-19 Pandemic in Vietnam	Hien et al. [51]	• Customer Loyalty	Satisfaction and trust measurements are not considered
Customer Loyalty in the COVID-19 Pandemic: The Application of Machine Learning in Survey Data	Khoa et al. [52]	• Customer Loyalty	Trust and customer satisfaction study was the limitation
The impact of private labels on consumer store loyalty: An integrative perspective	do Vale et al. [53]	• Store Loyalty	The authors did not work in the Indian context

secondary data was also collected through official websites and journals. The primary data was collected through a self-administered questionnaire instrument. Further, researchers used convenience sampling to collect the data from 460 respondents. The sample validation process omitted 14 responses due to incompleteness.
A 5-point Likert scale was adopted to evaluate the relationships between the variables. The items corresponding to each variable were carefully selected from the body of existing literature and foundational works by numerous experts. The scale comprised five items from the literature to assess trust and related aspects [19]. These items measured dependability, expectation, honesty, safety, and trust related to private brands. A four-item scale from [56, 57] examined consumer loyalty. The selected items assessed the customer's inclination to buy, intention to buy, likelihood of future purchase, and influence. A five-item scale was drawn for measuring customer satisfaction [58, 59]. Structural equation modelling (SEM) was used to evaluate the theoretical Model, VIF to check multicollinearity among variables, Cronbach's alpha for reliability, and KMO and Bartlett's for sample adequacy.

RESULTS

A reliability test was used to assess the reliability of the data collected. The consistency of the responses to any item used in the questionnaire and the based on the data collected should be more than 0.70. The overall internal consistency of all the items is 0.772, as shown in table 2. The Kaiser Meyer Olkin (1997) and Bartlett's test for Sphericity (1954) were used to determine the adequacy of the sample, and the result of the test, as shown in table 2, is 0.867, which lies between the 0.8–0.9 range. Hence, both test results show positive internal consistency and sample size adequacy results.

Table 2

RELIABILITY AND SAMPLE ADEQUACY

Cronbach's alpha	KMO and Bartlett's
0.772	0.867

A variance inflation factor (VIF) was used to measure the degree of collinearity (or multicollinearity) among variables (i.e., the independent variables considered are Customer Satisfaction & Trust, and the dependent variable is Customer Loyalty) [60]. If the VIF factor value is less than or equal to 5, it is not a problem and does not result in the rejection of any independent latent variable. The values of VIF from table 3 indicate that there is no multicollinearity with a VIF value of 2.683 for the variables Customer Satisfaction & Trust. Thus it suggests that Trust and Satisfaction independently predict Loyalty, confirming their respective and combined effects on forming customer loyalty.

Table 3

VIF

Variables	VIF Value
Customer Satisfaction	2.683
Trust	2.683

SEM (Structural Equation Modeling)

SEM analyses data based on acquired information, the relationship between customer satisfaction, an independent variable, and customer trust and Loyalty, dependent variables. The result of the analysis is shown below:

Table 4

OVERALL TEST

Label	X^2	df	p
User Model	154	74	<0.001
Baseline Model	3661	91	<0.001

Table 5

FIT INDICES

SRMR	95% Confidence Intervals		Upper	RMSEA p
	RMSEA	Lower		
0.026	0.049	0.038	0.060	0.530

The total model test results, which contrast the User Model with the Baseline Model, are shown in table 4. There is a significant difference between the models, as indicated by the chi-square (X^2) statistic, which is substantial at $p<0.001$. The User Model's fit indices are shown in table 5; the Standardized Root Mean Square Residual (SRMR) is 0.026, the Root Mean Square Error of Approximation (RMSEA) is 0.049, and the RMSEA p-value is 0.530, which is not statistically significant. These values, which are within acceptable bounds, imply a satisfactory fit. Both fit indices and statistical tests show that the User Model performs significantly better than the Baseline Model [61–65].
Table 6 shows parameter estimates with 95% confidence ranges for the given relationships. Customer satisfaction has a significant and strong impact on trust ($\beta=0.9288$, $p<0.001$), although customer satisfaction positively influences Loyalty but fails to establish a hypothetical significance ($\beta=0.0782$, $p=0.610$). Trust significantly enhances the relationship between Satisfaction and Loyalty ($\beta=0.8678$, $p<0.001$).
According to the projections, stronger Customer Loyalty leads to better trust and, ultimately, greater Satisfaction. Robust statistical significance throughout the interactions analysed supports these findings, highlighting trust's critical role in influencing consumer happiness within the study setting.

Table 6

PARAMETER ESTIMATES								
Dep	**Pred**	**Estimate**	**SE**	**Lower**	**Upper**	**β**	**z**	**p**
Customer Loyalty	Satisfaction	0.0949	0.1859	–0.269	0.459	0.0782	0.511	0.610
Customer Loyalty	Trust	0.8255	0.1539	0.524	1.127	0.8678	5.363	< 0.001
Trust	Satisfaction	1.1850	0.0859	1.017	1.353	0.9288	13.801	<0.001

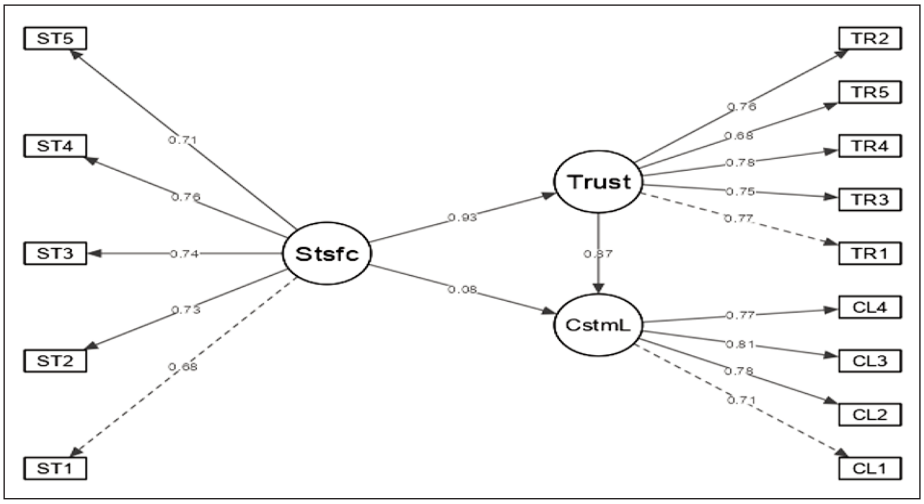

Fig. 4. Path diagram of the model

Satisfaction, and Customer Loyalty. Ha3 accepts the role played by the customer's trust as a mediator in the association between the Satisfaction of the customers and Loyalty generated among them [16, 20, 21]. The effect or impact of customer trust on customer loyalty is limited, and the effect of Satisfaction is even sustained when trust is introduced into the relationship with customer loyalty. Customer trust benefits private-label apparel retailers by increasing consumer trust in brands and companies [46]. Table 7 shows that hypothesis Ha1 is rejected, and hypotheses Ha2 and Ha3 are not rejected, which depicts that trust mediates between Satisfaction and Loyalty for a customer in the apparel retail arena. The post-pandemic textile market of Belagavi, India, highlights the vital role of trust and customer satisfaction in driving customer loyalty for private-label textiles. The study revealed that trust exerts an even more substantial influence and mediates Satisfaction and Loyalty [42]. Additionally, retailers can build trust by providing transparent and clear information about the materials used, the manufacturing process, and the working conditions of the people who make their products.

The measurement model yields parameter estimates with 95% confidence intervals for latent constructs and their observable indicators. As shown in figure 4 (ST1 through ST5), all five indicators show strong positive loadings in the Satisfaction latent variable, indicating their role in measuring Satisfaction. Similarly, the Customer Loyalty indicators (CL1 through CL4) have strong positive loadings, suggesting that they help determine the latent variable. Each of the five indicators (TR1 through TR5) for trust shows notable and positive loadings, highlighting their importance in capturing trust. The robust loadings across indicators indicate the measurement model's dependability, which validates the efficient assessment of latent components in the context under study.

Table 7

RESULT OF HYPOTHESIS ACCEPTANCE AND REJECTION		
Hypothesis	**Relationship**	**Result**
Ha1	Satisfaction and loyalty	Rejected
Ha2	Satisfaction and trust	Not Rejected
Ha3	Satisfaction-trust-loyalty	Not Rejected

DISCUSSION

All the hypotheses were tested in the study's selected research frameworks. Critical are the alternatives Ha1 and Ha2, which deal with the significance of the effect generated among customer satisfaction, trust,

CONCLUSION

This study provided insightful information for the Belagavi textile market and other markets in north Karnataka. The customer is very knowledgeable today, and their taste and buying patterns vary with demographic factors such as age and lifestyle. Hence, it is necessary to build trust among the customers with the enhanced influence of Satisfaction, which leads to their repeat purchases of private-label textile brands; further, customer satisfaction is the primary driver of Loyalty to private-label textiles. Today's retailers have to adopt a responsible method of doing business to build trust among their customers. Textile retailers may enhance customer loyalty by developing and strengthening their relationship with customers by integrating faith and Satisfaction into their business in other regions of India. They may also test the above Model to get the best results in terms of profit shortly. The strategy in the present competitive environment goes beyond a specific private label textile branding, offering a foundation for sustainable growth and success in the post-pandemic landscape for the chosen category in the textile industry in need of an hour.

Future scope of research

The study presently focuses on the significant relationship between Satisfaction, trust, and customer loyalty among the organized retail stores in the apparel segment in Belagavi city, Karnataka, India. The study has a great scope that can be extended to other places in different states and countries across the globe. The variables used in identifying the construct of Loyalty for the apparel segment were only Satisfaction and trust. Still, more research needs to be done on branding private labels and developing Loyalty among customers based on brand image, store image, and brand awareness, which play a dominant role in the construction of Loyalty [44]. The present research also gives the scope to deepen the research in analysing customer loyalty based on its understanding, specifically on its form like repurchase, future purchase intention, and referring the same to others. The researchers can be more specific in their research to better understand Loyalty for private brands offered by an organized textile retailer. This leads to improvements in creating private labels and loyalty segments. Future research related to Technology can take up topics like the power of personalization and customization in private label brands to target B2B markets, Loyalty beyond transactions, and how advanced data analytics can be used to segment customers based on buying behaviour and preferences.

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Relationship between elastic properties and energy absorption of different types of aramid and UHMWPE composites used in ballistic protection

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ABSTRACT – REZUMAT

Relationship between elastic properties and energy absorption of different types of aramid and UHMWPE composites used in ballistic protection

This study aimed to analyse composite materials' mechanical and elastic properties from various aramid and ultra-high-molecular-weight polyethylene fabrics used in ballistic armour materials. Furthermore, a comprehensive analysis was conducted to examine the correlations between the energy absorption data acquired from the low-velocity impact, dynamic compressive, and ballistic impact V50 tests performed in our prior investigations and the tensile test outcomes of these composites. The research revealed a notable correlation between Poisson's ratio, elasticity modulus values, and energy absorption capability. The composite material with the lowest Poisson ratio exhibited superior energy absorption performance in all tests. Composites reinforced with unidirectional textiles have attracted attention due to their low Poisson ratio and high elasticity modulus values, resulting in exceptional energy absorption capability.

Keywords: *elastic properties, aramid, UHMWPE, ballistic, Poisson's ratio, auxetic structure*

Relația dintre proprietățile elastice și absorbția de energie a diferitelor tipuri de compozite cu fibre aramidice și UHMWPE utilizate în protecția balistică

Acest studiu și-a propus să analizeze proprietățile mecanice și elastice ale materialelor compozite realizate din diverse țesături din fibre aramidice și polietilenă cu masă moleculară foarte ridicată utilizate în producerea materialelor de blindaj balistic. Mai mult, a fost efectuată o analiză cuprinzătoare pentru a examina corelațiile dintre datele de absorbție a energiei obținute din testele V50 de impact la viteză redusă, compresiune dinamică și impact balistic efectuate în investigațiile noastre anterioare și rezultatele testelor de tracțiune ale acestor compozite. Studiul a evidenţiat o corelație notabilă între coeficientul lui Poisson, valorile modulului de elasticitate și capacitatea de absorbție a energiei. Materialul compozit cu cel mai scăzut coeficient al lui Poisson a prezentat performanțe superioare de absorbție a energiei în toate testele. Compozitele armate cu materiale textile unidirecționale au atras atenția datorită coeficientului lui Poisson scăzut și valorilor ridicate ale modulului de elasticitate, rezultând o capacitate excepțională de absorbție a energiei.

Cuvinte-cheie*: proprietăți elastice, aramidă, UHMWPE, balistic, coeficientul lui Poisson, structură auxetică*

INTRODUCTION

High-performance fibres and their fabrics, such as aramid and ultrahigh molecular weight polyethylene (UHMWPE), are widely used in personnel armour systems against exploding ammunition fragments, such as protective helmets and armour panels [1–5]. Manufacturers often utilize these fibres as reinforcement in the form of continuous filaments or woven fabric embedded in a resin [6]. Considering the nature of the fibres, a high fibre volume ratio was chosen to maximise the ballistic performance of the composite materials [5–8].

The behaviour of composite materials under high-velocity impact loading is complex and needs to be better understood. The structure of the reinforcing fabric makes this situation even more complicated. Because composites are inherently complex and few studies exist, looking at reinforcement fabrics from different angles can make them more resistant to impact. Textile reinforcement is critical in composite materials, as it profoundly affects their mechanical and impact performance. The type of reinforcement fabric, weave type, and Poisson's ratio are critical determinants of the composite's impact performance. These different parameters allow us to create ballistic materials with a high strength-to-weight ratio and energy absorption performance optimised for ballistic applications. The primary functions of reinforcement in composite materials include distributing applied impact or mechanical forces and providing protection against external forces. It is possible to achieve high-impact resistance by choosing the right combination of matrix material and fibres [9].

Optimizing the layers of ballistic composite materials maximizes the energy absorption performance. Reinforcements can be divided into three forms according to their structure: unidirectional structures (UD), two-dimensional structures (2D), and three-dimensional structures (3D) [10]. Furthermore, two main types of reinforcement materials in ballistic applications are para-aramid and UHMWPE [11]. Para-aramid fibres, like Kevlar, offer remarkable tensile strength and resistance to impact. Certain UHMWPE fabrics, such as unidirectional (UD)

Dyneema provide exceptional strength and rigidity in the direction of the fibres. Additionally, they have exceptional strength relative to their weight and exhibit remarkable impact absorption capabilities, making them ideal for lightweight ballistic armour applications [12]. Some researchers are studying the effect of UD reinforcement on the mechanical and impact properties of composites (such as) Barhoumi et al., investigating the mechanical properties of fibres and fabrics used in ballistic protection [13]. Bajya et al. investigated the effectiveness of soft armour panels for ballistic protection. They tested these panels at a speed of 430 m/s and against 9 mm bullets. UHMWPE UD reinforced panels have been replaced with woven fabric-reinforced panels [14]. While 2D-woven composite materials have outstanding strength-to-weight ratios and can be easily shaped into complex forms, they have limitations, including poor impact properties. Some researchers, such as Zhou et al., studying the effect of 2D woven composites on mechanical and impact properties stated that knitting models significantly affect parameters such as stress-strain curves and Poisson's ratio. Lower crimp ratios were associated with linear stress-strain curves and higher strength and elasticity, while higher crimp ratios exhibited nonlinear behaviour. They concluded that the crimp ratio directly affects flexibility, strength, and Poisson's ratio [15]. Lopresto et al. investigated the mechanical properties of 2D-woven plain and twill-woven fabrics made of basalt fibre. According to this study, plain weaving is better than twill weaving for tensile and bending strength because it has a more compact structure. However, twill weaving is better than plain weaving for energy absorption performance, such as fracture toughness and shear strength, because it has reduced waviness/lower crimp [16].

Poisson's ratio, another parameter determining energy absorption performance, is the ratio of lateral stress to longitudinal stress in axial tension [17]. Poisson's ratio can be positive or negative. Auxetic structures have a negative Poisson's ratio. A material with a Poisson's ratio close to 0 is considered nearly incompressible [18]. The negative Poisson's ratio shows that the material expands in the lateral direction at the beginning of the axial force on the material. The auxetic structure of these reinforcing elements makes them expand when they are under tension. They have advanced mechanical properties like high impact resistance, better tensile strength, and better energy absorption [19]. Moreover, with their extraordinary expansion capacity under sudden dynamic forces, the energy absorption of composites increases significantly. Due to all these features, auxetic structures are highly desirable in ballistic armour applications, where dynamic impact resistance is significant [20]. Some researchers who studied the effect of Poisson's ratio on the impact properties of composites: Li et al. They investigated the impact of auxetic structures by comparing non-auxetic and auxetic structures. They measured modulus, energy absorption and hardness values with various mechanical tests. The study showed that auxetic structures exhibit high modulus [21]. Zhou et al. performed repeated low-speed drop-weight impact tests on textile-based composites. When compressed statically, the non-auxetic structure composite is much softer and absorbs less energy than the auxetic structure composite. However, during the impact test, the auxetic textile composite increases its maximum negative Poisson ratio value, resulting in higher energy absorption performance [22]. Hassan et al. investigated the effect of auxetic structures on impact resistance using different types of yarns and showed that the difference in woven structures had a significant effect on impact energy. Auxetic results concluded that if the pattern of binding yarn and ground weave has the same float length, then the structure will have higher auxetic. Secondly, the higher float length also significantly affects the auxetic of the structure [23]. A study by Alderson et al. compared textile-based auxetic and non-auxetic structures. They discovered that auxetic structures were better at absorbing energy and resisting impacts when put under compressive force than non-auxetic structures [24]. According to Steffens et al., auxetic structures exhibit outstanding impact performance, making them suitable for protective applications [25]. Liaqat et al. compared auxetic-reinforced composites with non-auxetic-reinforced composites. The study found that the composite with woven auxiliary material had 2.72 J more impact energy than the reinforced composite sample without [26].

Various studies have investigated the mechanical properties and ballistic performance of ballistic fibres and composites. Before discussing the impact properties of composites, it is necessary to understand their deformation behaviour and mechanical properties. Previous studies in the literature have yet to find a comprehensive relationship between the mechanical properties of aramid and UHMWPE composites and their ballistic protection and energy absorption properties. Our previous studies investigated the energy absorption properties [1, 2, 6, 7, 27] and ballistic protection properties [28] of various aramid and UHMWPE fabric composites. The mechanical and elastic properties of thermoplastic composites made from different aramid and UHMWPE fabrics used to make ballistic protective composites were looked into in these studies. So, this study aims to investigate how the mechanical and elastic properties of different aramid and UHMWPE composites used for ballistic protection relate to the energy-absorbing properties achieved with these materials.

MATERIALS AND METHODS

Materials

Six different ballistic fabrics, whose properties are given in table 1 and whose structures are shown in figure 1, were used as reinforcement and nolax A21.2007 low-density polyethylene (LDPE) adhesive film (density 0.94 g/cm^3, melting temperature 80–90 °C and melt flow rate of 6–9 g/10 min) was used as a

Table 1

PROPERTIES OF REINFORCEMENTS USED IN THE STUDY											
Reinforcement type	Reinforce-ment code	Reinforce-ment producer	Weave type	Linear density of Warp/Fill yarns (Tex)		Warp/Fill (or 0°–90°) yarns		Yarn density (yarns/m)	Areal density (y/m^2)	Crimp Warp/Fill (%)	Reinforce-ment thickness (mm)
				Warp	Fill	Warp	Fill				
Aramid woven fabric-CT 736	R_1	Teijin	2×2 Basket weave	336/	336	Twaron 2000	Twaron 2000	127/127	410	0.8/0.8	0.6
Aramid woven fabric-Artec	R_2	Pro-System	1×1 Plain weave	58/	58	Artec	Artec	116/116	135	0.2/0.2	0.23
Aramid Bi-Axial non-crimp fabric-XA450	R_3	Saertex	Bi-axial non-crimp	336	-	Twaron 2000		127/127	465	Non-crimp	0.40
Aramid UD GS3000	R_4	FMS	UD	126	-	Kevlar 49/Kevlar 49		-	510	Non-crimp	0.50
UHMWPE UD Dyneema H62	R_5	FMS	UD	176	-	Dyneema SK62		-	262	Non-crimp	0.25
UHMWPE UD Dyneema H5T	R_6	FMS	UD	176	-	Dyneema SK62		-	235	Non-crimp	0.25

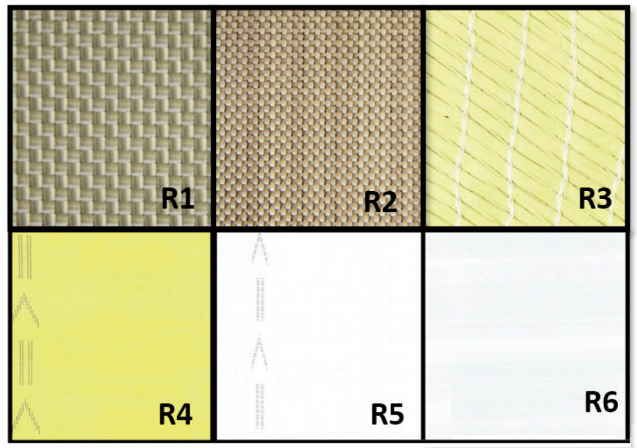

Fig. 1. Ballistic fabrics used as reinforcements

matrix system. The properties of fibres, which were used in the preparation of reinforcement structures, are given in table 2.

Table 2

PARAMETERS OF THE ARAMID AND UHMWPE FIBRES USED IN THE STUDY				
Param-eters	Twaron 2000® (Aramid)	Kevlar 49® (Aramid)	Dyneema SK62® (UHMWPE)	Artec® Russian Aramid
Young modulus (GPa)	85	112	113	103
Strength (cN/Tex)	235	208	338	181
Ultimate elonga-tion (%)	3.5	2.4	3.6	2.8
Density (g/cm^3)	1.44	1.44	0.97	1.44

Composite manufacturing

The ballistic fabrics were cut to a size of 500 mm × 500 mm and composite laminates were prepared, with the same number of fabric layers and different panel thickness, different fabric layers and same panel thickness, different orientations of fabric layers and same panel thickness and different number of fabric layers and different panel thickness, using the autoclave process. The temperature of the process was kept at 110°C and the pressure of the vacuum to 14.8 bar (table 3). Figure 2 shows the different stages of the manufacturing process.

Determination of the elastic properties of composite materials

This section determined the tensile modulus, extension ratio, and Poisson's ratio values of composite materials under static tensile loading. The materials, test methods, and measurement systems used in the tests are presented below. Measurement of the above properties is crucial for accurately modelling the materials used. Only materials that passed the

Table 3

PROPERTIES OF THE COMPOSITE PLATES USED IN THIS STUDY							
Sample code	**Reinforcement type**	**Reinforcement layer number**	**Stacking direction**	**Resin**	**Plate thicknesses (mm)**	**Volume fraction (V_f)**	**Areal weight (g/m^2)**
C1	R1	8	0°/90°	LDPE	4.1±0.23	55.56	3790
C2	R2	12	0°/90°		3.8±0.39	59.61	2130
C3	R3	8	45°/–45°		3.8±0.45	67.98	4230
C4	R4	8	0°/0°		3.9±0.25	72.65	4590
C5	R5	12	0°/0°		3.8±0.40	78.13	3390
C6	R6	12	0°/0°		3.8±0.50	78.13	3390

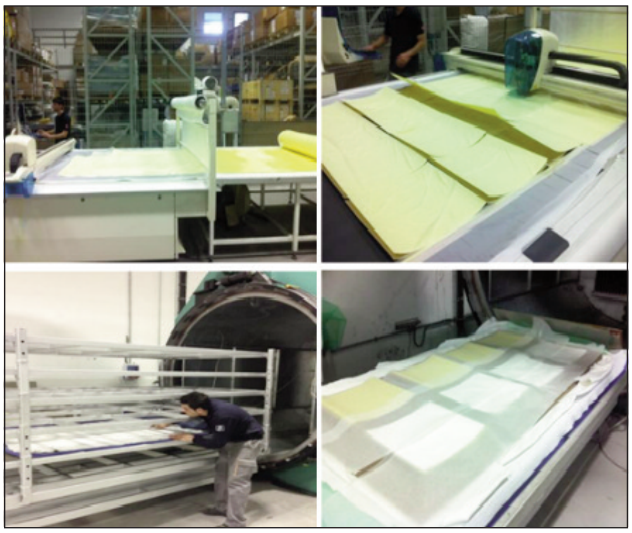

Fig. 2. Different stages of composite manufacturing process

preliminary screening were used in these tests. Tensile tests were carried out with Besmak-BMT 100E brand Universal Tensile Tester (100 kN). The samples for the tensile test were prepared according to TS EN ISO 527 standards. The tensile speed and the pre-stress value were set as 2 mm/min and 10 N, respectively. The measuring length was 50 mm video extensometer and the test conditions were carried out at 21°C. Tensile tests were carried out at the Bursa Technology Coordination and R&D Center (Bursa, Türkiye).

Measurement system

Each type of composite sample is assigned a code, and researchers determine all results based on these codes. The researchers conducted the testing of samples using the MTS Bionix II axial testing system (figure 3) available in the laboratory. The researchers recorded strain values from the surfaces of the samples using optical methods and calculated them using Vic3D software. For each loading case, special software matched the optical strain values and force values. This made it possible to calculate and plot the tensile modulus, the Poisson's ratio (equation 1), and the tensile (stress-strain) curve.

$$\nu = -\Delta T / \varepsilon_{yy} \qquad (1)$$

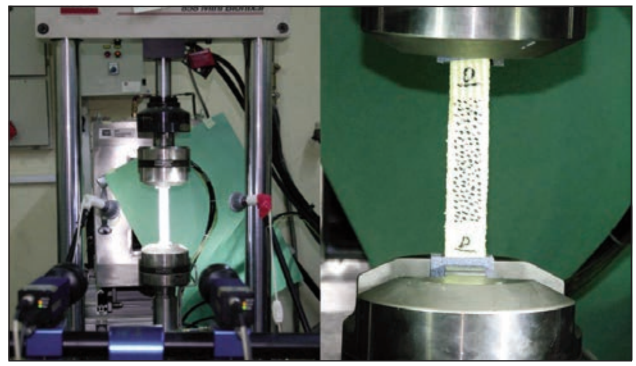

Fig. 3. MTS Bionix II Axial test system

In the above equation, ν is the Poisson's ratio, ΔT represents the change in thickness, and ε_{yy} represents the axial stress.

Results and discussion

Figure 4 and table 4 present the tensile test results of composite samples. According to these graphs, the tensile-strain curves showed a very similar character. A different character is seen only in the C3 sample. This is because there is a 45° angle between the tensile direction and the fibre direction in the C3 sample. All other samples exhibited a fairly linear tensile curve. According to the test results, C2 has the highest, and C3 composite has the lowest tensile strength value. When evaluating aramid composites among themselves, C2 exhibits a tensile strength value 4.2 times higher than C1 and 2.3 times higher than C4. When UHMWPE composites are evaluated among themselves, C5 exhibits a tensile strength that is 1.02 times higher than that of C6. C2, reinforced with aramid fibre, exhibits a strength value 1.3 times higher than C5, reinforced with UHMWPE.

A material with a high tensile modulus is more rigid and less deformed. This may affect the material's energy absorption performance under impact or load. Materials with a higher modulus suffer less deformation and have higher energy absorption performance [29]. In this context, Table 4 shows that C4, C5, and C6 modulus values are the highest, with no significant difference between them. C5 has the highest modulus value, while C3 has the lowest modulus value. Among aramid-reinforced composites, the

Table 4

TENSILE TEST RESULTS OF SAMPLES					
Sample code	**Strain range is taken into account in calculations**		**Tensile modulus, E (GPa)**	**Tensile strength (MPa)**	**Poisson's ratio, ν**
	ε_{min} (-)	ε_{max} (-)			
C1	0.00300	0.00594	4.17	70	0.223
C2	0.00378	0.00822	9.42	290	0.875
C3	0.00276	0.00651	0.30	3.5	1.217
C4	0.00157	0.00428	28.95	130	0.075
C5	0.00193	0.00611	29.14	220	–0.05
C6	0.00085	0.00595	28.51	215	–0.015

modulus value of C4 is 7 times higher than C1 and 3 times higher than C2. C5 has a modulus 1.2 times greater than C6 when UHMWPE composites are evaluated among themselves. The tensile strength of Artec reinforced composite, which shows the highest tensile strength among aramid-reinforced composites, is 1.4 times higher than that of Dyneema H62 reinforced composite, which shows the highest tensile strength among UHMWPE UD-reinforced composites. However, when compared in modulus value, UHMWPE UD Dyneema H62 reinforced composite is 3.1 times more than Aramid woven Artec composite.

First, we evaluated the optical data recorded during the tests using the Vic3D software. Then, we calculated the stress values from the force values and matched them precisely with the strain values. Figure 5 presents the strain distributions obtained from the Vic3D software. The interlocking of warp and weft in C2 (290 MPa), which showed the highest tensile strength value, transfers the load to more than one yarn when examining the strain distribution in the tensile direction (ε_{yy}). When subjected to a load, these yarns contribute as a whole and absorb more energy before breaking. As shown in previous studies [6], the hybrid composite panel made of woven C1 and C2 reinforcements is better at absorbing energy than the others. It was observed that the load distribution of the C3 sample was not homogeneous, and as a result, the tensile strength value was at its lowest value compared to other samples.

Poisson's ratios-strain curves of composite samples are given in figure 6. The tensile test of the composites revealed different tendencies in the change of Poisson's ratios. Poisson's ratio is lowest in C6 and highest in C3. The order of Poisson's ratios is C5<C6<C4<C1<C2<C3. The increase in tensile strain caused a positive Poisson's ratio response in the C1, C2, and C3 samples. However, it caused a

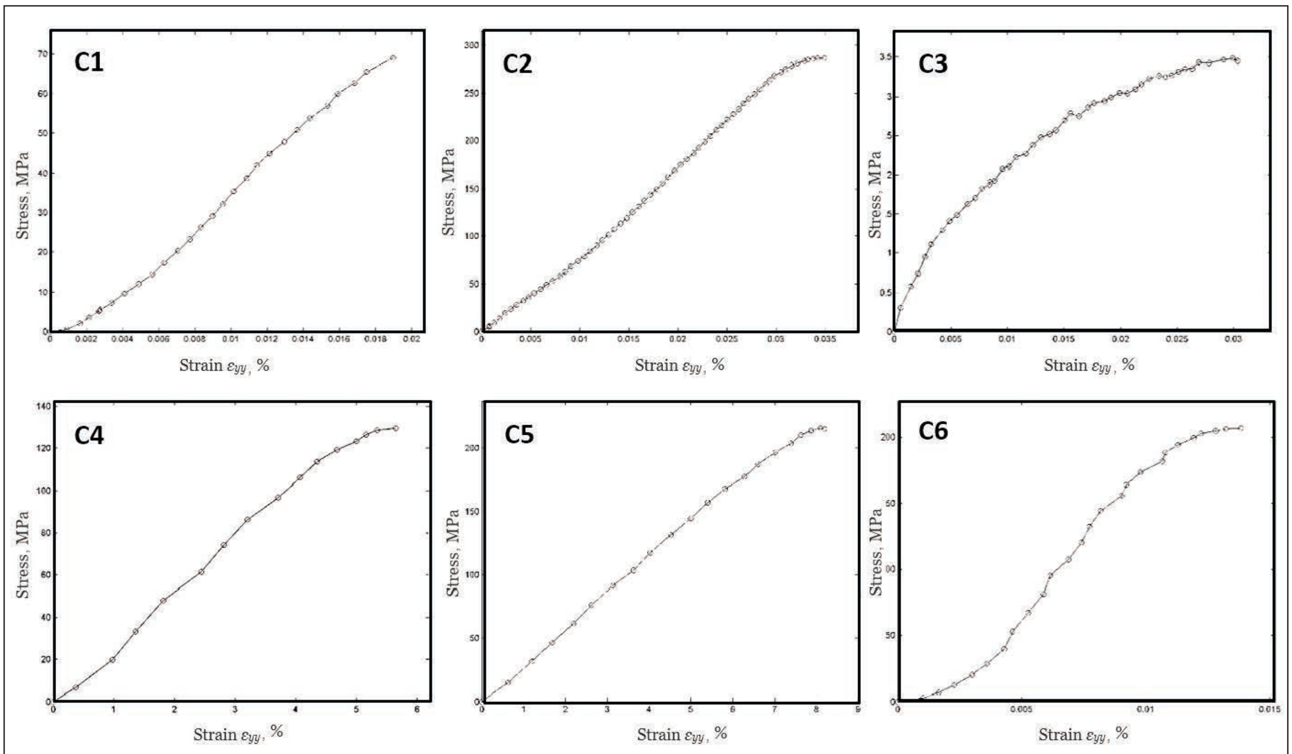

Fig. 4. Tensile stress versus strain curves of composites

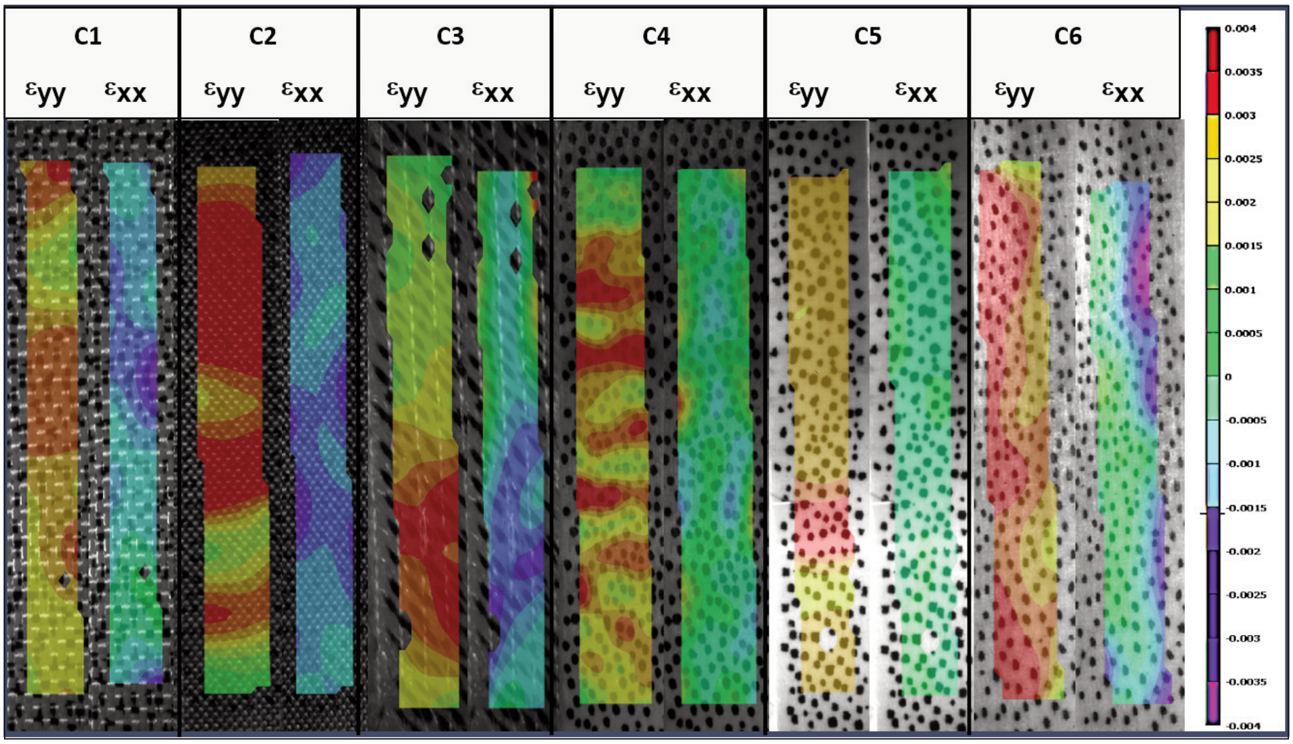

Fig. 5. Strain distributions of composite (ε_{yy} ≈ % 3)

negative Poisson's ratio (auxetic structures) response in C4, C5, and C6 samples. In this way, these samples expand as the tensile stress increases. It was seen that the C4, C5, and C6 samples grew in the *x* direction or lateral direction, even though a tensile force was being applied in the *y* direction when the strain distributions shown in figure 5 were looked at. It is observed that the Poisson's ratio decreases as the strain value increases in the C4 and C5 samples, but this decrease is unstable in the C4 sample. However, the C6 sample had the lowest Poisson ratio value at a strain of 7%. It was observed that this value progressed in a positive direction as the compression ratio increased, and this increase was observed to be faster after a tension value of 20%. Thanks to these auxetic structures, the composite will perform more effectively by dissipating or absorbing energy. In addition, in the C3 (Aramid Bi-Axial Non-Crimp) sample, the Poisson's ratio is relatively higher than in other samples due to the fibre arrangement of the fabrics being 45°/–45°. Figure 5 shows an apparent narrowing in the lateral direction when the sample is exposed to load in the tensile direction. Therefore, it will not be possible to distribute the load when exposed to impact, so its energy absorption performance will be quite low. This subject will be discussed in detail in the following sections (figure 6).

The tensile strength, modulus, and Poisson's ratio values of the samples are compared among themselves in table 4 and figure 7. Changes in fabric properties highly affect the performance of the reinforcement. This can be attributed to the difference in the reinforcement material's areal density, tensile strength, and architecture. The fabric structure and mechanical properties of the fibre caused these differences. In this context, although the C2 composite consists of woven fabric, its tensile strength is 4.1 times higher than C1 and 2.2 times higher than C4, thanks to the thin yarn (58/58 Tex) that causes the crimp to be low. It is known that a lower crimp results in higher mechanical properties [5, 30, 31].

The C1 sample had a much higher tensile strength value compared to the C3 sample, despite both samples being produced from the same yarn and having approximately equal unit area masses. There was non-crimp in the yarn in the C3 sample, so it was expected to have better mechanical properties than the C1 sample [5]. However, the results show that the maximum force value of sample C3 is lower than sample C1, which consists of woven fabric. The deformation of the filament by the needle due to friction between the needle and yarn during the production of biaxial fabric can explain this paradox. In addition, all tests were carried out in the 0 direction, whereas in the C3 (Aramid Bi-Axial Non-Crimp) sample, the fibre alignment of the fabrics was 45°/–45°. Due to this, the tensile strength value was very low, as the fibres could not fully carry the load. Other researchers have also reported this situation [32, 33]. C4 has 86% higher tensile strength compared to C1. The R4 fabric used to reinforce composite panel C4 exhibits a higher areal density, a larger tensile modulus, and a unidirectional structure. In contrast, the R1 fabric used in the C1 composite panel is woven with a basket weave with 0.8% crimp. The undesirable effect of this bending is excessive bending of the panel during loading, which causes the panel to have a lower tensile value. The thicker yarn linear density

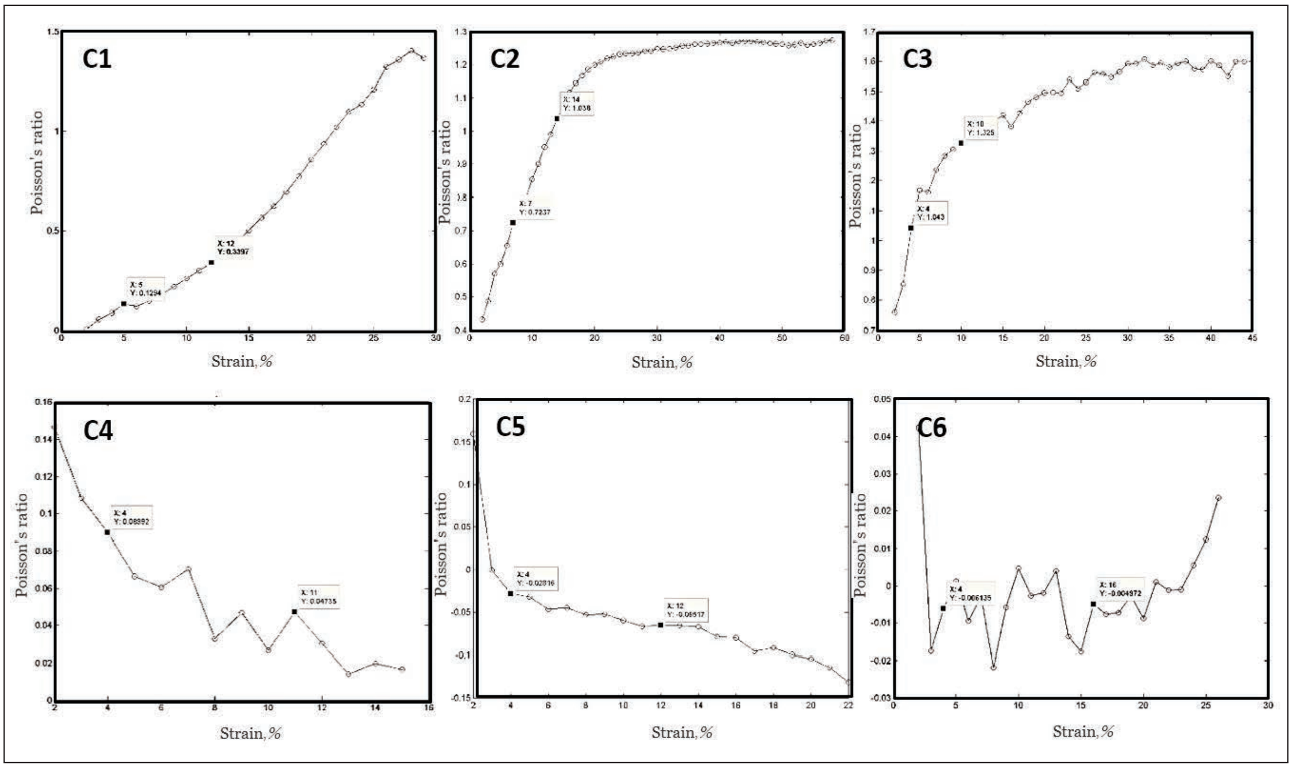

Fig. 6. Poisson's ratio of composites

(336 Tex) in reinforcement R1 contributes to the lower tensile strength value. Thin yarn offers more surface area and can carry more load than thick yarn. The stress-strain values of composite panel C4 reinforced with fabric R4 (non-crimp and thin yarn linear density) show that this effect is real.

C5 and C6 composites produced from UHMWPE H62 and H5T sheets show similar tensile strength values, respectively. The architecture area and yarn linear density of the reinforcement fabrics used for C5 and C6 panels are the same. C5 and C6 composite are lighter than others (C1, C3, and C4). Lighter plates resulted in better stress-strain values.

Ballistic armour resists penetration by bullets through the dissipation of impact energy. Critical features in ballistic armour design include hardness, strength, and toughness. A low Poisson ratio indicates that a material does not undergo much lateral expansion when subjected to axial deformation. This property affects the way the material distributes and absorbs impact energy. In this case, in table 4 and figure 7, the C5 and C6 composite panels made by strengthening the UD layer of UHMWPE Dyneema H62 and H5T have the lowest Poisson's ratio values, which are about –0.05. This negative Poisson's ratio (Auxetic) indicates that the material expands in the lateral direction when axial force is applied. This lateral expansion increases the composites' energy absorption and impact resistance, effectively reducing ballistic and explosive damage. Among the plates reinforced with Aramid fabrics, the one with the lowest Poisson ratio is the C4 composite reinforced with Aramid UD GS3000 fabric. Since the fibres of UD fabrics are aligned in one direction, deformation occurs more quickly. Aligning the fibres in one direction reduces the tendency to expand in the other direction when tension is applied. The high modulus, low density, and negative Poisson's ratio of C4, C5,

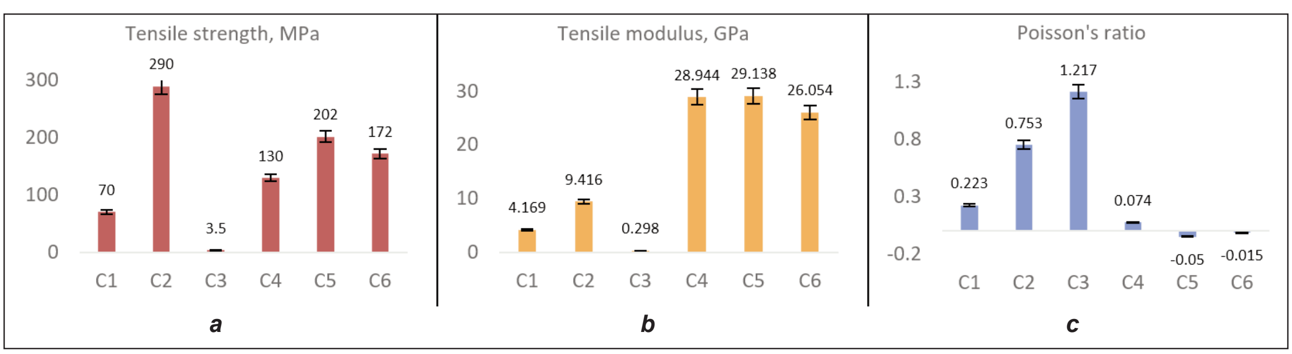

Fig. 7. Tensile test results of composite panels: *a* – Tensile strength; *b* – Tensile modulus; *c* – Poisson's ratio

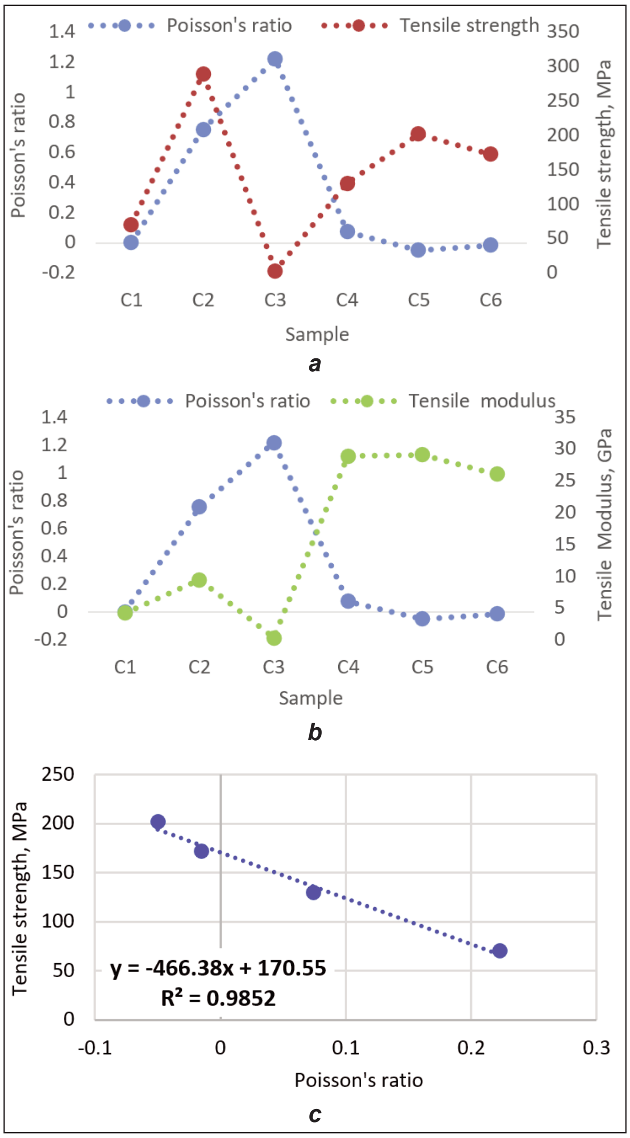

Fig. 8. Poisson's ratio versus: *a* – Tensile stress; *b* – Modulus of composites; *c* – Pearson correlation coefficient between Poisson's Ratio and tensile strength

and C6 composite panels with non-crimp UD fabrics can quickly disperse the strain wave away from the impact point.

Figure 8 depicts the relation of Poisson's ratio with tensile strength and modulus. It was concluded that Poisson's ratio has an inverse relation with tensile strength and modulus.

Relationship between elastic properties and energy absorption properties under low-velocity impact

Researchers examined the energy absorption behaviour of composites under low-speed impact in a previous study [6] using the same samples. Figure 9 illustrates the relationship between the energy absorption results obtained under low-velocity impact and the Poisson ratio results obtained in this study.

When table 5 is examined, the best results of energy absorption performance were obtained from C1 and C4 samples. There was no significant difference between the energy absorption performances of these two. The C3 sample exhibited the lowest energy absorption performance.

Table 5

IMPACT TEST RESULTS OF SAMPLES AT 1680 J ENERGY LEVEL [6]

Sample code	Absorbed energy (%)	Absorbed energy (J)
C1	91.8	1469±67
C2	86.8	1388±42
C3	76.3	1222±210
C4	91.7	1467±58
C5	87.9	1406±33

Figure 9 shows that the energy absorption performance under low-impact strain is related to Poisson's ratio. The lateral expansion tendency of C1, C4, and C5, as evident in the strain distributions (figure 5) and Poisson's ratio-strain curves (figure 6), significantly increased the energy absorption performance of

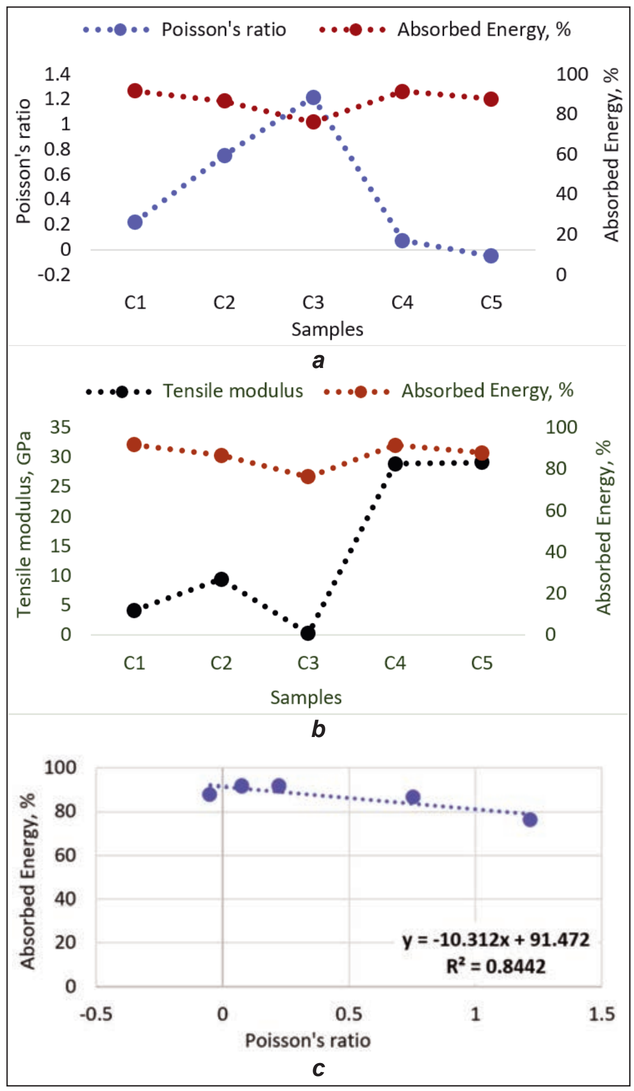

Fig. 9. Relationship between: *a* – Poisson's ratio-absorbed energy and *b* – Tensile modulus-absorbed energy; *c* – Pearson correlation coefficient between Poisson's Ratio and absorption energy under low-velocity impact (absorbed energy values taken from [6])

these samples. The C3 sample with the highest Poisson ratio showed the lowest energy absorption performance. In addition, although the C1 sample is higher than C4 and C5, its energy absorption performance is close. This phenomenon can be attributed to the architecture and area density of the reinforcement fabric of sample C1. However, as shown in figure 6, C1 showed Poisson's ratio values of 0 at low strain ratios (1–4%), and as a result, it showed energy absorption performance similar to C4 and C5 under low-velocity impact. When figure 9, *b* is examined, the modulus value of the C4 and C5 samples is the highest. A high modulus increases the deformation resistance of the material under tension, thus absorbing energy. C4 and C5 have the highest energy absorption performance, in line with their high modulus values.

Relationship between elastic properties and energy absorption properties under dynamic compressive loading

In a previous study [27] with the same samples, the composites' high strain rate compression properties and their energy absorption behaviour under the Split Hopkinson Pressure Bar (SHPB) 8 bar pressure test at room temperature were examined. Figure 10 shows the relationship between the energy absorption results obtained under high-speed impact and the Poisson's ratio results obtained in this study.

In the relevant study [27], dynamic compressive loading tests of composites reinforced with woven and UD fabrics made of aramid and UHMWPE were performed. The strain rate was changed in the tests by changing the bullet shot pressure. The pressure bar value was selected as 8 bar. The energy absorption behaviour of eight types of samples was noted.

The energy absorption performance of C1, C4, C5 and C6 composite panels under the split Hopkinson 8 bar pressure test is shown in table 6. The C5 sample showed the best energy absorption performance, and C1 showed the worst. It was observed that the absorption energies of C5 and C6 were very close.

Composites reinforced with a high auxetic structure showed higher impact energy absorption performance than composites reinforced with a lower auxetic structure. Figure 10 shows the absorbed energy results of the Poisson's ratio of the structure and the corresponding composites. The absorbed energy of the corresponding composites had a direct relationship with the negative Poisson's ratio of the samples.

Table 6

ABSORBED ENERGY VALUES OF THE COMPOSITE SAMPLES FOR 8 BAR (ABSORBED ENERGY VALUES TAKEN FROM [27])	
Sample code	**Absorbed energy (J/mm^3)**
C1	47.78
C4	49.15
C5	60.86
C6	57.36

This finding suggests that reinforcement fabrics with a lower Poisson's ratio have a greater capacity to couple and resist the applied force at the point of impact, resulting in increased energy absorption capacity. Figure 10 shows a direct relationship between the modulus and the energy absorption performance of the samples. The energy absorption performance of C4, C5, and C6 samples, which have approximately the same modulus values, is at very close values. The C1 sample with the lowest modulus value has the lowest energy absorption performance. The noteworthy point is that although the energy absorption performance of the C1 sample showed close values to C5 under the low-velocity impact test, it showed the lowest value in the dynamic compressive loading test. This showed that the stress gradually and moderately linearly increased with the applied strain. This is in line with what we found in the low-velocity impact testing study [6]: the composites behaved almost statically when strain rates were low. As shown in figure 6, while the

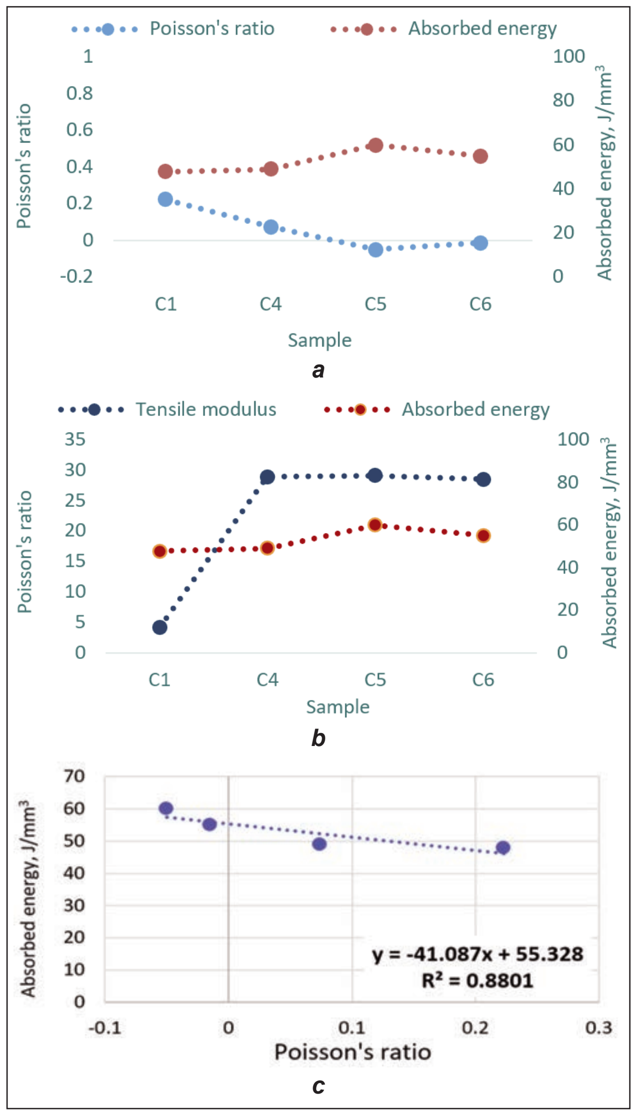

Fig. 10. Relationship between: *a* – Poisson's ratio and absorbed energy; *b* – Tensile modulus-absorbed energy; *c* – Pearson correlation coefficient between Poisson's Ratio and absorption energy under dynamic compressive loading (absorbed energy values taken from [27])

Poisson's ratio of C1 showed 0 values at low strain ratios, as the strain ratios increased, the Poisson's ratio rapidly increased positively. As a result, the energy absorption peak decreased. However, as the strain rate increased during the SHPB test, a noticeable improvement in material hardness and strength appeared, indicating the existence of strain rate sensitivity. This can be attributed to the inherent viscoelastic properties of thermoplastic composites, resulting in energy dissipation at high strain rates. The strain rate sensitivity observed in the SHPB test reveals the material's potential for energy-absorbing applications under impact and dynamic loading conditions. In addition, SHPB test data facilitated the calculation of the composites' dynamic modulus and damping properties and offered valuable information regarding their response to rapid deformation. These findings underscore the importance of considering strain rate effects when designing composites for high-speed applications.

Relationship between elastic properties and energy absorption properties under ballistic impact

In a previous study [8] with the same samples, the energy absorption performances of the composites under the ballistic impact V50 test were examined. Figure 11 shows the relationship between the energy absorption results obtained under ballistic impact and the Poisson’s ratio results obtained in this study.

This part focuses on the analysis of composites composed of aramid and UHMWPE. The main focus of this research is on the evaluation of the impact behaviour of these composites. The effects of various factors, especially fibre type, fabric structure, and orientation of the fabric layer, have been investigated. Three different fabric structures were used to reinforce aramid composites, while two were used for UHMWPE composites. The researchers evaluated the ballistic performance by measuring energy absorption. The findings of the study revealed that UD composites exhibited superior ballistic performance in terms of energy absorption (Ea) per ballistic unit weight [8].

Table 7 presents the properties of composite panels of the same thickness (9.5 ± 0.6 mm) reinforced with different numbers of fabric layers. Because the areal density of all reinforcement fabrics differs, the density of all composites differs according to the number of fabric layers. Composites with a more significant area density exhibit higher energy absorption performance. The C4 composite panel reinforced with UD-aramid-GS3000 shows the highest Ea values due to the areal density. The C3 panel has 34.06% higher Ea than the aramid CT736 reinforced panel and 23.2% higher than the UHMWPE-H5T® sheet reinforced panel. However, UD-UHMWPE-H62® and UD-UHMWPE-H5T® reinforced composites showed better energy absorption per unit area density (Ea/AD). It would be more accurate to compare the Ea/AD of composites to see the effect of different material types on ballistic performance. The Ea/AD

Table 7

CONTACT ANGLE MEASUREMENT RESULTS OF FABRICS

Sample code	*Ea* (J)	*Ea*/AD (Jm^2/kg)
C1	547	54
C3	536	56
C4	732	60
C5	569	70
C6	594	68

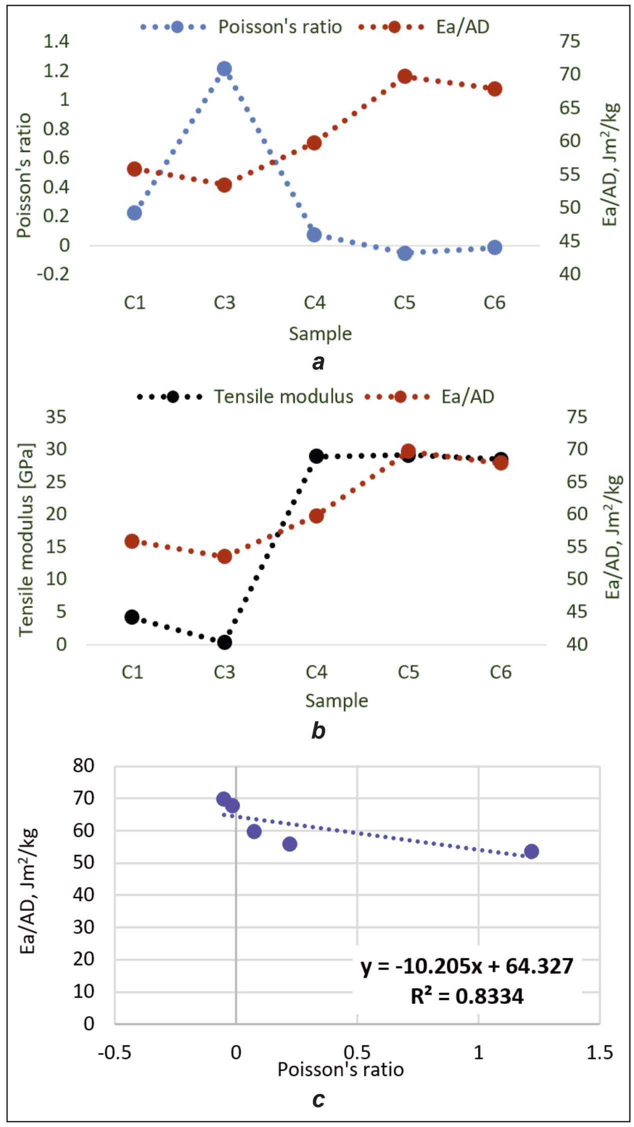

Fig. 11. Relationship between: *a* – Poisson's ratio and Ea/AD; *b* – Tensile modulus-Ea/AD; *c* – Pearson correlation coefficient between Poisson's Ratio and Ea/AD under ballistic impact (absorbed energy values taken from [8])

values of composites reinforced with UD-UHMWPE fabrics are higher than composites reinforced with woven aramid fabrics. The Ea/AD hierarchy of composites is as follows [8]:

Ea/AD C5 > C4 + C5 > C6 > C4 > C3 > C1

Figure 11 shows the variation of energy absorption per unit area density (Ea/AD) according to Poisson's ratio. In general, it has been observed that Poisson's ratio and Ea/AD are inversely related. Plates C3, C4, and C5 exhibited a negative Poisson's ratio. When axial force is applied to the material, it expands in the lateral direction. Their ability to expand under sudden dynamic forces has significantly increased the energy absorption capacity of the plates. These auxiliary materials, which expand when exposed to tension, have given new mechanical properties to C4, C5, and C6 plates. This increased tensile strength resulted in increased resistance to delamination. As a result, Aramid UD GS3000, UHMWPE UD Dyneema H62, and UHMWPE UD H5T UD reinforcement materials are highly effective for use in body armour systems where superior mechanical performance and dynamic impact resistance are critical. After applying impact force, structural changes account for the small changes in impact energy in UHMWPE UD Dyneema H62 and UHMWPE UD H5T reinforced composites. Figure 11 shows the change of Ea/AD according to the modulus value. As a result of the ballistic impact V50 test, the Ea/AD value showed the same characteristics as the modulus value. C5 and C6 samples with high modulus values showed the highest Ea/AD value. Sample C3, which has the lowest modulus value, showed the lowest Ea/AD value.

Relationship between elastic properties and energy absorption properties under low-velocity impact, dynamic compressive loading and ballistic impact

The energy absorption abilities per area density of Aramid woven fabric (CT 736), Aramid UD-GS3000, and UHMWPE UD-Dyneema H62 reinforcement fabrics were compared according to the results of our previous studies, low-velocity impact [6], split Hopkinson pressure bar [27], and ballistic impact V50 test [8] results.

In this context, the relationship between the energy absorption abilities of reinforcement fabrics per normalized area density and Poisson's ratio as a result of low-velocity impact testing, split Hopkinson pressure bar testing, and ballistic impact V50 testing is given in figure 12.

The split Hopkinson pressure bar test and the ballistic impact V50 tests at high speed showed that Aramid UD-GS3000 reinforced plates did better than CT-736 reinforced plates. The high impact energy of Aramid UD-GS3000 and UHMWPE UD-Dyneema H62 reinforced plates is because of the changes in their structure when the impact force is applied. These changes happen because of the high compression stress in split Hopkinson pressure bar tests and ballistic impact V50 tests. The force changes the thickness of the initial sample; the plates expand laterally; thus, the force dissipation capacity of the sample increases, and thus the energy absorption performance increases. The Poisson's ratio graphs of C4-C5 samples in figure 5 indicate this phenomenon. Aramid UD-GS3000 and UHMWPE UD-Dyneema H62 reinforcement fabrics act as auxiliary materials at high-impact stresses. The crimp-free yarns of these fabrics absorb impact loads efficiently and distribute the force throughout the structure. Higher filler yarn density increases energy absorption.

Interestingly, unlike other tests, Aramid woven fabric (CT 736 fabric) gave the best results in low-velocity impact testing. As seen from here, the energy absorption capacity decreases as the impact speed increases in CT 736-reinforced plates. Figure 6 shows that the Poisson's ratio of the Aramid woven fabric-CT 736 reinforced plate is close to 0 at low-impact strains. This caused this reinforcement fabric to show better energy absorption ability at low-impact velocities. Aramid UD-GS3000 and UHMWPE UD-Dyneema H62 reinforcement fabrics showed similar results in low-velocity impact testing, but UHMWPE UD-Dyneema H62 reinforcement fabric showed a slightly higher energy absorption performance. As stated in figure 6, this means that UHMWPE UD-Dyneema H62 has a slightly lower Poisson ratio than Aramid UD-GS3000 at low-impact strains, resulting in higher energy absorption performance.

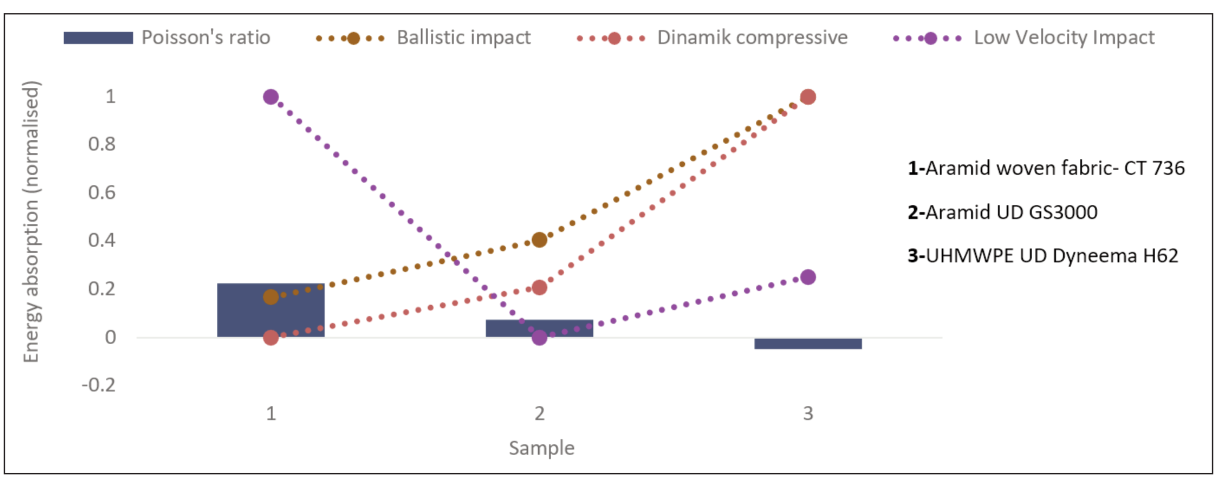

Fig. 12. The relationship between the energy absorption abilities (normalised) of reinforcement fabrics and Poisson's ratio

CONCLUSIONS

Within the scope of this study, the mechanical properties and strain distributions of composite materials produced from different aramid and ultra-high molecular weight polyethylene fabrics were examined. Then, these analysis results were analysed in detail about the energy absorption data obtained from our previous studies, including low-velocity impact, dynamic compressive, and ballistic impact V50 tests. Based on our results, the following conclusions are made:

- Although the tensile modulus values of unidirectional fabric-reinforced composites are very close, they have higher tensile modulus values than other woven and biaxial composites. The UHMWPE UD with the highest tensile modulus was obtained in the Dyneema H62 composite.
- The tensile strength value of Artec aramid-woven fabric-reinforced composite is higher than all other composites, thanks to the thin yarn (58/58 Tex). Among UHMWPE UD composites, the highest tensile strength value was obtained from Dyneema H62 sheet-reinforced composite. Artec aramid composite has 32% higher tensile strength than Dyneema H62 composite.
- Poisson's ratios of UHMWPE UD fabric-reinforced composites showed negative values. As a result of the strain distributions obtained from Vic3D software, it was seen that they behaved as an auxetic structure. The UD aramid-GS3000 fabric reinforced and Dyneema H62 composite exhibited a negative Poisson's ratio as the tensile value increased. In contrast, the UHMWPE H5T composite displayed an unstable structure with a positive Poisson's ratio after reaching the 20% tensile value.
- Among aramid fabric-reinforced composites, the lowest Poisson ratio is UD aramid-GS3000 fabric-reinforced composite and is approximately 0. Additionally, as the stress value increased, the Poisson's ratio moved negatively. However, the Aramid woven fabric-CT 736 woven reinforced composite was close to 0 at a low-tension value and showed a rapid positive increase as this tension value increased.
- A linear relationship was observed between energy absorption performance, Poisson's ratio, and tensile modulus.
- In dynamic compressive and ballistic impact V50 tests, the UHMWPE UD composites absorb energy the best, with Poisson's negative ratio. The UD aramid-GS3000 composite has the lowest Poisson ratio of all the aramid composites. The energy absorption of UHMWPE UD composite is 27% higher than that of Aramid woven fabric-CT 736 composite. However, in the low-velocity impact test, Aramid woven fabric-CT 736 composites showed the highest absorption performance. It has been observed that this situation is directly due to Poisson's ratio showing 0 values at the low-tension value of the Aramid woven fabric-CT 736 composite.

According to these findings, it has been determined that Poisson's ratio, tensile modulus, architecture, and areal density of the reinforcement materials are the main factors affecting the energy absorption performance of composites. Composites with high modulus, negative Poisson's ratio, low density, and non-curling UD fabrics have the highest energy absorption performance. It was concluded that these parameters should be analysed in detail in selecting reinforcement materials for composites to be used in ballistic protection applications.

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Study of extraction and characterization of ultimate kenaf fibres

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ABSTRACT – REZUMAT

Study of extraction and characterization of ultimate kenaf fibres

This study proposed an extraction process of Tunisian kenaf fibres to obtain ultimate fibres with minimum aspect ratio, minimum retention capacity and high yield and high absorption capacity. The extraction process was performed by varying the treatment duration (120–180 min), the temperature (110–130°C), and the sodium concentration (10–40 g/l). After that, a factorial design, that has been built using statistical software Minitab.17, was followed to identify the optimum operating conditions. After the extraction process, kenaf fibres were used to produce dry-laid nonwoven fabrics. Results reveal that mixed treatment improves the absorption properties of fibres. To characterize these fibres, some properties were measured like morphological structure and absorption properties: absorption and retention capacity. The morphology of the cellulose fibres (length and, diameter distribution), obtained from the optimum process, was determined by measuring 300 fibres with «Leica» optical microscopy. Ultimate fibres extracted from kenaf had an absorption capacity of 12.5 g/g and a retention capacity of 0.65 g/g. Finally, the characteristics of the optimum ultimate kenaf were compared to those of other vegetable fibres.

Keywords: *kenaf fibre, extraction, morphological structure, absorption capacity and retention capacity*

Studiul extracției și caracterizării fibrelor finale de chenaf

Acest studiu a propus un proces de extracție a fibrelor de chenaf din Tunisia pentru obţinerea fibrelor finale cu raport de aspect minim, capacitate minimă de retenţie și randament ridicat și capacitate mare de absorbție. Procesul de extracție a fost realizat prin varierea duratei de tratament (120–180 min), a temperaturii (110–130°C) și a concentrației de sodiu (10–40 g/l). După aceea, a fost urmat un model factorial, care a fost construit folosind software-ul statistic Minitab.17, pentru a identifica condițiile optime de funcționare. După procesul de extracție, fibrele de chenaf au fost folosite pentru a produce neţesute prin fixare uscată. Rezultatele arată că tratamentul mixt îmbunătățește proprietățile de absorbție ale fibrelor. Pentru a caracteriza aceste fibre, au fost determinate unele proprietăți precum structura morfologică și proprietățile de absorbție: capacitatea de absorbție și retenţie. Morfologia fibrelor celulozice (lungimea şi distribuţia diametrului), obţinute în urma procesului optim, a fost determinată prin măsurarea a 300 de fibre prin microscopie optică „Leica". Fibrele finale de chenaf extrase au avut o capacitate de absorbție de 12,5 g/g și o capacitate de retenţie de 0,65 g/g. În cele din urmă, caracteristicile fibrelor de chenaf optime finale au fost comparate cu cele ale altor fibre vegetale.

Cuvinte-cheie: *fibră de chenaf, extracţie, structură morfologică, capacitatea de absorbţie şi capacitatea de retenţie*

INTRODUCTION

Improving natural fibre exploitation, particularly ligno-cellulosic fibres, has become one of the main tracks for sustainable manufacturing. Several recent research have focused on how raising extraction process efficiency while keeping into consideration the ecological concern. It has resulted in a renewed interest in cellulosic fibres [1, 2]. Many natural fibres, such as alfa, sisal, luffa, and kenaf, are of interest because they are environmentally friendly. In addition to their multiple uses, natural fibres have shown many advantageous properties such as lightness, resistance and flexibility which give them a wide perspective of application in the textile field. Twofold gains can be realized: these materials are recyclable and eco-friendly hence many advantages are taken in the automobile industry and medical applications. Many researches [3, 4] illustrated the application of agave fibres. Ben Marzoug and Saieb [5–7] presented the utility of technical esparto fibres. Valcineide et al. have studied luffa fibres [8]. Thompson et al. have investigated henequen fibres, especially their absorbent properties [9]. According to their extraction methods, natural fibres have very different qualities. Indeed, one can obtain discontinuous and short fibres or continuous and long ones [10].

A multidisciplinary team of scientists, experts and farmers has been mobilized to plant kenaf in different regions of Tunisia. This allowed carrying out tests in a scientific way based on maximizing yield and reducing costs per hectare. In this work, we are interested in finding the appropriate method to extract Tunisian kenaf fibre directly from the stem and this is the difference and the novelty of our work. Indeed, the previous research works report that the extraction is carried out on the Liberian part previously extracted from the kenaf stem by retting. Extraction methods are presented in this work: enzymatic retting and chemical extraction. The obtained fibres are characterized and a comparative study of their properties was carried out [15–19]. This work is aimed at developing an optimized extraction process of ultimate kenaf fibres from technical fibres obtained from a combined process using mechanical and chemical extraction.

MATERIALS AND METHODS

Materials

Kenaf (*Hibiscus cannabinus*), a herbaceous annual plant similar to jute, is quite popular in the Western world because of its eco-friendly nature. It has high biological efficacy and ecological adaptability. It can absorb CO_2 and NO_2 three to five times faster than forests and its deep roots can improve the soil. The plant has an ideal blend of long and short fibres for many paper and paperboard products (figure 1) [1].

Fig. 1. Kenaf stem

Technical fibre extraction

To extract fibres from the organic matrix, different methods can be used. These methods have a great influence on the fine structure of the obtained fibres [11]. In the current study, a mechanical method has been used to extract kenaf fibre. The harvested kenaf plant as a whole is processed in a mechanical fibre separator “horizontal opener machine”, making possible separation of the bast and core fibres possible. Technical fibres were not sufficiently separated. For this reason, and to ensure an effective separation, two passages in the “Shirley Analyser machine” were used (figure 2).

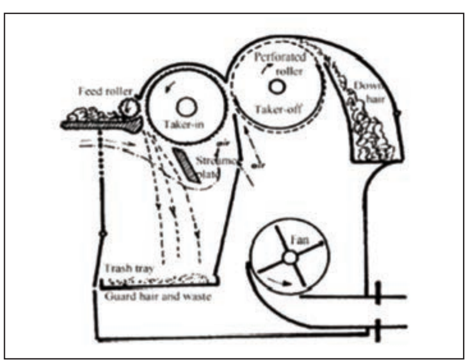

Fig. 2. Schematic of the Shirley Analyser

Ultimate fibre process

Long vegetal fibre extraction methods, such as linen, agave and kenaf, can be mechanical, chemical or biochemical. In this work, a chemical process was used. This process preserves the fibre and is based on eliminating only non-cellulosic materials.

Chemical extraction could be processed in different ways using, for example, sodium sulfate, bisulfite, kraft and so on.

In this study, a combined process was used. This process aimed to eliminate the non-cellulosic material using NaOH and bleaching process by the use of hydrogen peroxide. The extraction bath is as follows:

- 5 g dried fibres;
- Liquor ratio 1/40;
- 30 g/l of sodium hydroxide;
- 35 ml/l of hydrogen peroxide;
- 25 ml/l of stabilizer of hydrogen peroxide.

The treated fibres were thoroughly washed in warm water to remove dissolved substances. The resulting fibres were neutralized using a solution of acetic acid (10 ml/l), rinsed abundantly with water and dried under ambient conditions. Based on this process, several experiments were carried out to find the suitable extraction method for kenaf fibres. A series of preliminary experiments were conducted and they demonstrated that less than 120 min at 110°C and 20 g/l of soda concentration, the individual fibres were always stuck together and the extraction appeared to be impossible and more than the highest conditions, the extraction degraded the fibres and needed more time and energy. Therefore, the extraction process parameters were fixed as follows:

- the treatment duration *D* (min): from 120 to 180;
- temperature *T* (°C): from 110 to 130;
- the soda concentration *C* (g/L): from 20 to 40.

Hydrogen peroxide was added to the pulp bath for bleaching, with a concentration of 35 ml/l. A stabilizer (CHTT stabilizer A4) was also added to slow the rate of peroxide decomposition under alkaline conditions and combined with neutralized metal impurities that could catalyse the decomposition of H_2O_2 and induce fibre damage. The resulting pulp was washed, neutralized and finally dried at 105°C.

Methods

This study aims to evaluate the effect of extraction parameters on fibre properties. So, we measured some properties of kenaf fibre obtained. To characterize these fibres, some tests were made like morphological structure and absorption properties.

Extraction optimization

In this work, we used a composite Box-Behnken design to investigate the influence of extraction parameters (temperature, time and soda concentration) on the fibre properties, to determine the optimum operating conditions for the process and to establish statistical models for the prediction of fibre properties [12]. A Box-Behnken design is a three-level design in which all the design points are at the centre of the design and cantered on the edges of the cube, equidistant from the centre. Key features of this design are as follows:

- allows efficient estimation of quadratic terms in a regression model;

Table 1

THE EXPERIMENTAL DESIGN USED				
Factor	**Min**	**Centre**	**Max**	**Level**
Treatment duration (mn)	120	150.00	180	3
Temperature (°C)	110	120.00	130	3
[NaOH] concentration (g/l)	20	30.00	40	3

- consists of fewer design points therefore, is less expensive to run than central composite designs.

So to better assess the effect of the temperature, the time and the soda concentration on the fibre properties, a statistical study was performed using Minitab 17. So ANOVA was used and diagrams of the main effects of these parameters and the interaction between them were drawn (figure 3) [12].

In this statistical study, the soda concentration, the duration of treatment and temperature are the input parameters. However, the yield, absorption, retention capacity, and L/D are the output parameters as presented in figure 3.

Desirability function

An experimental database was elaborated by varying extraction parameters. In this database, we used as input variables the temperature, treatment duration and soda concentration. The outputs were the satisfaction degrees. They were related to the extraction yield, Absorption, retention capacity and length/diameter ratio (L/D). We evaluated the satisfaction degree by using a mathematical function, in only one parameter that grouped these different degrees of satisfaction, and that permitted us to define a global desirability index. For each property influencing the global satisfaction, we calculated the individual satisfaction degree and we affected a relative weight to indicate the property's importance. We used the desirability functions shown in figure 4, *a* and *b* in which we took into account the target "Ytarget", and the importance of every property "Yi" in the definition of global desirability.

In this study, we used two types of desirability functions "di": desirability function to maximize and to minimize. Thus, to maximize a property "Yi", such as the yield and absorption capacity, the desirability function (shown in figure 4, *a*) had to be used, where d_i was calculated as follows:

$$d_i = 0 \quad \text{if} \quad Y_i \leq Y_{min} \tag{1}$$

$$d_i = \left[\frac{Y_i - Y_{min}}{Y_{target} - Y_{min}}\right]^S \quad \text{if} \quad Y_{min} \leq Y_i \leq Y_{target} \tag{2}$$

$$d_i = 1 \quad \text{if} \quad Y_i \geq Y_{target} \tag{3}$$

To minimize a property "Yi", such as the aspect ratio and retention capacity, the desirability function (shown in figure 4, *b*) had to be used, where d_i was calculated as follows:

$$d_i = 1 \quad \text{if} \quad Y_i \leq Y_{target} \tag{1}$$

$$d_i = \left[\frac{Y_i - Y_{max}}{Y_{target} - Y_{max}}\right]^S \quad \text{if} \quad Y_{target} \leq Y_i \leq Y_{max} \tag{2}$$

$$d_i = 0 \quad \text{if} \quad Y_i \geq Y_{max} \tag{3}$$

For each property affecting the global desirability, we calculated the satisfaction degree "di" and we attributed a relative weight to indicate the property's importance. We grouped these different satisfaction degrees by using the Derringer and Suich desirability function [13] defined as follows:

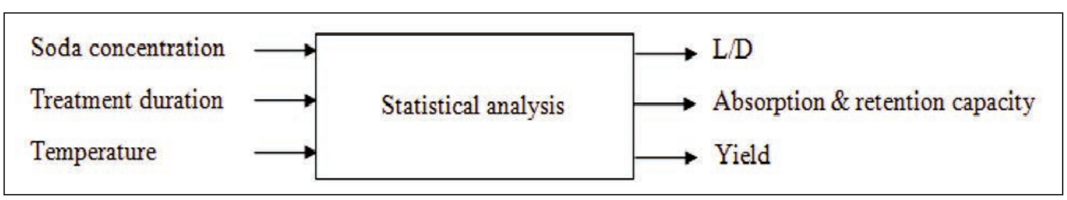

Fig. 3. Statical model

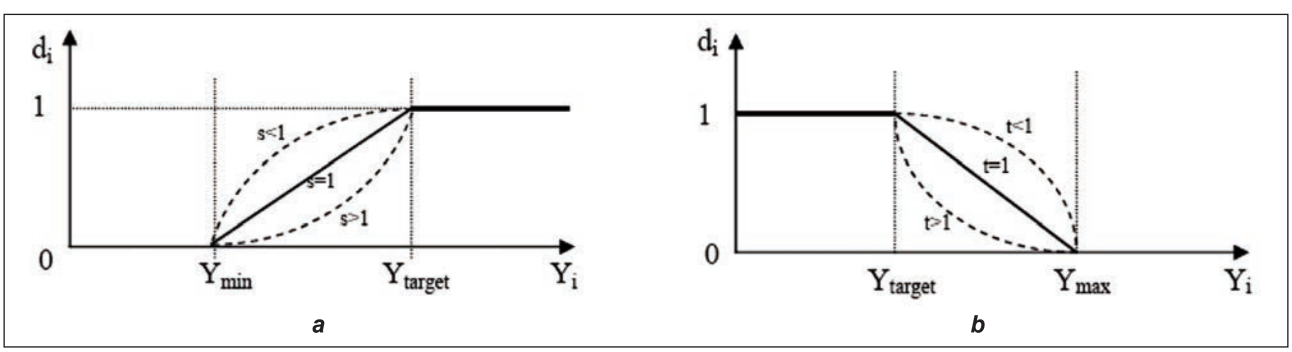

Fig. 4. Desirability function to: *a* – maximize; *b* – minimize

$$d_g = \sqrt[w]{d_1^{w_1} \times d_2^{w_2} \times \ldots \times d_n^{w_n}} \qquad (7)$$

where d_i is the individual property's desirability function Y_i, $i \in [1…n]$, w_i – the weight of the property Y_i in the "dg" desirability function, w – the sum of w_i and n – the number of properties. The compromise between the properties (maximize yield and absorption capacity, minimize ratio aspect and retention capacity) was better when "dg" increased; it became "perfect" when "dg" was equal to 1. When the satisfaction degree "di" of the property Y_i was equal to 0, the response had a value outside of tolerance the function "dg" was equal to 0 and so the compromise was rejected.

RESULTS AND DISCUSSIONS

Morphological and physical characterization of technical fibre

Studies of morphologic characteristics can ensure a comparison between different extraction methods, give more information about the surface and evaluate a fibre diameter.

SEM results

A scanning electron microscopy (SEM) photograph of technical fibre illustrated that it was composed of individual cellulosic fibres bound together by lignin (figure 5).

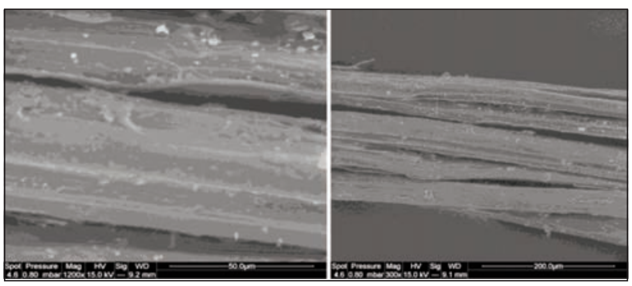

Fig. 5. SEM photographs of technical fibre

Diameter distribution

The results give us an average of 69,16 microns in diameter for crude fibre. Figure 6 represents the diameter distribution of the crude fibre, this distribution confirms the natural character of the fibre.

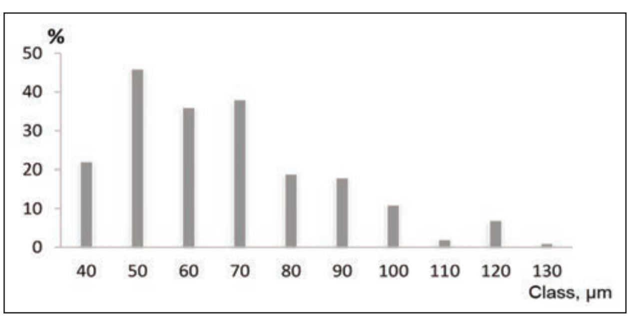

Fig. 6. Diameter distribution

The length distribution

The crude fibre presents an average length of 37 mm. Figure 7 presents the length distribution of the crude fibre. This distribution is similar to all-natural fibre. In one batch of fibre length, there are different length classes of fibres. The variation of length compared to the average, was 51% which means that the batch of the raw fibres is not homogeneous and that the fibre is quite irregular.

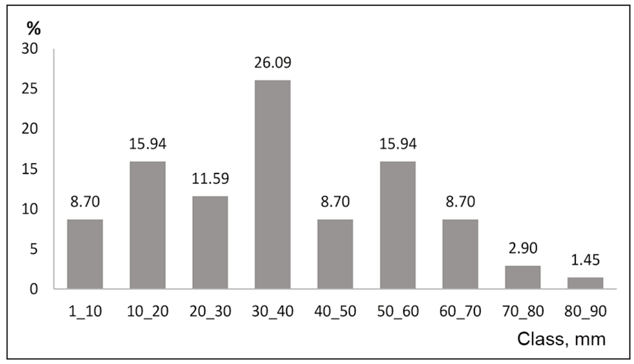

Fig. 7. Length distribution

Optimization of ultimate fibre extraction

The kenaf extracted fibres will be used for producing a wet-laid nonwoven textile used for insoles. For this reason, we optimize the extraction of fibre to have the appropriate characteristics of fibre for this use. Figure 8 presents the resulting ultimate fibres extracted from the technical Tunisian kenaf fibres.

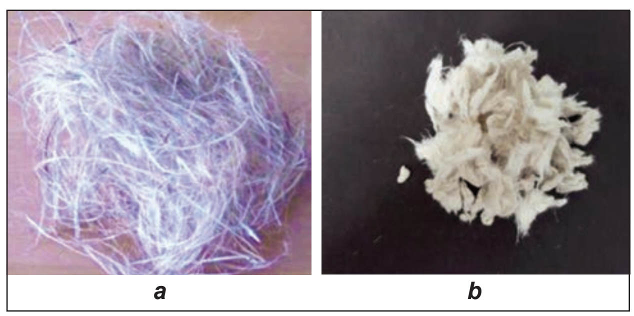

Fig. 8. Kenaf fibres:
a – technical fibres; *b* – ultimate fibres

Statistical analysis

To evaluate the effect of extraction parameters on extraction yield, the diagrams of the main effect and the interaction diagrams were used.

It is observed, from figure 9, that the soda concentration and the temperature are the most influential parameters in the extraction yield. Figure 10 reveals that all parameters: Temperature (T), Treatment Duration (D) and soda concentration (C) are influential in aspect ratio. Through the exploitation of figure 11, it can be noted that all parameters are influencing the absorption capacity. The most influential parameter in retention capacity property is both the soda concentration and the duration. The temperature has less impact. To ensure the validity of the results obtained by the diagrams of the main effect or interaction diagrams, the ANOVA was used.

The results of this test are presented in table 2 where we notice:

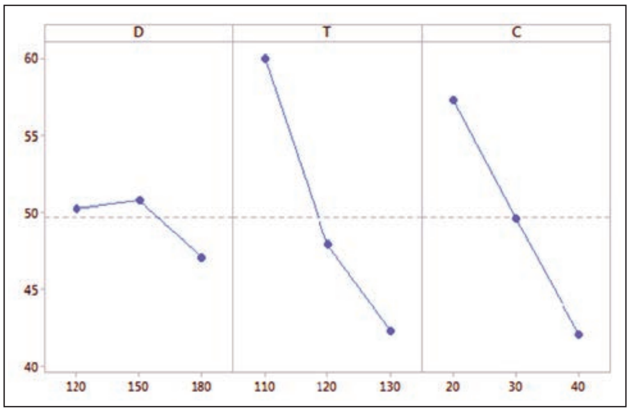

Fig. 9. Main effect diagram for extraction yield

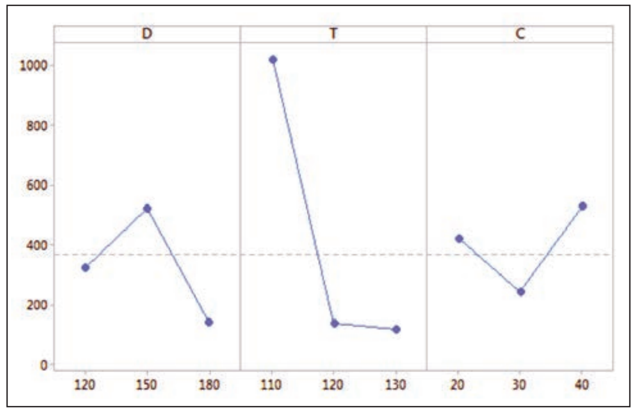

Fig. 10. Main effect diagram for L/D

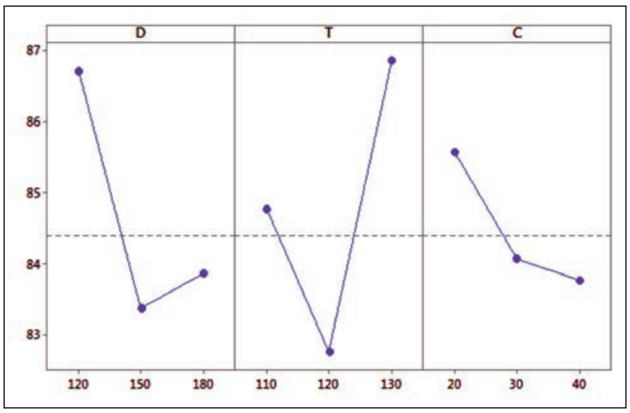

Fig. 11. Main effect diagram for absorption capacity

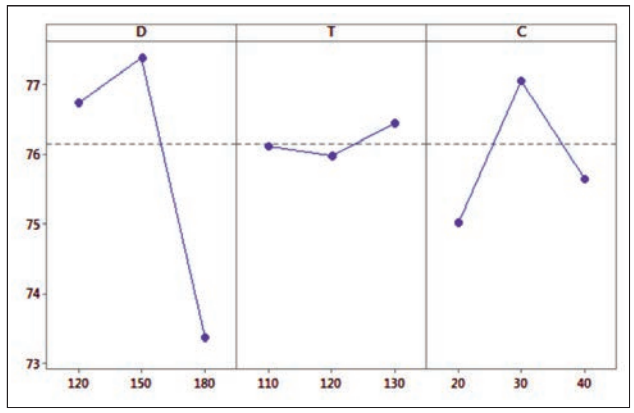

Fig. 12. Effect diagram for retention capacity

Table 2

ANOVA results

Indicator	Parameter	DL	Sum of squares	F-value	p-value
Yield (%)	D	1	20.963	1.66	0.254
	T	1	626.757	49.73	0.001
	C	1	462.080	36.66	0.002
Aspect Ratio L/D	D	1	65418	0.50	0.511
	T	1	1622397	12.38	0.017
	C	1	24524	0.19	0.683
Absorption capacity (g/g)	D	1	16.289	23.80	0.005
	T	1	8.797	12.85	0.016
	C	1	6.5479	9.57	0.027
Retention capacity (g/g)	D	1	22.984	8.70	0.032
	T	1	0.219	0.08	0.785
	C	1	0.769	0.29	0.613

Note: DL – degree of freedom; p-value is the significance level for the hypothesis that the coefficient is zero; F-value – The F-value in an ANOVA is calculated as the variation between sample means/variation within the samples.

We conclude from table 2 and through the p value that all parameters affect all measured properties. The temperature, treatment duration and soda concentration are influential parameters, especially for absorption capacity. In this study, we choose to optimize the extraction process of kenaf fibre to obtain ultimate fibres with minimum aspect ratio, minimum retention capacity, a high yield and absorption capacity. The coordinates of the optimum properties' values for the extraction parameters and properties obtained are prescribed in the following table.

This multiple-response optimization method allows having a compromise between the various answers or outputs. The quality of the solutions found is

Table 3

EXTRACTION OPTIMISATION RESULTS					
Output	**Yield (%)**	**Absorption capacity (g/g)**	**Retention capacity (g/g)**	**Aspect ratio (L/D)**	**Optimum extraction**
Value «d_i»	64.58	12.48	0.65	199.95	-
Desirability «Dg» (%)	98.04	86.45	47.68	76.49	74.56

determined by the value of the global desirability «Dg», the closer this value is to 1 the better properties will be met. Through this optimization study based on the calculation of the individual desirability «d_i» of each output parameter and the combined desirability presenting the compromise between all the properties, the optimum conditions were set. From this study, we have chosen:

- [NaOH] = 20g/l;
- Temperature: 110°C;
- Duration: 180 min.

We choose these optimal values of temperature and duration of treatment the lowest for economic reasons. After choosing the optimum conditions for the extraction of fibres, we have to validate them. For this reason, we apply these conditions to extract fibres and we characterize them.

Characterization of the optimum process

Length and diameter of the fibre

The fibres' morphological analysis had a major utility. In fact, throughout the manufacture of the pulp, the cellulose fibres were subjected to physicochemical treatments with high intensity, and their morphology was modified. Therefore, it was important to limit the harmful effects of the processes on morphology to the profit of the positive effects. The measured pulp properties could be related to the fibres' morphological properties. For example, the more the fibres had a high length, the more the number of connections was important and the pulp mechanical resistance was significant.

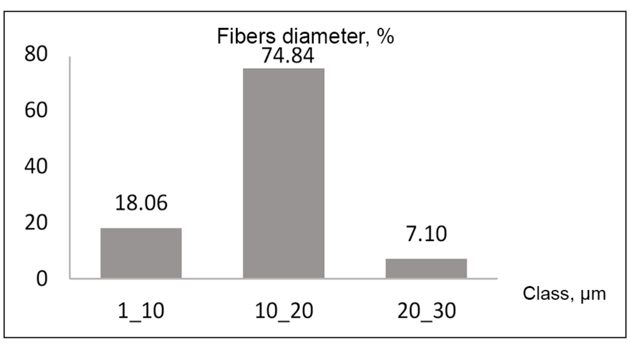

Fig. 13. Diameter distribution of Kenaf ultimate fibres

The results give us an average of 69.16 microns in diameter for crude fibre and 13.98 microns for chemically extracted fibre. This is due to the elimination of impurities stuck in the fibre. Figure 13 represents the diameter distribution of the ultimate fibre; this distribution confirms the natural character of the fibre.

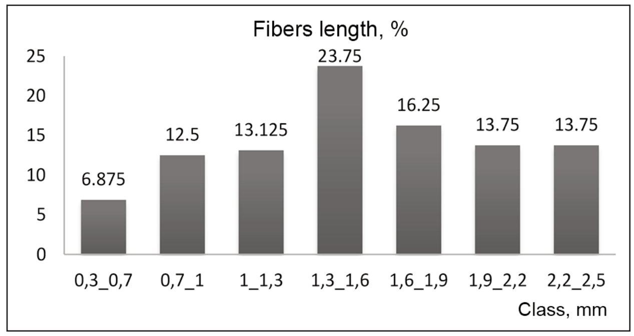

Fig. 14. Length distribution of kenaf ultimate fibre

The ultimate fibre presents an average length of 1.32 mm (figure 14).

SEM results

Studies of morphologic characteristics can ensure a comparison between different extraction methods, give more information about the surface and evaluate a fibre diameter. The longitudinal view of kenaf fibre (figure 15, *a*) shows that there are impurities accumulated on the surface of the mechanical extracted fibre. It is also lignin and pectin. These impurities were dissolved in figure 15, *b* by the chemical treatment which is why the treated fibre became thinner, and more flexible, and the ultimate fibres were separated.

The microstructure images of the kenaf fibre are presented in figure 15, *a* and *b* represent longitudinal and transversal views of the crude kenaf fibres. This figure shows that the kenaf fibre is covered with non-cellulose compounds. Figure 5 shows SEM images for fibres treated with enzymes which still have non-cellulosic materials on the surfaces of the fibre after extraction, this figure shows also an incomplete extraction. These deposits on the surface of the fibres are highly visible in the SEM images of the ultimate fibres and they are aligned parallel and always seem to be less stuck, the structure of the fibre shows that the surface of the fibre is clean and

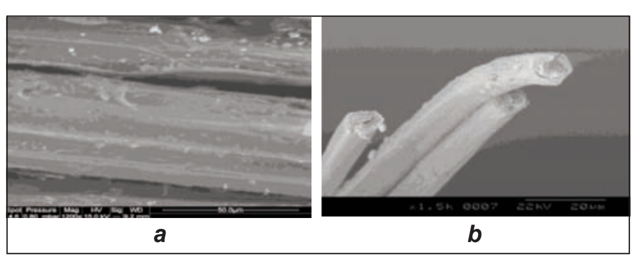

Fig. 15. Morphologic images: *a* – technical fibre; *b* – ultimate fibre

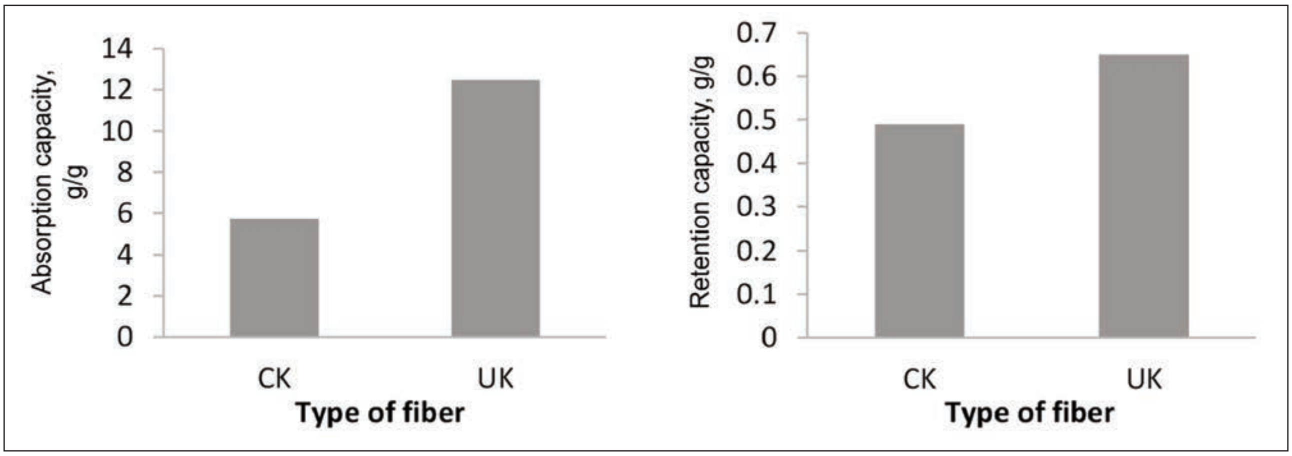

Fig. 16. Retention and absorption capacity of crude kenaf (CK) and ultimate Kenaf (UK) fibres

become smoother, the ultimate fibres are visible but not yet separated or deteriorated. The SEM images for chemically extracted fibres show that the fibres are degraded after prolonged exposure to high concentrations of sodium hydroxide. Although the ultimate fibres are visible, we can still see non-cellulosic substances covering the surface of the fibre and that is not completely removed. The transversal view of kenaf fibre shows that is composed of many fibre cells which are presented as aligned fibrils with materials cementing the fibres together. This material in the interfibrillar region is etched away as a result of the treatment done. The ultimate kenaf fibre has a circular section measuring approximately 12 microns in external diameter and 6,5 microns in internal diameter. We also note the presence of a very small lumen, which gives the fibre a thermal insulating power. So to conclude, vegetable fibres have generally a similar morphology and they can be simulated as a natural composite composed of ultimate fibre bundles of cellulose, linked together by gummy and waxy substances, constituting the matrix. The same result has been showed by other researches [16, 18, 19].

Absorption capacity and retention measurement

Absorption and retention capacities are linked to hydrophilic groups and amorphous zones. Figure 16 lists retention and absorption capacities for unmodified and modified kenaf fibres. The analysis of data shows that the treatment with NaOH/H_2O_2 yielded higher absorption and retention capacity values. The kenaf absorption capacity was approximately 12.5 g/g with a variation coefficient of 3%; this was higher than the alfa one (a value of 9.4 g/g) and the Agave one (a value of 10.5 g/g). This indicated that the wettability and penetrability of the material to liquid improved due to the removal of ligneous cement and the creation of supplementary hydrophilic sites consisting mainly of hydroxyl groups [14].

CONCLUSION

In other studies, we have chosen to work with a mixed extraction process that combines a NaOH extraction process and an oxygen peroxide bleaching process. We started by studying the kenaf fibre mechanical extracted, then we dealt with optimizing the extraction process to obtain ultimate fibres. A composite Box-Behnken design was used to identify the optimum operating conditions (temperature, treatment duration and soda concentration) for Tunisian kenaf fibre. The optimum extraction conditions were found by using 20g/l soda concentration, time =180 min and temperature = 110°C. In the second step, we investigated the control test (yield, morphological properties, absorption and retention capacity). Once extraction was achieved, characterization of ultimate kenaf fibres was done. The ultimate kenaf fibres obtained had a capacity absorption was about 12.5 g/g and an average diameter of 13.98 µm. The arithmetic length was about 1.32 mm. Tunisian kenaf fibres could potentially be utilized for many applications such as paper products including handicrafts, geotextiles, filters, packaging, baby diapers and composites.

The chemical and physical analysis of the kenaf fibres were determined and found suitable as textile-grade fibre for various applications. The moisture content of the fibres was found suitable which will further enhance the comfort properties of the fabric. The cellulose content of the fibre was found satisfactory. The increase in cellulose per cent will give higher strength to the fibre.

The morphological properties of kenaf bast fibres were found to be significantly affected by the extraction methods used in this work. In our case, we are interested in applying these fibres in the manufacturing of wet-laid nonwoven which will be put in insoles.

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Design and research on the posture-adjustable mannequin for chest-up and hunchbacked posture

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ABSTRACT – REZUMAT

Design and research on the posture-adjustable mannequin for chest-up and hunchbacked posture

The development of garment personalization has put forward diverse requirements for mannequins. In this paper, we present a garment mannequin that can continuously alter the body posture in response to changes in human body posture in the chest and back regions. This research is founded on an analysis of the patterns and ranges of movement in the mannequin's chest and hunchbacked motions. We segmented the mannequin into six modules: neck, front chest, back, left and right shoulders, and waist and abdomen. By employing stepper motors, we independently drive the front chest, back, and left and right shoulders to achieve the simulation and continuous adjustment of the mannequin's body posture for chest and hunchbacked positions. The comparison of the 3D scans shows that the mannequin fits well in several cross-sections with the corresponding body variations of real people, and the results of the real shirt also show that the shirt made based on the simulated hunchbacked body mannequin is significantly better than the standard shirt in terms of comfort and aesthetics for a person with a hunchbacked body posture. The body posture adjustable mannequin can replace multiple static mannequins, which can provide strong support for the business model of personalized clothing customization. Compared with the existing dynamic mannequin, it has the advantages of high relevance, simple structure and low production cost.

Keywords: *adjustable mannequin, garment personalization, hunchbacked posture, chest-up posture, garment customization, 3D scanning, electromechanical integration technology*

Proiectare și studiu asupra manechinului cu postură ajustabilă pentru postura cu spatele drept şi postura cu spatele încovoiat

Dezvoltarea personalizării articolelor de îmbrăcăminte a impus diverse cerințe pentru manechine. În acest studiu, prezentăm un manechin pentru îmbrăcăminte care își poate modifica continuu postura ca răspuns la schimbările în postura corpului uman în regiunile pieptului și spatelui. Această cercetare se bazează pe o analiză a tiparelor și intervalelor de mișcare a pieptului manechinului și a mişcărilor cu spatele încovoiat. Am segmentat manechinul în șase module: gât, piept, spate, umărul stâng și umărul drept, talie și abdomen. Prin folosirea motoarelor pas cu pas, am acţionat în mod independent pieptul, spatele, umărul stâng și umărul drept pentru a realiza simularea și ajustarea continuă a posturii corpului manechinului pentru postura cu spatele drept şi postura cu spatele încovoiat. Comparația scanărilor 3D arată că manechinul se potrivește bine în mai multe secțiuni transversale cu variațiile corespunzătoare ale corpului omenesc real, iar rezultatele unei cămăşi reale realizate pe baza manechinului cu spatele încovoiat simulat sunt semnificativ îmbunătățite decât cele ale unei cămăşi standard în ceea ce privește confortul și estetica pentru o persoană cu o postură corporală cu spatele încovoiat. Manechinul cu postura corpului ajustabilă poate înlocui mai multe manechine statice şi poate oferi un sprijin real pentru modelul de afaceri în ceea ce priveşte îmbrăcămintea personalizată. În comparație cu manechinul dinamic existent, are avantajele unei relevanțe ridicate, structură simplă și costuri de producție reduse.

Cuvinte-cheie*: manechin ajustabil, personalizarea articolelor de îmbrăcăminte, postură cu spatele încovoiat, postura cu spatele drept, scanare 3D, tehnologie de integrare electromecanică*

INTRODUCTION

The issue of garment fit permeates garment design and sales [1], and during the design process, designers and pattern makers need to accurately assess the fit of garments to optimize the designed garment products [2]. In apparel retail, consumers' primary concern is garment fit. Irrespective of the clothing's aesthetic appeal, a mismatch in clothing size will deter consumers from making a purchase. Clothing fit remains the principal factor influencing customers' purchase choices [3–7].

Garment fit has emerged as a pivotal measure for assessing garments [4], influenced by a multitude of factors, with body size [5] being a significant criterion. However, people often have habitual chest-up and hunchbacked posture changes, making standardized clothing difficult to fit, and this can not be resolved through the refinement of the clothing size. Research has demonstrated that over 50% of consumers express dissatisfaction with clothing fit [3].

Consequently, the difference in body shape [8] has emerged as a pivotal element for clothing personalization [9].

Mannequins are foundational tools in garment production and fit assessment [10–13], and they serve a pivotal function in personalization. However, existing commercial mannequins are mainly static mannequins with little consideration of body changes, which has led to a dramatic increase in the number of mannequins, not only increasing investment costs but also taking up a lot of space. A common method currently used is pattern correction for standard-size garments [10–12], however, this method still falls short in effectiveness when compared to cutting directly using the corresponding posture garment mannequin. Therefore, adjustable mannequins have been widely studied as an effective method to solve this problem.

About the alteration of the body shape and posture of the mannequin, early methods of augmentation and correction of the standard mannequin were used to obtain the body surface morphology of the mannequin with a chest-up [14–16], a convex belly and a hunchbacked back [17] by filling specific areas with materials such as cotton cores and elastomeric cloth [15]. 3D printing technology has further refined this approach, and the printed padding for the chest, waist, and hip areas can better fit the body's curves [18]. However, this method still has shortcomings such as complicated operation, long time consumption, high cost, and difficulty in achieving concavity, especially because it can cause changes in body shape while the mannequin is changing. Therefore, it is especially important to manufacture adjustable mannequins that can fit the changes in human body posture [19].

A patent by Liu et al. [20] proposed an adjustable mannequin, which cut the torso of the mannequin into seven segments horizontally and achieved continuous changes in the body shape of the mannequin by changing the circumference of each segment. Abels et al. [21] designed a deformable mannequin model for cutting applications, comparing the shape of the human model with the actual human body using the Iterative Closest Point algorithm, and determining the degree of similarity between the human surface model and the actual human body using a defined similarity metric which can assist in exploring improvements to mannequin models. Zhang et al. [22] proposed a microcontroller-controlled fitting robot that deforms the shoulder width, bust and waist circumference of a mannequin through a stepper motor drive system consisting of a guide rail and a sliding table [23]. Weng [24] designed a "skeletal-muscle-skin" multi-layered fitting robot that could simulate shoulder-holding movements by adjusting the position of the shoulder peak point relative to the lateral neck point. However, these mannequins are still not perfect in the simulation of body posture, and it is difficult to simulate shoulder retraction with a chest-up and hunchbacked back. Chan et al. [21] invented an intelligent adjustable mannequin, which could change the body size and structure of the mannequin by driving the movement of the adjustment plate through an internal detector and gear structure. However, the model could only achieve the adjustment of neck circumference, chest circumference, waist circumference, and hip circumference, and could not fit the hunchbacked body shape well.

Guo et al. [23] produced a female mannequin that can change body shape and posture. They have subdivided the mannequin into 29 modules and have driven and controlled each module with up to 21 stepper motors to achieve a continuous change of 10 main parameters of the human body shape and posture. The double-layered panels made of soft materials can well simulate the shape and posture of the female body and achieve a good effect of being able to try on clothes remotely [24]. Li et al. [25] proposed a robot model consisting of a flexible belt and an elastic rod as the main body and designed the pushing amount of the elastic rod and linear actuator according to the shape of the human body so that the flexible belt can effectively mimic the concave and convex situation of the human contour. Although Guo and li research can simulate diverse female body shapes, none have been designed for particular body postures (e.g., hunchbacked body postures) and the structural designs are often complex, resulting in high manufacturing costs that are not conducive to commercial use at scale. While these investigations can simulate diverse body shapes, the structural designs tend to be intricate, resulting in higher manufacturing costs.

This paper introduces an adjustable mannequin capable of continuously changing body postures, referred to as PAM. The design divides the standard mannequin into six parts and uses stepper motors to drive four of the movable parts, thus realizing the continuous posture adjustment function. Compared with the existing dynamic mannequins, the PAM design has the following advantages: the PAM can realize continuous adjustment between the chest-up and hunchback postures, and has higher relevance and accuracy for the simulation of chest-up and hunchback postures. Secondly, the PAM has a simple structure, low production cost, and is easy to mass-produce, which makes it practical and economical.

KEY INDICATORS OF CHEST-UP AND HUNCHBACKED BODY POSTURE CHANGES

When the body undergoes postural changes, all body parts experience varying degrees of alteration. Among these, chest convexity, back convexity, and the shoulder opening angle stand out as the three foremost key indicators. Illustrated in figure 1, chest convexity and back convexity are measured as the distances from the point of chest height and the point of the back bulge to the coronal plane (figure 1, *a*). Meanwhile, the shoulder opening angle is defined based on the motion of the sternoclavicular joint, specifically, the forward and backward swinging angle of the shoulder about the front neck point (figure 1, *b*). This angle is established by measuring the angle formed between the line connecting the front neck point and the acromion point, and the coronal plane. This angle alters corresponding to the extent of the chest-up or hunchbacked postural change.

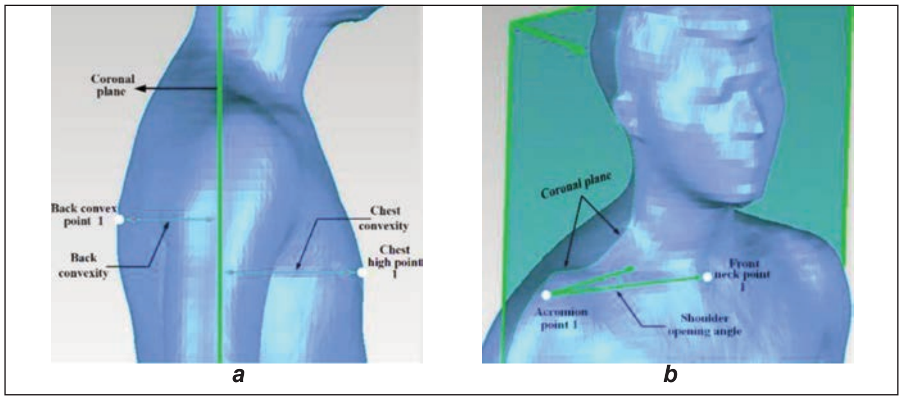

Fig. 1. Schematic diagram of key indicators for chest-up and hunchbacked posture changes: *a* – chest and back projection data; *b* – shoulder opening angle

To ascertain the direction and range of movement for the three key indicators of the mannequin in chest-up and hunchbacked postures, 17 young men whose body sizes closely matched the 180/96A mannequin were recruited as participants. They were instructed to be shirtless and to adopt a natural standing position as the baseline, a military stance for chest-up posture, and a writing stance at a table for the hunchbacked posture. Utilizing the X Scan 2017 Bock 3D body scanner, their upper bodies were scanned to obtain digital models, representing three different body types.

Table 1 lists the minimum and maximum values of the three key indicators obtained through the scanning of 17 men when the chest-up and hunchbacked posture changed. As can be seen from the table, the range of displacement for chest convexity is 2.2 to 35.9 mm, the range of displacement for back adduction is 1.7 to 19.8 mm, and the range of angle of the shoulder back swing is 0.04 to 16.89° in the upright position. In the hunchbacked posture, the range of inward displacement of the chest is 19.2 to 45.1 mm, the range of convex displacement of the back is 0.9 to 38.6 mm, and the range of forward swing angle of the shoulder is 0.39 to 10.72°. Indeed, we are more interested in the maximum values of the three key indicators in table 1 when body posture changes, using them as the range of variation in mannequin conditioning.

DESIGN AND FABRICATION OF POSTURE-ADJUSTABLE MANNEQUIN (PAM)

Design of panels

A standard male mannequin, sized 180/96A, was selected as the reference model and divided into six parts: neck, left shoulder, right shoulder, chest, back, and waist and abdomen, as depicted in figure 2. In figure 2, the neck panel is the part above the neck root circumference line and the waist and abdomen panel is the part below the chest circumference line, both of which are fixed and immobile. The cutting lines for the two shoulder panels are determined by diagonal lines intersecting from the lateral neck point to the opposite armpit, aligned adjacent to the fixed neck, the movable front chest, and the back panels, respectively.

The panels are cut with a sufficiently large gap along the cutting line to ensure that they do not come into contact with each other at the maximum range of motion. Through several adjustments, the gap

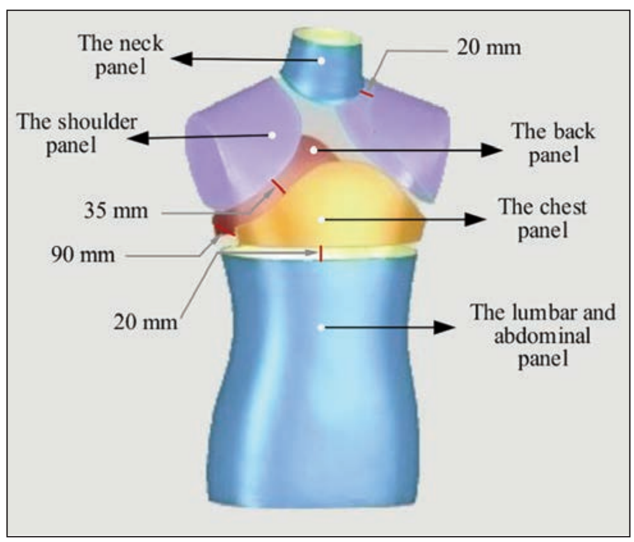

Fig. 2. Diagram of panel segmentation for the mannequin

Table 1

STATISTICAL TABLE OF KEY INDICATORS OF DIFFERENT POSTURES				
Measured items	**Chest up posture**		**Hunchbacked posture**	
	Minimum value	**Maximum value**	**Minimum value**	**Maximum value**
Chest convexity (mm)	2.2	35.9	19.2	45.1
Back convexity (mm)	1.7	19.8	0.9	38.6
Shoulder opening angle (°)	0.04	16.89	0.39	10.72

between the neck panel and the shoulder panel was determined to be 20 mm, the gap between the shoulder panel and the chest back panel to be 35 mm, and the gap between the chest back panel and the lumbar and abdominal panels to be 20 mm. due to the large range of motion of the chest and back, their clearance in the armpits was determined to be 90 mm.

Design of mechanical structures

Figure 3 depicts a schematic diagram detailing the mechanical structure within the mannequin. In figure 3, *a*, four stepper motors are secured in the lower section. Specifically, the two central motors facilitate the forward and backward movements of the chest and back modules via gears and racks, while the two motors on either side rotate the oscillating bar through a gear set to achieve the retraction and release movements of the left and right shoulder modules. The mechanism's connection to each moving panel is illustrated in figure 3, *b*. Notably, despite the two racks not being centred on the chest and back panels, the design allows the chest and back panels to move backwards and forwards in parallel. This is feasible due to one end of the rack being anchored to the panel, which possesses rigidity.

Assembly of the structure

Figure 4 shows the different body posture effects of the assembled mannequin. The mannequin can be well changed continuously from a chest-up posture (figure 4, *a*) to a standard normal posture (figure 4, *b*) and a hunchbacked posture (figure 4, *c*). Although there are gaps between the movement modules of the panel, these gaps are covered when wearing the designed elastic fabric skin (39% spandex), and a smoother transition between the modules can be achieved, even at maximum movement, and the gap areas between the modules remain smooth. In addition, these gaps are in the area of the scapula to the underarm line and the lower bust loop, which are not critical areas of the garment and therefore have little impact on their use in the garment-making process.

VALIDATION OF VALIDITY BY 3D SCANNING

We have examined the effectiveness of the use of PAM posture changes by using 3D scanning technology and actual garment making.

Two men, possessing body shapes akin to a standard mannequin, were separately recruited for 3D scanning. One exhibited a habitual chest-up posture, while the other displayed a hunchbacked posture. The aim was to acquire 3D scans and contour curves of pivotal cross-sections. The resulting contour curves were compared to the scanned contour lines of the PAM under standard, chest-up posture, and hunchbacked posture respectively.

Figure 5 illustrates the comparison of the body curves of the man with a chest-up posture and three critical cross-sectional contour curves of the PAM in the standard posture and the chest-up posture. In this figure, the curve of the chest-up man's body is depicted as a black solid line, the standard posture of PAM is represented by a red dotted line, and the chest-up posture of PAM is indicated by a blue dashed line. As observed in the comparison of shoulder cross-sectional profile curves in figure 5, *a*, the PAM successfully diminishes the 8 mm depression near the anterior middle of the normal posture to 2 mm. Furthermore, it diminishes the 25 mm convexity in the posterior middle to 12 mm, consequently reducing the convexity at both scapulae from 12 mm to below 4 mm. In the comparison of the chest convex section shown in figure 5, *b*, the PAM reduces the depression of the two

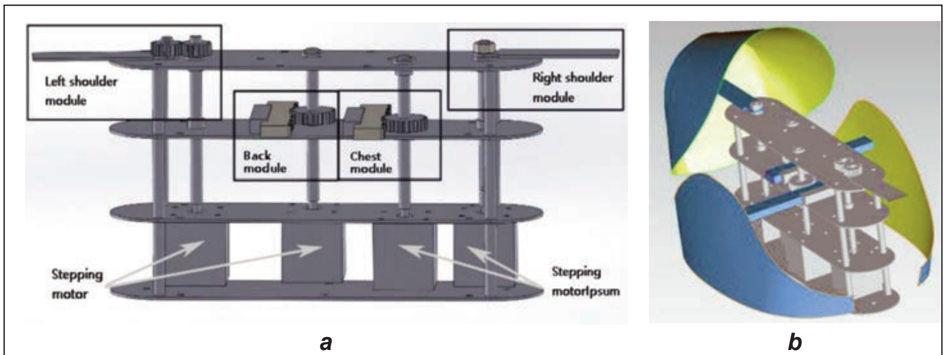

Fig. 3. Diagram of mechanical structure and installation: *a* – mechanical structure; *b* – installation diagram

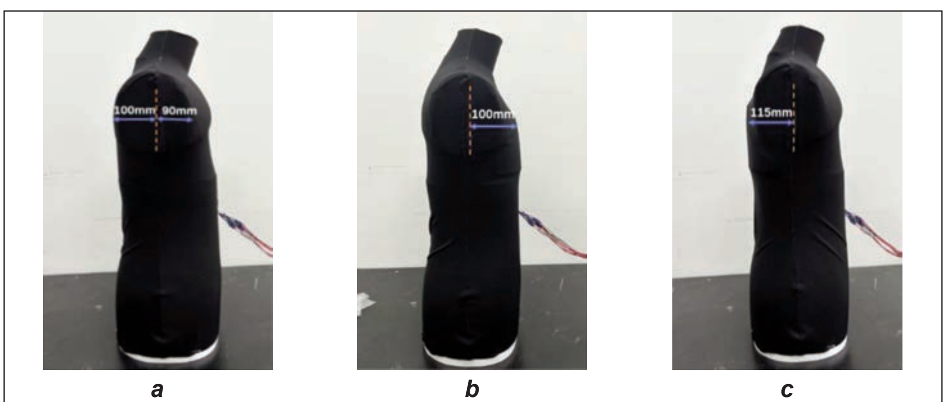

Fig. 4. The posture-adjustable mannequin: *a* – distance between the front and back of the chest in the standard state; *b* – chest protrusion/chest up posture state; *c* – back protrusion in hunchbacked state

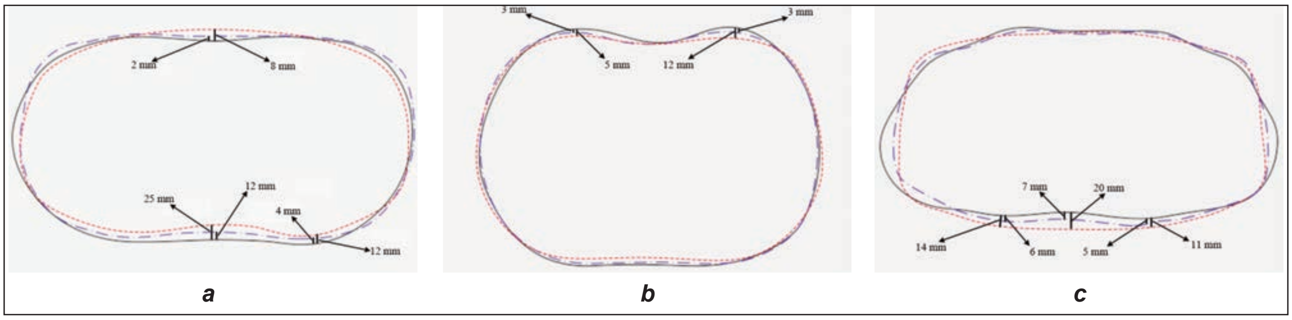

Fig. 5. Comparison of contour curves for three critical sections between PAM and the man in chest-up posture (black solid line – the curve of the chest-up of the human body; red dotted line – the curve of the standard posture of PAM; blue dashed line – the curve of the chest-up posture of PAM): *a* – shoulder cross-section; *b* – chest convex cross-section; *c* – back convex cross-section

chest convex points measuring 12 mm and 5 mm to below 4 mm. In the cross-sectional view of the back convexity illustrated in figure 5, *c*, the PAM decreases the 20 mm convexity at the rear centre that is present in the normal posture to 7 mm. Similarly, the convexity at each back convexity point is reduced from 14 mm and 11 mm to 6 mm and 5 mm, respectively.

Figure 6 illustrates a comparison of crucial cross-sectional profile curves between the hunchbacked man and the PAM. The shoulder cross-section contours presented in figure 6, reveal that the standard posture of the PAM (depicted by the red dashed line) and the contour of the human body (indicated by the black solid line) both exhibit a convexity of 12 mm in the front-middle region and an 8 mm convexity in the back-middle region. Through adjustments to the PAM's body posture, the convexities in the front-middle and back-middle areas (illustrated by the blue dashed line) can be eliminated. Figure 6, *b* displays the cross-sectional profile of the chest. In the standard PAM posture, two chest convexities are observable, but these can be eradicated by altering the PAM's body shape. Moreover, the concavity in the posterior middle area can be diminished from 16 mm to 8 mm. In the back cross-sectional profile depicted in figure 6, *c*, the PAM successfully removes the 22 mm convexity in the mid-front area, along with the 6 mm concavity present at the two back convexities in the standard PAM posture.

By utilizing scans and conducting comparative analyses of actual male bodies, it can be deduced that the PAM can effectively emulate and accommodate diverse body forms. During the chest-up posture, the PAM can minimize the chest's concavity, the inward curvature of the back, and the rearward shoulder angle, thus approximating the standard body posture. When in the hunchbacked posture, the PAM can mitigate the shoulders' and chest's convexity while eliminating the back's concave curvature, thus achieving the attainment of a more harmonized posture. These results demonstrate the adaptability and effectiveness of the PAM in simulating and adjusting to realistic body postures.

GARMENT-MAKING AND TESTING

A comparison was conducted between a hunchbacked body posture and a standard body posture (standard mannequin) on the PAM through the draping method. Shirt garment patterns, incorporating an ease allowance of 8 cm, were designed, and garments were created for both the hunchbacked and normal body postures. Figure 7 illustrates a comparison between garment patterns for the two body postures. The dashed line corresponds to the normal body posture, while the solid line represents the hunchbacked body posture. The chest line serves as the horizontal reference, aligning the front piece with the front centre, the back piece with the back centre, and the sleeve pieces with the cuff line. The disparities are evident in the diagrams: in figure 7, *a*, notable expansion can be observed in the width of the hunchbacked posterior piece, the armhole line, and the yoke line. The posterior collar line and shoulder line

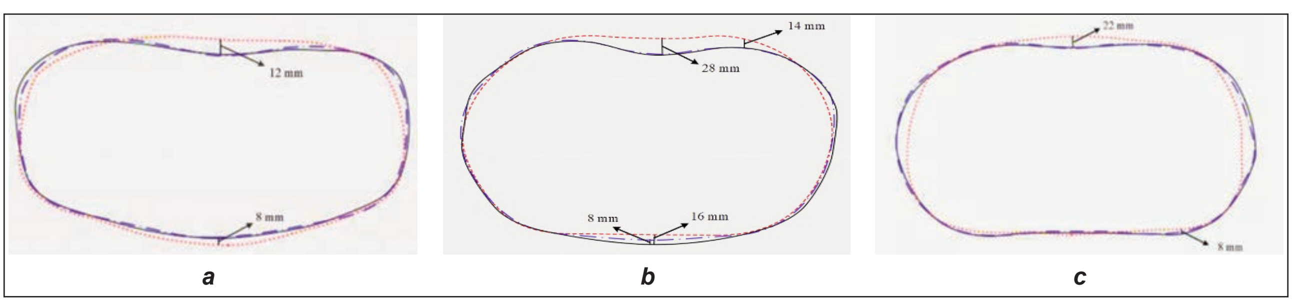

Fig. 6. Comparison of contour curves for three critical sections between PAM and the man in hunchbacked posture (black solid line – the curve of the hunchbacked posture of the human body; red dashed line – the curve of the standard posture of PAM; blue dashed line – the curve of the hunchbacked posture of PAM): *a* – shoulder cross-section; *b* – chest convex cross-section; *c* – back convex cross-section

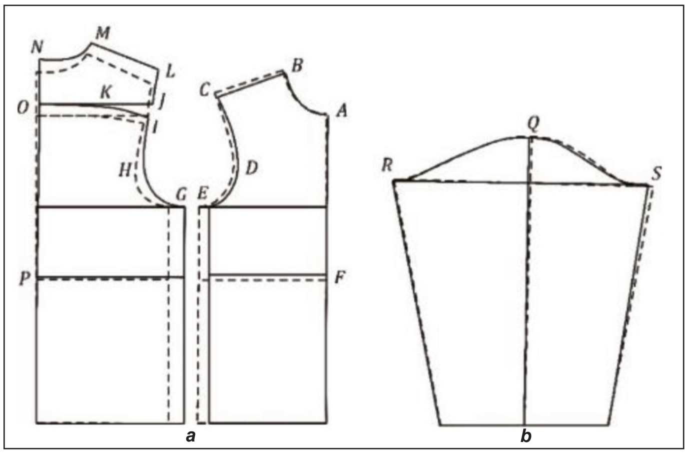

Fig. 7. Shirt paper pattern comparison (dashed line for normal posture, solid line for hunchback posture): *a* – front and back pieces; *b* – sleeve pieces

of the yoke piece have also expanded, along with an increased width in the yoke area where the yoke and posterior piece intersect. In contrast, the width of the front piece, the armhole line, and the shoulder line have proportionately narrowed. From the comparison of sleeve pieces in figure 7, *b*, it can be observed that there is little change in the sleeve pieces between the hunchbacked posture and the normal posture, and the hunchbacked pattern only has a slight retraction in the front and back sleeve width. Overall, when transitioning from a normal to a hunchbacked posture, the garment patterns widen and lengthen across the back piece's width and length, while the front piece experiences narrowing and shortening. These modifications align with the corrective adjustments proposed by Zhang et al. [13] for garment paper patterns

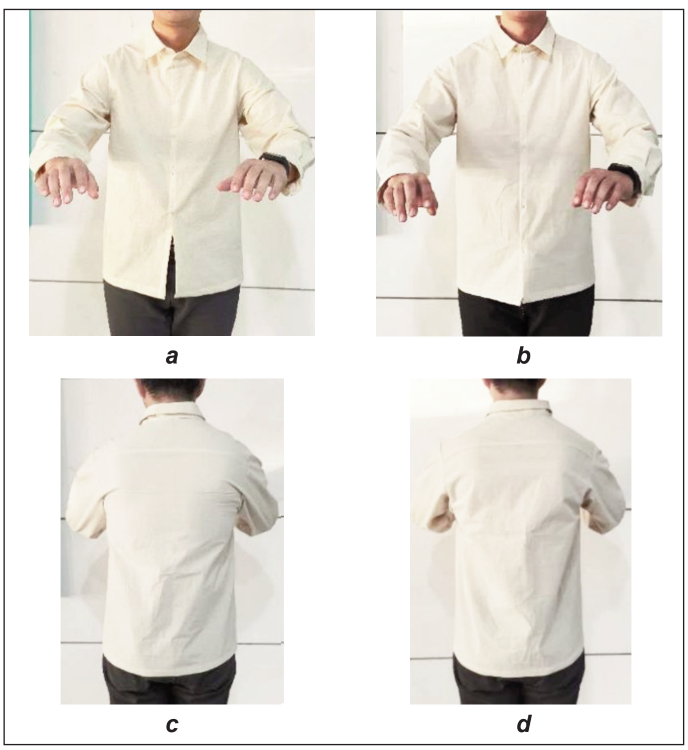

Fig. 8. Comparison of the shirt's appearance when worn: *a* – effect of the standard shirt, front view; *b* – effect of the hunchbacked shirt, front view; *c* – effect of the standard shirt, back view; *d* – effect of the hunchbacked shirt, back view

tailored to unique body types. The amount of change determined through the use of PAM is more precise.

To visually show the effect of the PAM, the body size of the mannequin was adjusted to simulate the body posture of a slightly hunchbacked person.

Subsequently, a shirt representing a slightly hunchbacked posture and another in a standard body posture was crafted. From the front perspective, the standard shirt depicted in figure 8, *a* exhibits an excess of fabric on the front chest, marked by a diagonal crease extending from the shoulder to the centre front. Numerous folds gather at the front shoulder, and a substantial diagonal wrinkle emerges at the armhole, consequently leading to inadequate closure of the placket at the bottom hem. In comparison when donning the shirt tailored to a hunchbacked posture (figure 8, *b*), there is less fabric build-up on the front chest, fewer shoulder creases, and diagonal stripes at the armholes, and the centre front placket closes well.

From the rear perspective, the standard shirt's rear fabric appears taut, and a conspicuous diagonal stripe is visible at the shoulder sleeves. This observation suggests that the shirt, in this condition, exerts pressure on the hunchbacked body's back, significantly compromising both comfort and aesthetics (see figure 8, *c*).

Conversely, when donning the hunchbacked shirt (figure 8, *d*), the fabric's tightness on the body's rear is markedly ameliorated, and the raglan design on the shoulder sleeves is eradicated. This alteration provides ample room for back movement and enhances the garment's aesthetic appeal.

Consequently, individuals with a habitual hunchbacked posture may encounter discomfort while wearing a standard shirt during everyday activities (such as the previously mentioned office tasks). However, by leveraging the PAM to design a garment tailored to their posture, this inconvenience can be substantially alleviated, thereby enhancing both the garment's fit and aesthetic appeal. Individuals with a habitual chest-up posture face a comparable issue, which can be similarly addressed through targeted application of the PAM.

Combining the above results, this article divides the standard-size human platform into 6 parts and uses mechanical structures to design motion control for 4 of them. It can simulate the most common posture changes of the human body, such as chest-up and hunchbacked postures. The crafted posture-adjustable mannequin can achieve posture alterations without necessitating changes in mannequin dimensions. This design has the advantages of high accuracy of size, accurate body simulation, easy to make and control and low cost, and the benefit of easy support for the transformation of clothing customization of small and medium-sized enterprises.

CONCLUSION

Mannequins play a pivotal role in garment design and production. This paper divides the standard mannequin into six modules: neck, front chest, back, left and right shoulders, and waist and abdomen. By using stepper motors to drive the four modules of the front chest, back, and left and right shoulders respectively, a mannequin is created that can continuously change its posture from chest-up to hunchbacked. The extent of motion for each module was established through the measurement of posture alteration data from 17 men. A comparison of the 3D scans shows that the PAM fits well with the corresponding posture of the real man in several cross-sections. Simultaneously, a comparison of the draping cut-out patterns revealed that for the humpbacked body, the patterns produced a change in the width and height of the back piece and a narrowing and shortening of the front piece. Furthermore, by comparing the wearing of real clothes on hunchbacked individuals, the results also show that the PAM can produce better-fitting shirts, significantly improving the inconvenience of standard clothing when performing certain common movements. From a commercial standpoint, the PAM, enabling continuous postural adjustments encompassing chest-up and hunchbacked poses, can substitute multiple static mannequins while bolstering the personalized clothing business model.

The research in this paper has room for improvement due to objective constraints. During the process of chest and back posture changes, the neck lumbar and abdominal regions also change to maintain the center of gravity balance. This paper focuses on the changes in the shoulders, chest and back, and will further investigate the changes in the neck, waist and abdomen of the hunchback and chest posture in the future. By increasing the corresponding mechanical structures of the neck, waist and abdomen as well as the number of movable panels, the simulation effect of the body-adjustable mannequin will be improved.

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Navigating the complexity of sustainable transition in the textile and apparel industry: a comprehensive analysis across disciplines, geographies and stakeholders

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ABSTRACT – REZUMAT

Navigating the complexity of sustainable transition in the textile and apparel industry: a comprehensive analysis across disciplines, geographies and stakeholders

This research study provides an exhaustive bibliometric analysis of the sustainability transitions within the textile and apparel sector. Utilizing the advanced tools of Biblioshiny and VOSviewer, the study maps out the intellectual structure of this field, elucidating co-citation, co-word, and collaboration networks. The prominence of keywords such as "sustainable development", "sustainability", and "textile industry" emphasizes the sector's growing focus on sustainable practices. Furthermore, an assessment of gender and ethical dimensions in research revealed a potential gap in inclusivity, prompting a call for more equitable research representation. Geographically, the prominence of contributions from regions like China and India suggests the need for region-tailored sustainable strategies. Simultaneously, the fusion of technological innovations with sustainability highlighted the interdisciplinary nature of current research. Real-world impacts of this academic discourse were examined, spotlighting the translation of theory into tangible industry practices. Despite the significant insights, the study recognizes its limitations, including potential geographical and publication biases. For policymakers, stakeholders, and academics, this study offers invaluable insights into the current landscape of sustainability research in the textile and apparel industry, suggesting areas of focus and potential opportunities for future exploration.

Keywords: *sustainability transitions, textile and apparel sector, bibliometric analysis, interdisciplinary research, sustainable practices*

Navigarea prin complexitatea tranziției sustenabile în industria textilă și de îmbrăcăminte: o analiză exhaustivă între discipline, zone geografice și actori implicați

Acest studiu de cercetare oferă o analiză bibliometrică exhaustivă a tranzițiilor sustenabile în sectorul textil și de îmbrăcăminte. Folosind instrumentele avansate precum Biblioshiny și VOSviewer, studiul evidențiază structura intelectuală a acestui domeniu, elucidând rețelele de co-citare, co-word și colaborare. Proeminența cuvintelor cheie precum „dezvoltare durabilă”, „sustenabilitate” și „industrie textilă” subliniază accentul tot mai mare al sectorului pe practicile sustenabile. Mai mult, o evaluare a dimensiunilor etice și de gen în cercetare a relevat un potențial decalaj în ceea ce privește incluziunea, determinând un apel pentru o reprezentare mai echitabilă a cercetării. Din punct de vedere geografic, importanța contribuțiilor din regiuni precum China și India sugerează necesitatea unor strategii sustenabile adaptate regiunii. Simultan, fuziunea inovațiilor tehnologice cu sustenabilitatea a evidențiat caracterul interdisciplinar al cercetării actuale. Au fost examinate efectele reale ale acestui discurs academic, punând în evidență traducerea teoriei în practici tangibile din industrie. În ciuda perspectivelor semnificative, studiul își recunoaște limitările, inclusiv potențialele segmentări geografice și de publicare. Pentru factorii de decizie, actorii implicați și cadrele academice, acest studiu de cercetare furnizează perspective de neprețuit asupra peisajului actual al cercetării în domeniul sustenabilității în industria textilă și de îmbrăcăminte, sugerând domenii de interes și potențiale oportunități de explorare viitoare.

Cuvinte cheie: *tranziții sustenabile, sector textil și de îmbrăcăminte, analiză bibliometrică, cercetare interdisciplinară, practici sustenabile*

INTRODUCTION

The textile and apparel industry, with its intricate supply chains, vast consumer base, and economic significance, is undeniably one of the keystones of global commerce. From the raw materials extracted and synthesized for fabric production to the intricate designs that cater to multifaceted fashion demands, this industry touches nearly every corner of human society. However, along with its economic and cultural imprint, the textile and apparel sector also holds a more dubious distinction: it ranks among the world's most polluting and resource-intensive industries. As a mid-rising environmental and social concern, sustainability has become an inescapable imperative. The term "sustainability" is not merely a catchphrase but encapsulates a comprehensive approach that seeks to harmonize environmental, social, and economic dimensions. In the context of textiles and apparel, this means not only the adoption of eco-friendly materials and practices but also ensuring fair labour conditions, ethical business practices, and long-term economic viability. However, the sustainability journey is not without its complexities. It requires a collective effort that transcends disciplines, borders, and sectors. This research seeks to chart the intricate pathways of sustainable transition in the textile and apparel industry, exploring its myriad facets through a comprehensive lens. In doing so, the study underscores the significance of a unified approach that intertwines disciplines, geographies, and stakeholders.

Historically, the textile and apparel industry has been both celebrated and criticized. On one hand, it has been an essential source of livelihood for millions and a canvas for cultural expression. On the other, it has faced criticism for unsustainable practices, ranging from excessive water use in cotton farming to the detrimental effects of fast fashion cycles leading to monumental waste. The rise of consumer awareness, coupled with mounting evidence of environmental degradation and climate change, has brought the industry's sustainability challenges to the forefront. As globalization took root, the geographical complexity of the textile and apparel industry expanded. Production hubs emerged in regions that balanced cost-effectiveness with skill availability. Yet, with this geographical spread came a disparity in sustainability practices and standards. Some regions, driven by stringent regulations and informed consumer bases, made significant strides in sustainable practices. In contrast, others lagged, often due to economic pressures or a lack of awareness and infrastructure.

Navigating the sustainable transition in the textile and apparel industry requires understanding its inherent multidimensionality. Technological advancements, especially from related fields like biotechnology and material science, have presented opportunities for more sustainable fabrics and production processes. Innovations such as bio-fabrics, waterless dyeing techniques, and closed-loop recycling have not just emerged from dedicated textile research but also from interdisciplinary efforts. Furthermore, the ethical dimension of sustainability has gained prominence. Fairtrade, ethical sourcing and labour rights are now integral to sustainability discussions. Yet, there's also an imperative to understand the nuanced challenges across geographies, from the sweatshops of some regions to the advanced, automated factories in others. Moreover, the role of gender cannot be underestimated. Historically, the textile and apparel industry has been a significant employer of women, often in roles and regions where female labour is undervalued and sometimes exploited. As the industry navigates its sustainability journey, it's essential to ensure it's also a journey toward gender equity and inclusivity.

No transition to sustainability can occur in a vacuum. It demands the collective effort of a plethora of stakeholders. Academic institutions drive research and innovation, businesses adapt and implement these innovations, governments create the regulatory landscape, and consumers, with their choices, drive demand for sustainable products. Each stakeholder plays a distinct and critical role. However, it's also crucial to recognize that some voices and contributors often remain underrepresented or unheard. These could be from lesser-known academic institutions, emerging economies grappling with their unique sustainability challenges, or interdisciplinary researchers whose work doesn't fit neatly into traditional categorizations.

Given the aforementioned complexities, this study aims to provide a comprehensive analysis of the sustainable transition in the textile and apparel industry. By examining the confluence of disciplines, geographies, and stakeholders, this study aspires to map the current landscape, identify gaps, and highlight opportunities for more cohesive and effective sustainable transitions. In charting this course, the research underscores the interwoven tapestry of challenges and solutions, emphasizing the need for a collaborative, holistic approach to truly realize sustainability in the textile and apparel sector.

Research questions

The study sets out to the following research questions:

RQ1: What are the dominant theories and conceptual frameworks underpinning sustainability transitions in the textile and apparel industry?

RQ2: How have gender and ethical considerations been incorporated into the research and practices of sustainable textiles and apparel?

RQ3: Which regions and institutions have been the primary contributors to sustainability research in this industry, and how do their contributions differ?

RQ4: How are technological advancements in related disciplines influencing the sustainability transition in textiles and apparel?

RQ5: What are the real-world impacts of research contributions in the textile and apparel industry in terms of environmental, economic, and social outcomes?

RQ6: How does the textile and apparel industry's sustainability research adapt to global events, such as economic downturns, pandemics, or significant policy shifts?

RQ7: Who are the underrepresented voices in sustainability research for textiles and apparel, and what unique perspectives or solutions do they offer?

RQ8: To what extent are academic insights on sustainability in the textile and apparel industry being translated into practical implementations?

Objectives

The study sets out to achieve the following objectives:

- To map out the intellectual structure of sustainability transitions in the textile and apparel sector using co-citation and co-word analysis.
- To analyse the gender and ethical dimensions of sustainability research in the textile and apparel industry, assessing representation and focus areas.
- To evaluate the geographical and institutional distribution of research contributions and identify dominant trends and potential research gaps by region.
- To examine the influence of technological and interdisciplinary innovations on the sustainable practices and research of the textile and apparel industry.
- To quantify the real-world impacts of sustainability research in the textile and apparel sector, focusing on case studies, policy changes, and environmental metrics.
- To investigate the adaptive nature of sustainability research in textiles and apparel, especially in response to significant global events and challenges.
- To spotlight and evaluate contributions from lesser-known institutions, developing regions, and cross-disciplinary researchers in the textile and apparel sustainability domain.
- To assess the translation of academic insights into tangible industry practices, focusing on implementation success stories, barriers, and scalability challenges.

REVIEW OF LITERATURE

The textile and apparel industry has long been recognized for its substantial economic and socio-cultural contributions. However, in recent decades, the industry's environmental footprint and the intricate dynamics governing its sustainability transition have garnered significant attention. The literature on sustainable transition in this industry is vast, traversing multiple disciplines, geographies, and stakeholders.

A fundamental starting point for discussions about sustainability in the textile and apparel industry centres around its environmental impact. The textile industry alone accounts for nearly 10% of global carbon emissions and remains a significant contributor to water pollution, especially in cotton-producing regions [1]. Similarly, it is elucidated that the rapid cycles of fashion production and consumption, known colloquially as "fast fashion", have exacerbated waste and resource depletion [2]. Chemical pollutants are another concern. As highlighted [3], dyes, and chemical treatments, essential for textile production, often lead to harmful discharges, impacting aquatic ecosystems. However, environmental challenges are not solely limited to production. It is emphasized that post-consumer waste, reveals that an alarming proportion of garments end up in landfills without recycling [4]. Another study utilized a Window DEA Approach to analyse the efficiency of Indian Oil and Gas Companies, which informs the study's analytical approach [5]. The significance of sentiment analysis provides insights into consumer behaviour in e-commerce sectors like Flip Kart and Amazon [6]. Transitioning to sustainable practices demands technological evolution. Innovations such as bio-fabrics and alternative fibres suggest that these materials could substantially reduce the environmental footprint of textile production [7]. Additionally, waterless dyeing techniques noted their potential to curb water pollution significantly [8].

However, technology's role isn't merely about new materials. They underscore the importance of integrating information technology, particularly in streamlining supply chains to minimize waste and enhance resource efficiency. Such integrations, as per the authors, can create transparency, enabling consumers to make informed, sustainable choices. Beyond environmental aspects, the textile and apparel industry faces ethical challenges. It offers an empirical study on stock market volatility, with a case study focusing on the BSE Ltd. of India [9]. The linkage between behavioural finance and investment decisions among Indian Gen Z investors is also evaluated [10]. The cryptocurrency market's volatility and its relationship with the energy market were detailed, which has parallels with volatility patterns in the textile industry [11]. Further insights into the dynamics of financial technology and environmental sustainability [12] and the challenges of blockchain technology in the financial sector are discussed [13]. The labour-intensive nature of the industry, especially in garment production, has led to concerns about workers' rights, wages, and working conditions. As noted, some production hubs, especially in developing nations, have been marred by incidents of labour exploitation [14]. Fairtrade also enters the sustainability discourse. The fair-trade practices in the textile and apparel sector can not only ensure just compensation but can also foster sustainable production practices by creating incentives. The interconnectedness of ethical and environmental sustainability underscores the industry's multidimensionality.

The gendered nature of the textile and apparel industry, especially in production roles, has been a notable point of discussion. Women, who constitute a significant portion of the workforce, particularly in countries like Bangladesh and Cambodia, face challenges ranging from low wages to workplace safety issues [15]. Addressing these gender-specific challenges is not just a matter of equity but also crucial for the industry's holistic sustainable transition. The global nature of the textile and apparel industry leads to significant geographical disparities in sustainability practices and challenges. While regions like Europe have seen stringent regulations promoting sustainability, other regions grapple with different socio-economic dynamics. It is noted that while Scandinavian countries have seen substantial advancements in sustainable textile production, other areas face challenges of infrastructure, awareness, and economic constraints. Stakeholders, as pointed out, play pivotal roles in navigating these disparities [16]. While governments can enforce regulations and incentivize sustainable practices, businesses have the onus of implementation. Moreover, academic institutions, as champions of research and innovation, are the bedrock on which many sustainability transitions are built. One cannot overlook the pivotal role consumers play in propelling sustainability in the textile and apparel industry. The modern consumer is increasingly informed, discerning, and values-driven [17]. This shift has placed pressure on brands to prioritize sustainability, not merely as a marketing tool but as an intrinsic part of their business ethos. An empirical study underscores the impact of the COVID-19 pandemic on volatility patterns in the textile industry, focusing on the Shanghai Stock Exchange of China [18]. Another study was conducted to check the assessment of energy efficiency based on CO2 emissions, which offers perspectives on sustainable practices [19]. The illicit practices' repercussions on banking stability were explored [20]. Moreover, the circular economy in fashion has emerged as a transformative model to counteract the industry's waste issues. Circular fashion refers to designing, producing, using, and recycling clothes with longevity, efficiency, and sustainability in mind [21]. This circular approach not only addresses waste concerns but also promotes a more conscientious consumer culture. The rapidly evolving landscape of the textile and apparel sector is notably influenced by technological advancements and financial inclusions. Recent literature emphasizes the integration of digital financial services within the FinTech sector as pivotal in driving economic development and financial inclusion within industries like textiles and apparel [22]. Such digital interventions not only bridge the financial divide but can potentially revolutionize the supply chains, consumer engagement, and business models in the textile sector. Moreover, the emergence and influence of artificial intelligence, exemplified by platforms like ChatGPT, are starting to find relevance in this sector as well. A comprehensive exploration of the potential of AI underscores its transformative capability, which, when applied to the textile and apparel industry, could herald unprecedented operational efficiencies and market dynamics [23].

The fashion and textile industries have faced extensive criticism for their substantial environmental impact, including high carbon emissions, significant waste generation, and extensive resource use [24]. Processes such as manufacturing and dyeing in these sectors contribute to the pollution of air, water, and soil [25]. The industry's approach to sustainability, encompassing environmental, social, and economic aspects, is notably deficient. Fashion products, often trend-driven, have a brief life cycle, encouraging consumers to frequently update their wardrobes, leading to excessive production and waste accumulation [26]. The demand for constant new offerings places immense pressure on retailers in the textile and apparel sectors, often resulting in compromised labour standards and cost-cutting measures [27, 28]. Research indicates that in 2014, the global textile industry produced approximately 92 million tons of waste, with only a small fraction being recycled, and the remainder ending up in landfills or incinerated [29]. Projections show a 60% annual increase in textile waste from 2015 to 2030, exacerbating the waste management challenge [30]. In response to these concerns, the United Nations launched the Sustainable Development Goals (SDGs) in 2015, comprising 17 objectives aimed at global sustainability [31]. Apparel companies have since been striving towards these goals, focusing on sustainable manufacturing and consumption, reducing water usage, and improving working conditions [32]. Despite these efforts, the focus on water and energy conservation overshadows the critical issue of managing textile waste [33, 34].

Various studies have explored sustainability in the textile industry from different angles. One study highlighted that increasing resource efficiency can foster sustainable textile production [35]. Another set of research advocated for a product-as-a-service or rental model in the textile sector to reduce environmental impact and enhance user value [36]. Many firms are now opting for biodegradable and recycled materials to minimize their carbon footprint [37]. Additionally, the involvement of external stakeholders is crucial for ensuring a circular economy in the industry [38]. Recently, there has been a shift in consumer behaviour, with a growing segment becoming more environmentally conscious and altering their shopping habits to reduce waste [39].

Given the multifaceted challenges the textile and apparel industry faces, interdisciplinary approaches are gaining momentum. By merging insights from material science, technology, social sciences, and even the humanities, more holistic solutions can emerge. As posited, interdisciplinary research can offer nuanced insights into consumer behaviour, production techniques, and policy-making, ensuring that sustainability efforts are both effective and inclusive [40]. To reiterate, the sustainable transition in the textile and apparel industry is not linear. It's a confluence of environmental, ethical, sociocultural, and technological dynamics, shaped by a myriad of stakeholders across various geographies. The literature provides a rich tapestry of insights, highlighting both progress made and challenges ahead.

METHODOLOGICAL FRAMEWORK

The foundation of this investigation is built upon a sophisticated methodological structure that integrates both Biblioshiny and VOSviewer tools for a rigorous bibliometric analysis. This combination facilitates a deep dive into the academic narrative and research progression on sustainable transitions within the textile and apparel industry. For data collection, the Scopus database has been identified as the primary research tool.

Choice of database and retrieval of data

For this endeavour, the Scopus database, renowned as the most extensive abstract and citation archive of reviewed scholarly literature, has been utilized. The preference for Scopus is grounded in its unparalleled global reach, interdisciplinary range, and the depth of bibliographic details it offers. The temporal scope of this research encompasses a period from 2000 to 2023, bringing under its purview a compilation of 1913 documents disseminated through 522 distinct sources.

Constructing the search query

The following search string has been meticulously crafted to encapsulate the myriad dimensions of sustainable transitions in the textile and apparel domain: ("sustainable transition" OR "sustainable transformation" OR "sustainable change" OR "eco-friendly transition" OR "sustainable development") AND ("textile industry" OR "apparel industry" OR "fashion industry" OR "garment industry") AND ("sustainable practices" OR "sustainable technologies" OR "waste management" OR "carbon emissions" OR "ethical considerations" OR "lifecycle analysis" OR "material science" OR "consumer behaviour" OR "gender dynamics" OR "geographical analysis" OR "corporate involvement" OR "policy impact" OR "funding" OR "ethical concerns" OR "interdisciplinary research").

Analysis through Biblioshiny

Biblioshiny, an intuitive interface within R's bibliometrix package, has been employed for extensive bibliometric scrutiny. This tool offers a wealth of insights about the dataset, delineating metrics such as the literature's annual progression rate, the median age of documents, and the mean citation count per publication. For this research, Biblioshiny was instrumental in pinpointing pivotal publications, notable authors, influential institutions, and leading nations based on metrics like document counts, citation frequencies, and cumulative link strength. Additionally, it unravelled patterns of collaboration amongst authors and illuminated the diverse array of publication types populating the research canvas.

Exploration through VOSviewer

After the insights derived from Biblioshiny, VOSviewer steps into the analytical process, offering enriched bibliometric visual depictions and network explorations. This tool is adept at crafting and manifesting bibliometric networks, encompassing facets like collaborative authorship, thematic co-occurrence, and the web of citations. For this investigation, VOSviewer played a pivotal role in unveiling predominant keywords, charting clusters of interrelated terms, and plotting the intricate co-authorship matrix, thereby illuminating emergent research trajectories and synergistic authorial groupings.

By leveraging this comprehensive methodological paradigm, the investigation is poised to deliver a cohesive, multifaceted, and visually engaging panoramic view of the research ecosystem, mirroring the expansive and nuanced dialogue on sustainable transitions in the textile and apparel sector.

DATA ANALYSIS THROUGH BIBLIOSHINY

An In-depth glimpse into the literature of the textile and apparel industry

The bibliometric analysis, summarized in table 1, of the textile and apparel industry literature from 2000 to 2023 revealed 1,913 documents sourced from 522 distinct publications. These documents experienced an annual growth rate of 26.91%. The average age of documents stood at 2.42 years, and they garnered an average of 23.25 citations each. A vast repository of keywords was identified, with 9,569 from "Keywords Plus" and 5,557 author-specified. Of the 5,830 contributing authors, 108 penned single-authored papers. Each paper, on average, represents nearly four authors, with 35.23% showcasing international collaborations. Notably, all the analysed documents were articles.

Table 1

DATA DESCRIPTION	
Description	**Results**
Main information about the data	
Timespan	2000:2023
Sources (Journals, Books, etc)	522
Documents	1913
Annual Growth Rate %	26.91
Document Average Age	2.42
Average citations per doc	23.25
References	143848
Document contents	
Keywords Plus (ID)	9569
Author's Keywords (DE)	5557
Authors	
Authors	5830
Authors of single-authored docs	108
Authors collaboration	
Single-authored docs	110
Co-Authors per Doc	3.92
International co-authorships %	35.23
Document types	
Article	1913

Yearly Citation Impact of the analysed literature

Table 2 reflects the citation impact of articles on the textile and apparel industry from the year 2000 to 2023. The year 2000, with two articles, observed an average of 22 citations per article, translating to an annual mean citation rate of 0.92 over 24 years. Similar citation averages persisted in 2001. A notable spike in citations was observed in 2002 with a singular article obtaining 119 citations, leading to an average of 5.41 citations annually over 22 years. Interestingly, 2003 was devoid of any articles, yet a prior article from 2002 continued its citation momentum. By 2018, the article counts surged to 94, with each article accruing a yearly average of 10.16 citations

Table 2

YEARLY CITATION IMPACT				
Year	**N**	**MeanTCperArt**	**MeanTCperYear**	**CitableYears**
2000	2	22	0.92	24
2001	2	22	0.92	24
2002	1	119	5.41	22
2002	0	119	5.41	22
2004	2	134.5	6.72	20
2005	2	51	2.68	19
2006	5	52.4	2.91	18
2007	3	83	4.88	17
2008	3	12	0.75	16
2009	6	76	5.07	15
2010	4	14.25	1.02	14
2011	5	99.8	7.68	13
2012	10	89.1	7.42	12
2013	19	82.74	7.52	11
2014	33	67	6.7	10
2015	34	78.82	8.76	9
2016	37	71	8.88	8
2017	61	47.31	6.76	7
2018	94	60.95	10.16	6
2019	107	35.2	7.04	5
2020	209	36.42	9.11	4
2021	309	22.09	7.36	3
2022	487	9.4	4.7	2
2023	480	2.09	2.09	1

Note: MeanTCperArt represents the average total citations per article; N represents the number of articles published that year; MeanTCperYear indicates the average number of citations per year for the articles published that year; CitableYears measures the number of years an article has been available to be cited.

over six years. The peak in the number of articles was reached in 2022 with 487 articles, albeit with a lower average citation count of 4.7 per year for two years. By 2023, 480 articles had been produced, currently averaging 2.09 citations in their first year.

Annual literature output across dominant publications

Table 3 provides insights into the yearly literature production related to the textile and apparel industry from key journals between the years 2000 to 2023 (figure 1). For the initial six years (2000–2005), there was no publication from the enlisted sources. It wasn't until 2006 that "Journal of Cleaner Production" began contributing with two articles. This source consistently maintained its output with a steady increase over the years, peaking at 262 articles in 2023. "Sustainability (Switzerland)" started its contributions in 2013 with one article, but witnessed substantial growth over the years, reaching its zenith in 2023 with 281 articles. "Environmental Science and Pollution Research" initiated its contributions in 2009, slowly building its repository and reaching 61 articles in 2023. "Business Strategy and the Environment" began its contributions slightly later, in 2017, but swiftly expanded its output, reaching 60 articles by 2023. "Sustainable Production and Consumption", though starting its contributions in 2017, remained relatively conservative in its outputs until a noticeable uptick in 2021 and 2022, producing 35 articles in 2023. While initial years showed limited research output from these sources, a significant uptick has been observed in recent years, indicating a growing scholarly interest in the domain.

Assessment of Top 10 journals by local impact

Table 4 delineates the local impact of the top 10 sources (journals) based on various bibliometric indicators. The "Journal of Cleaner Production" stands out as the most influential journal, with an h-index of 62, reflecting its substantial impact in the field since its inception in 2006. Furthermore, it possesses a g-index of 93 and an m-index of 3.44. With a total of 10,468 citations across 262 articles, it is evident that this source has significantly contributed to the domain. Next in line, "Sustainability (Switzerland)" initiated its contributions in 2013 and has already achieved an h-index of 32, a g-index of 46, and an m-index of 2.91, accruing 3,601 citations from 281 papers. "Business Strategy and the Environment",

Table 3

YEARLY PRODUCTION OF LITERATURE ACROSS MAJOR SOURCES					
Year	**Sustainability (Switzerland)**	**Journal of Cleaner Production**	**Environmental Science and Pollution Research**	**Business Strategy and the Environment**	**Sustainable Production and Consumption**
2000	0	0	0	0	0
2001	0	0	0	0	0
2002	0	0	0	0	0
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	0	2	0	0	0
2007	0	2	0	0	0
2008	0	2	0	0	0
2009	0	2	1	0	0
2010	0	3	1	0	0
2011	0	3	1	0	0
2012	0	3	1	0	0
2013	1	5	2	0	0
2014	3	9	2	0	0
2015	5	13	2	0	0
2016	9	27	2	0	0
2017	19	38	3	2	1
2018	32	61	5	6	2
2019	53	75	8	8	2
2020	88	114	10	20	2
2021	147	158	16	27	14
2022	213	205	30	40	29
2023	281	262	61	60	35

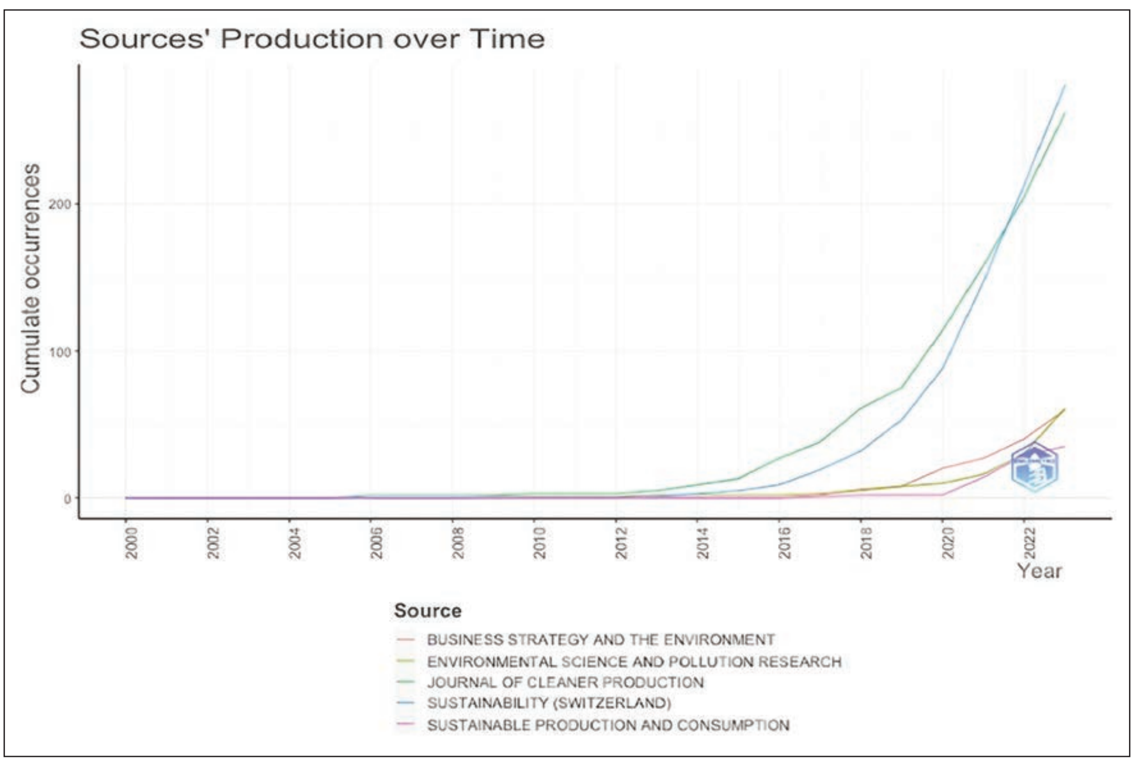

Fig. 1. Sources' production over time

Table 4

SOURCES' LOCAL IMPACT						
Element	**H_INDEX**	**G_INDEX**	**M_INDEX**	**TC**	**NP**	**PY_START**
Journal of Cleaner Production	62	93	3.44	10468	262	2006
Sustainability (Switzerland)	32	46	2.91	3601	281	2013
Business Strategy and the Environment	23	43	3.29	1938	60	2017
International Journal of Production Economics	18	29	1.80	1876	29	2014
Resources, Conservation and Recycling	17	29	0.71	1157	29	2000
Energy	16	24	1.33	1220	24	2012
Environmental Science and Pollution Research	15	26	1.00	767	61	2009
Science of the Total Environment	14	24	2.00	816	24	2017
Sustainable Production and Consumption	13	22	1.86	512	35	2017
Chemosphere	12	19	2.40	502	19	2019

which began in 2017, holds an h-index of 23, a g-index of 43, and an m-index of 3.29, collecting 1,938 citations from 60 articles. Following these are journals like "International Journal of Production Economics", "Resources, Conservation and Recycling", and "Energy", which have similarly made significant contributions. They've established themselves with high h-indices, g-indices, and substantial citation counts, even though some started their contributions relatively late, like "Science of the Total Environment" and "Sustainable Production and Consumption" in 2017.

The list concludes with "Chemosphere", which started in 2019 and has an h-index of 12, a g-index of 19, and an impressive m-index of 2.40. It has collected 502 citations from 19 articles, indicating its rising prominence in the field This analysis showcases the key journals that have made significant strides in terms of their scholarly impact within the domain of the textile and apparel industry's sustainable transition.

Yearly contributions by key authors

The provided dataset demonstrates the annual scholarly contributions and impact of prominent authors in a specific research domain (figure 2). Notably, authors Li Y., Wang Y., Kumar A., and Zhang Y. have had considerable contributions over the years, evidenced by the Total Citations (TC) and Citations per Year (TCpY). For instance, in recent years, LI Y's work in 2022 amassed significant citations, with a peak TC of 25 and a TCpY of 13. Similarly, KUMAR A had a prominent contribution in 2020 with a TC of 270 and a TCpY of 68. The list includes several other authors, each showcasing their impact and contributions over the years.

Words' frequency over time

Table 5 showcases the frequency of key terms over the years, from 2000 to 2023 (figure 3 and figure 4). Notably, the term "Sustainable development" has seen a steady increase, reaching its peak in 2023 with 1,019 mentions. "Textile industry" also gained traction over the years, reaching 488 occurrences in 2023. "Sustainability" surged dramatically in recent years, hitting 407 by 2023. Interestingly, terms like "Textiles" and "China" have also seen significant growth, especially post-2010. The terms "Recycling" and "Decision making" demonstrated notable increases, with both reaching over 200 mentions by 2023. The trends suggest a growing focus on sustainability, the textile industry, and related themes in the specified domain.

Trend topics

Figure 5 enumerates the frequency and distribution across years of various trending topics. The term "Sustainable development" dominates with 1019 mentions, having a median occurrence year of 2021. It, along with "Textile industry", "Sustainability", "Textiles", and "China", saw significant mentions post-2019, indicating a recent emphasis on these areas. "Environmental protection" and "Energy conservation" also display substantial frequencies, 91 and 46 respectively, illustrating a heightened focus on environmental concerns and conservation efforts in recent years. Terms like "Coffee" and "Eurasia" have a more sporadic appearance, with both initial and recent mentions. Other topics like "Textile processing" and "Gossypium hirsutum" have frequented discussions around the middle of the surveyed period, hinting at evolving concerns within the textile industry. The newest trending topics, appearing prominently around 2023, include "Ecosystem", "Eco-Friendly", and "Business models", signalling a potential shift or expansion of focus in discussions related to sustainable development and environmental considerations. This data conveys an evolving narrative and changing focal points within dialogues on sustainability, development, and industrial processes over time.

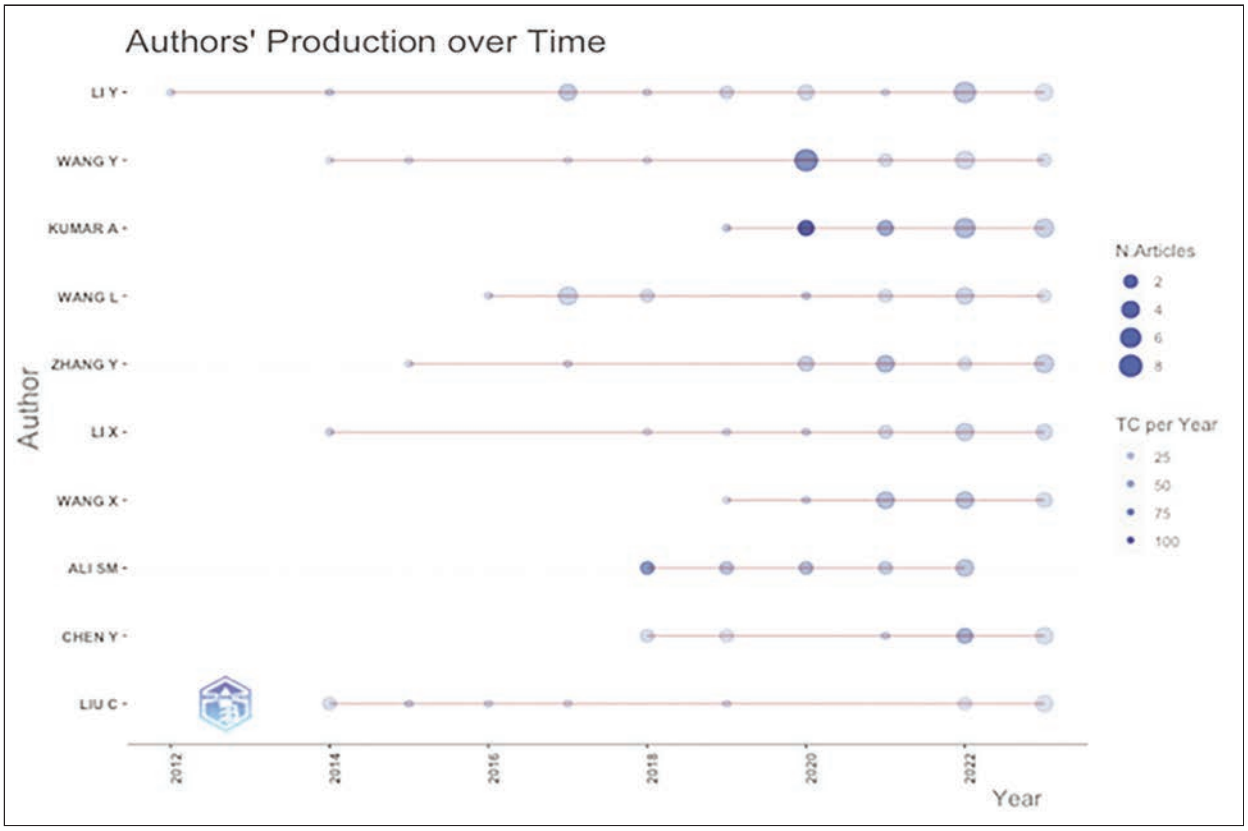

Fig. 2. Authors' production over time

Table 5

WORDS' FREQUENCY OVER TIME										
Year	Sustain-able devel-opment	Textile industry	Sustain-ability	Textiles	China	Recycling	Decision making	Waste Manage-ment	Article	Supply chain Management
2000	1	1	1	0	0	1	0	2	1	0
2001	1	1	1	0	0	1	0	2	1	0
2002	1	3	1	0	0	1	0	4	2	0
2003	1	3	1	0	0	1	0	4	2	0
2004	3	3	1	1	0	1	0	4	2	0
2005	4	4	2	2	0	4	0	5	3	0
2006	7	9	4	4	0	8	0	11	4	0
2007	8	10	4	4	0	8	0	12	4	0
2008	11	14	4	5	0	9	0	13	4	0
2009	13	18	5	6	1	9	0	14	7	0
2010	16	21	5	6	1	12	0	16	8	0
2011	19	26	5	9	3	12	2	16	9	1
2012	20	29	5	12	3	13	4	16	9	1
2013	29	33	8	14	3	16	5	18	10	3
2014	45	42	9	18	7	22	6	21	14	5
2015	68	62	12	27	11	26	10	27	21	7
2016	85	75	17	35	17	27	12	32	24	8
2017	116	90	34	42	28	35	19	41	27	22
2018	169	113	52	57	45	40	31	51	36	33
2019	228	134	82	70	67	50	41	64	50	57
2020	336	185	131	100	97	65	64	74	64	76
2021	512	249	206	144	132	105	99	100	95	107
2022	759	379	308	239	204	156	156	162	149	152
2023	1019	488	407	315	270	218	209	208	192	186

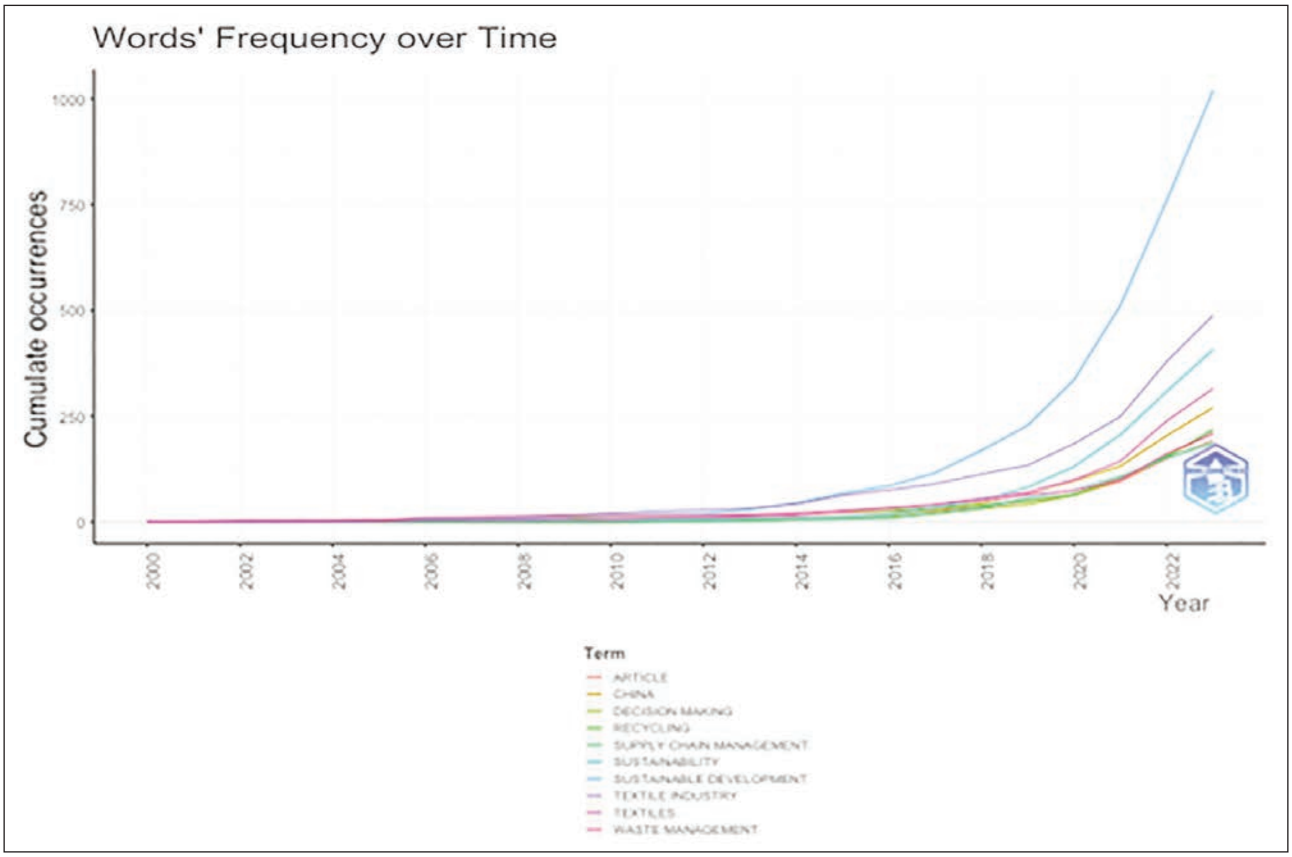

Fig. 3. Words' frequency over time

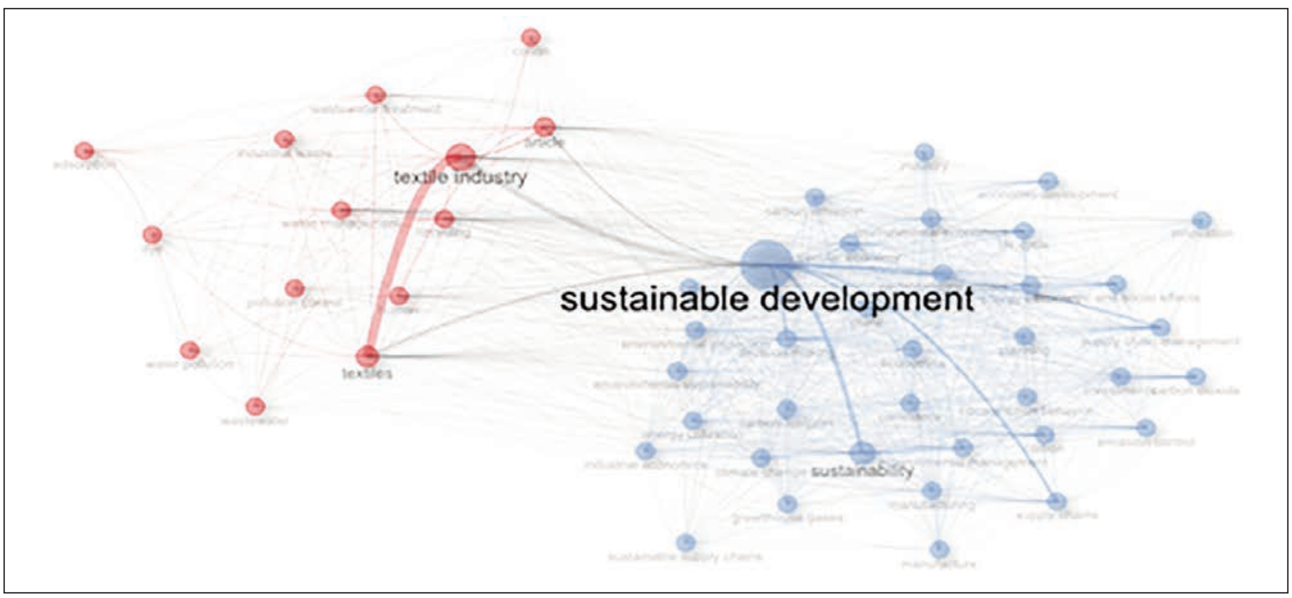

Fig. 4. Co-word Net

DATA ANALYSIS USING THE VOSVIEWER

Co-authorship among authors, countries, and organisations

The co-authorship network in table 6 illustrates the collaborative relationships among authors, countries, and organizations. High-frequency co-authorships indicate a strong collaborative bond and mutual influence in their respective research fields.

The most cited author, according to the data, is Liu J. and his collaborators, with 721 citations for a single document. They lead by a significant margin, followed by Sagar N.A. and his team with 599 citations. Other top-cited authors, such as Stević Ž. and Cheng C.C.J., have citations ranging from around 519 to 354 respectively, demonstrating the impact and reach of their work in their respective fields. When we turn our attention to organizations, there's an evident

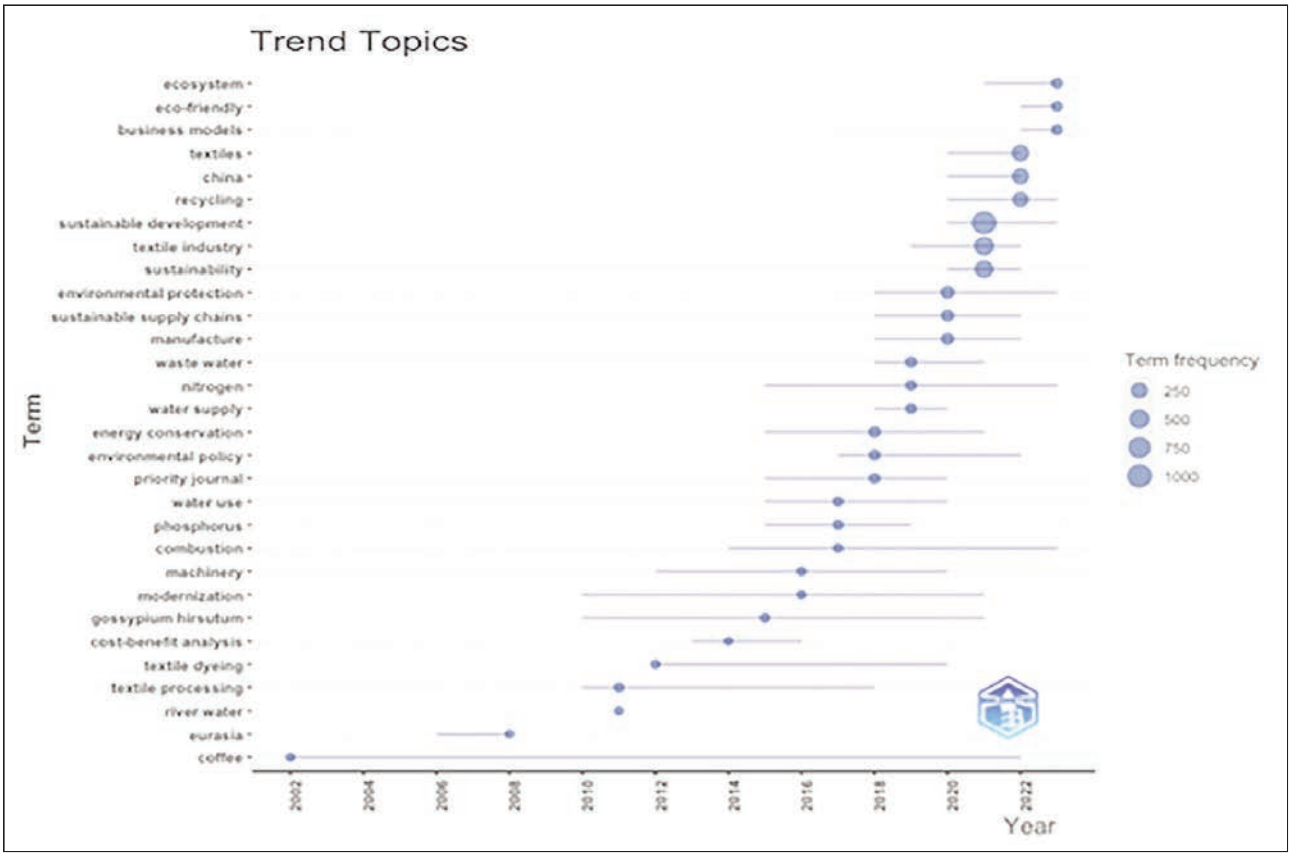

Fig. 5. Trend topics

tie among many of them, each boasting 1 document with 721 citations. This suggests the possibility that these organizations collaborated on one influential publication. Prominent institutions such as the China Agricultural University, the Chinese Academy of Sciences, and Columbia University are among them. Each of these institutions presents a total link strength of 13, suggesting strong co-authorship ties. On the geographical front, China stands out prominently. It is the most cited country with 454 documents amassing 11,962 citations. Following China are India and the United States, garnering 7,345 and 6,391 citations, respectively. It's intriguing to note that the United Kingdom, even though it has produced more documents than the United States, lags slightly behind in citations. This disparity might point to the depth, reach, or global impact of the research emerging from these nations. Furthermore, it's noteworthy that countries with fewer documents, like Denmark and the Netherlands, still feature prominently in the citation count, indicating the significant influence of their research contributions. This VOSviewer co-authorship analysis vividly highlights the leading voices and contributors in the research domain under consideration.

Co-occurrence of most frequently occurring keywords

Table 7 showcases the co-occurrence of frequently appearing keywords and provides a snapshot of the central themes and topics of discussion in a given dataset (see figure 6 for visualization). Among the keywords, "sustainable development" stands out as the most frequent, with 997 occurrences and a significant total link strength of 5,897. This suggests that the term is not only frequent but also highly interconnected with other keywords in the dataset. Following closely is "sustainability" with 831 occurrences and a link strength of 3,876. Interestingly, terms specific to the textile domain like "textile industry" and "textiles" have appeared 416 and 280 times, respectively, underlining the emphasis on sustainability in the textile sector. The keyword "circular economy" reflects a more recent trend in sustainability discussions and has been mentioned 241 times with a link strength of 1,502. Furthermore, the term "article" has 192 occurrences, yet its high link strength of 2,289 indicates its significant interrelation with other terms.

Geographically, "China" stands out with 174 mentions, and given its global manufacturing dominance, it's unsurprising to see it associated with keywords such as "recycling" and "environmental impact."

It's noteworthy that even though terms like "carbon" and "energy efficiency" have fewer occurrences when compared to leading terms, their relevance in discussions about environmental impact and sustainability remains prominent. This is evident from their respective link strengths of 1,056 and 901. Additionally, themes related to waste management, including "wastewater treatment" and "waste management" itself, underline the urgency and attention towards waste treatment and disposal methods. The

Table 6

CO-AUTHORSHIP AMONG AUTHORS, COUNTRIES, AND ORGANISATIONS			
Top cited authors	**Documents**	**Citations**	**Total link strength**
Liu J.; Hull V.; Batistella M.; Defries R.; Dietz T.; Fu F.; Hertel T.W.; Cesar Izaurralde R.; Lambin E.F.; Li S.; Martinelli L.A.; Mcconnell W.J.; Moran E.F.; Naylor R.; Ouyang Z.; Polenske K.R.; Reenberg A.; Rocha G.M.; Simmons C.S.; Verburg P.H.; Vitousek P.M.; Zhang F.; Zhu C.	1	721	0
Sagar N.A.; Pareek S.; Sharma S.; Yahia E.M.; Lobo M.G.	1	599	0
Carpenter A.W.; De Lannoy C.-F.; Wiesner M.R.	1	527	0
Stević Ž.; Pamučar D.; Puška A.; Chatterjee P.	1	519	0
Cheng C.C.J.; Yang C.-L.; Sheu C.	1	354	0
Afroze S.; Sen T.K.	1	337	0
Cherrafi A.; Elfezazi S.; Chiarini A.; Mokhlis A.; Benhida K.	1	323	0
Choudhary D.; Shankar R.	1	321	0
Chen L.; Zhao X.; Tang O.; Price L.; Zhang S.; Zhu W.	1	312	0
Glover J.L.; Champion D.; Daniels K.J.; Dainty A.J.D.	1	286	0
Top cited organisations	**Documents**	**Citations**	**Total link strength**
Cena University of São Paulo (Usp), Piracicaba, Sp, Brazil	1	721	13
China Agricultural University, Beijing, China	1	721	13
Chinese Academy of Sciences, Beijing, China	1	721	13
Columbia University, United States	1	721	13
Embrapa Satellite Monitoring, Campinas, Sp, Brazil	1	721	13
Federal University of Pará, Brazil	1	721	13
Institute For Environmental Studies, Vu University Amsterdam, Netherlands	1	721	13
International Union for Conservation of Nature, China	1	721	13
Massachusetts Institute of Technology, United States	1	721	13
Michigan State University, United States	1	721	13
Top cited countries	**Documents**	**Citations**	**Total link strength**
China	454	11962	311
India	264	7345	241
United States	163	6391	191
United Kingdom	196	6150	282
Italy	116	3141	107
Australia	95	2956	134
Brazil	98	2582	60
Germany	85	2066	105
Denmark	30	2022	64
Netherlands	39	1972	50

presence of terms like "environmental economics" and "economic and social effects" suggests a broader perspective on sustainability, one that considers the socio-economic implications alongside the environmental ones. The co-occurrence of these keywords paints a comprehensive picture of the evolving discourse on sustainability, indicating both established concerns and emerging focal points.

Bibliometric coupling analysis of Top cited sources, authors, organizations, and countries

The bibliometric coupling analysis in table 8 showcases interrelatedness and influence within the research community, emphasizing the importance of various sources, authors, organizations, and countries (figures 7–9). When considering the most cited sources, the "Journal of Cleaner Production" stands prominently with 262 documents, amassing 10,468 citations and a total link strength of 5,731. "Sustainability (Switzerland)", though having more documents at 281, has considerably fewer citations at 3,601 but still retains a noteworthy link strength of 2,154. Other pivotal journals in the realm of sustainability and environmental research include "Business Strategy and the Environment", "International Journal of Production Economics", and "Resources, Conservation and Recycling".

In the realm of authors, Liu J. and colleagues seem to be quite influential, given their 721 citations, albeit without any significant link strength. Sagar N.A. and his co-authors are next in line with 599 citations. It's interesting to note the variation in link strength among the top-cited authors, indicating diverse levels of interconnectedness and collaboration in their work. Regarding organizations, the "Department of Industrial and Production Engineering" at the Bangladesh University of Engineering and Technology in Dhaka emerges as the frontrunner with 12 documents and a link strength of 1,758. Other notable institutions include the "UTS Business School" at the University of Technology Sydney and the "Institute of Leather Engineering and Technology" at the University of Dhaka. The data also showcases the global spread of sustainability research, with significant contributions from institutions in Bangladesh, Australia, and China. Speaking of countries, China's dominance is evident with 454 documents, 11,962 citations, and a massive link strength of 47,155. India, the United States, and the United Kingdom follow suit, underlining their role as major contributors to the field. The total link strength, especially for countries like the UK and India, highlights their deep-rooted interconnectedness and collaboration in this academic domain.

In essence, the bibliometric coupling analysis underscores the significance of these sources, authors, organizations, and countries in shaping the discourse on sustainability and environmental topics. Their influence and interconnectedness provide a lens through which one can understand the current and emerging trends in this research area.

Table 7

CO-OCCURRENCE OF MOST FREQUENTLY OCCURRING KEYWORDS

Keyword	Occurrences	Total link strength
Sustainable development	997	5897
Sustainability	831	3876
Textile industry	416	3009
Textiles	280	2121
Circular economy	241	1502
Article	192	2289
Decision making	180	1180
Supply chain management	178	1153
China	174	1324
Recycling	160	1346
Environmental impact	158	1358
Waste management	157	1208
Supply chains	151	1042
Carbon	133	1056
Energy efficiency	125	901
Environmental management	116	887
Wastewater treatment	106	889
Environmental sustainability	97	795
Environmental economics	95	817
Economic and social effects	94	707

DISCUSSION

The textile and apparel industry has garnered substantial academic interest over the past few years, as evidenced by the in-depth literature analysis through Biblioshiny. The industry's multi-dimensional challenges, ranging from sustainability concerns to

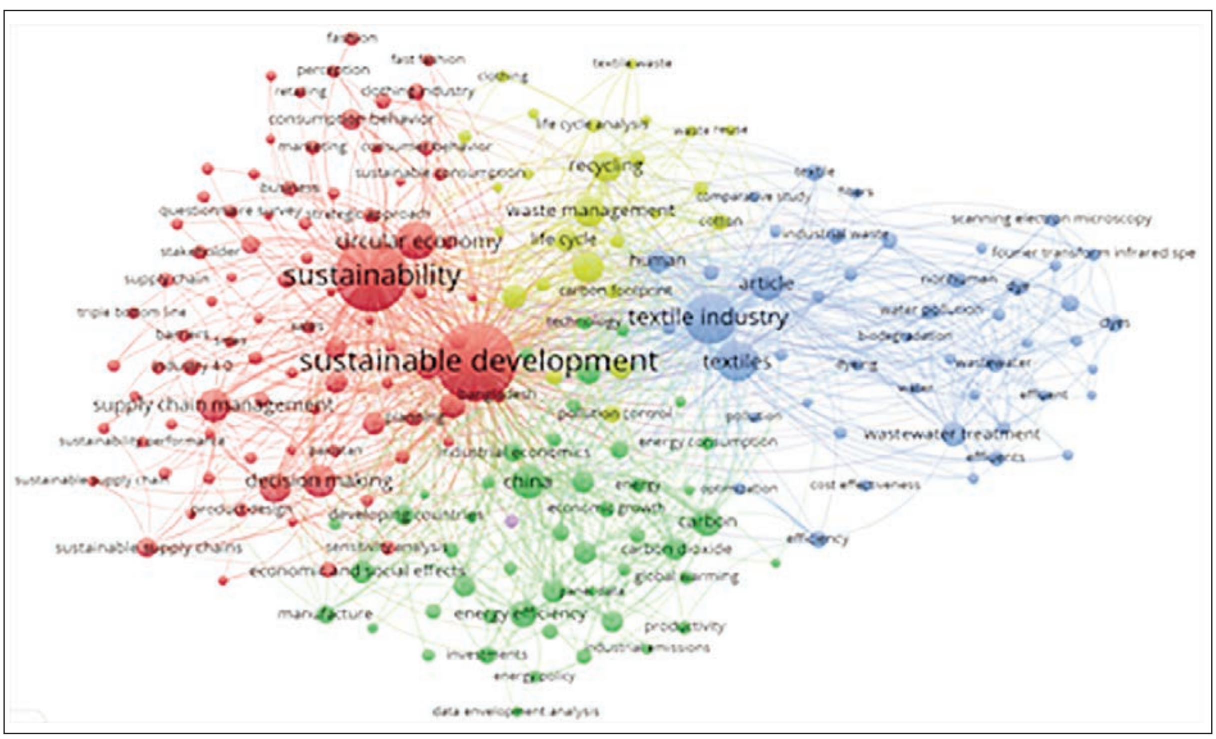

Fig. 6. Most Frequently Occurring Keywords

supply chain management intricacies, are reflected in the varied range of topics covered in the research [41]. When examining the yearly citation impact of the analysed literature, a clear upward trend is noticeable. This reflects the increasing relevance and recognition of research contributions in this area. The textile and apparel industry's evolution, especially its increasing focus on sustainability, mirrors findings posited that sustainable practices in textile manufacturing have become indispensable in recent times [42]. Annual literature output also provides crucial insights. Dominant publications, like the "Journal of Cleaner Production" and "Sustainability (Switzerland)", emerge as essential sources for disseminating industry-related knowledge.

Table 8

BIBLIOMETRIC COUPLING ANALYSIS OF TOP CITED SOURCES, AUTHORS, ORGANIZATIONS, AND COUNTRIES

Most cited sources	Documents	Citations	Total link strength
Journal of Cleaner Production	262	10468	5731
Sustainability (Switzerland)	281	3601	2154
Business Strategy and the Environment	60	1938	2341
International Journal of Production Economics	29	1876	1655
Energy	24	1220	195
Resources, Conservation and Recycling	29	1157	1010
Science of the Total Environment	24	816	313
Environmental Science and Pollution Research	61	767	282
Computers and Industrial Engineering	11	766	433
Journal of Retailing and Consumer Services	8	720	243
Most cited authors	**Documents**	**Citations**	**Total link strength**
Liu J.; Hull V.; Batistella M.; Defries R.; Dietz T.; Fu F.; Hertel T.W.; Cesar Izaurralde R.; Lambin E.F.; Li S.; Martinelli L.A.; Mcconnell W.J.; Moran E.F.; Naylor R.; Ouyang Z.; Polenske K.R.; Reenberg A.; Rocha G.M.; Simmons C.S.; Verburg P.H.; Vitousek P.M.; Zhang F.; Zhu C.	1	721	0
Sagar N.A.; Pareek S.; Sharma S.; Yahia E.M.; Lobo M.G.	1	599	0
Carpenter A.W.; De Lannoy C.-F.; Wiesner M.R.	1	527	0
Stević Ž.; Pamučar D.; Puška A.; Chatterjee P.	1	519	1
Cheng C.C.J.; Yang C.-L.; Sheu C.	1	354	3
Afroze S.; Sen T.K.	1	337	0
Cherrafi A.; Elfezazi S.; Chiarini A.; Mokhlis A.; Benhida K.	1	323	10
Choudhary D.; Shankar R.	1	321	0
Chen L.; Zhao X.; Tang O.; Price L.; Zhang S.; Zhu W.	1	312	30
Glover J.L.; Champion D.; Daniels K.J.; Dainty A.J.D.	1	286	14
Most cited organisations	**Documents**	**Citations**	**Total link strength**
Department Of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Dhaka, 1000, Bangladesh	12	695	1758
UTS Business School, University of Technology Sydney, Australia	5	616	1019
Institute of Leather Engineering and Technology, University of Dhaka, Dhaka, 1209, Bangladesh	5	569	1341
School of Management and Economics, Beijing Institute of Technology, Beijing, 100081, China	6	339	584
China Institute of FTZ Supply Chain, Shanghai Maritime University, Shanghai, 201306, China	8	334	1763
Guildhall School of Business and Law, London Metropolitan University, London, United Kingdom	8	325	709
Department of Business Administration, ILMA University, Karachi, Pakistan	6	251	1179
Sustainable Development Research Institute for Economy and Society of Beijing, Beijing, 100081, China	4	246	559
Sustainable Development Research Institute for Economy and Society of Beijing, Beijing, China	4	228	501
School of Management and Engineering, Xuzhou University of Technology, Xuzhou, China	4	219	952

Table 8 (*continuation*)

Most cited countries	Documents	Citations	Total link strength
China	454	11962	47155
India	264	7345	46839
United States	163	6391	27728
United Kingdom	196	6150	51003
Italy	116	3141	24571
Australia	95	2956	22325
Brazil	98	2582	13847
Germany	85	2066	17618
Denmark	30	2022	10314
Netherlands	39	1972	10489

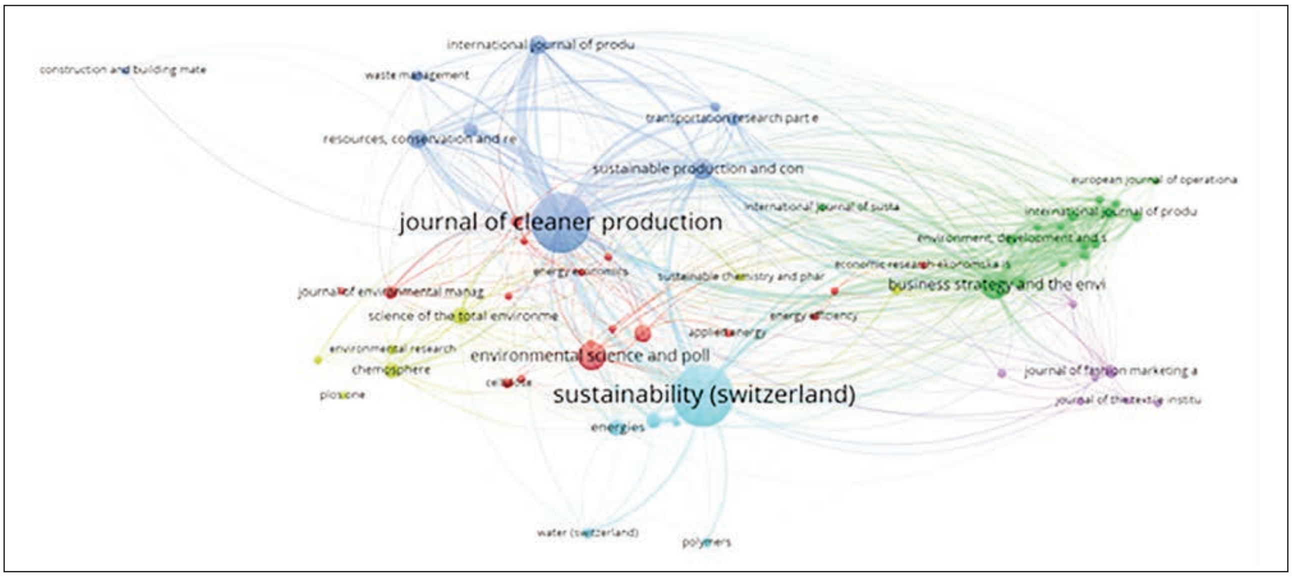

Fig. 7. Bibliometric coupling of sources

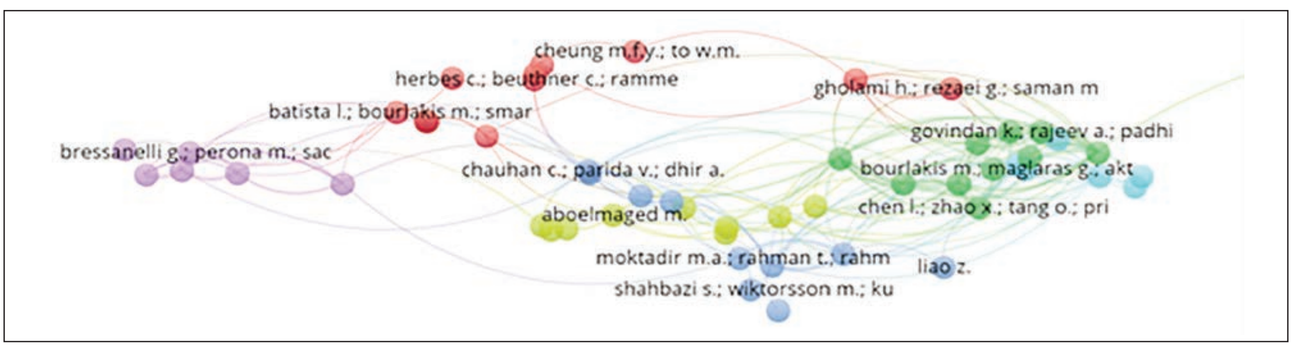

Fig. 8. Bibliometric coupling of authors

The prominence of these journals highlights the global push towards environmentally conscious manufacturing and business practices. Assessing the local impact of top journals indicates the depth and breadth of research in this domain. For instance, "Business Strategy and the Environment" boasts a commendable impact, emphasizing the amalgamation of business strategies with environmental considerations in the textile sector [43].

The contributions of key authors on a yearly basis exhibit the dynamic nature of research in this domain. Liu J. and his collaborators, for instance, have been instrumental in shaping discourse, even though their significant citation count contrasts starkly with their low link strength [44]. This discrepancy could be attributed to the diverse nature of collaborations and partnerships they engage in a chronological analysis of word frequency reveals the shifting paradigms within the industry. Words like "sustainable development" and "sustainability", which have grown in frequency over time, resonate with global trends in various industries aiming for sustainable growth [45].

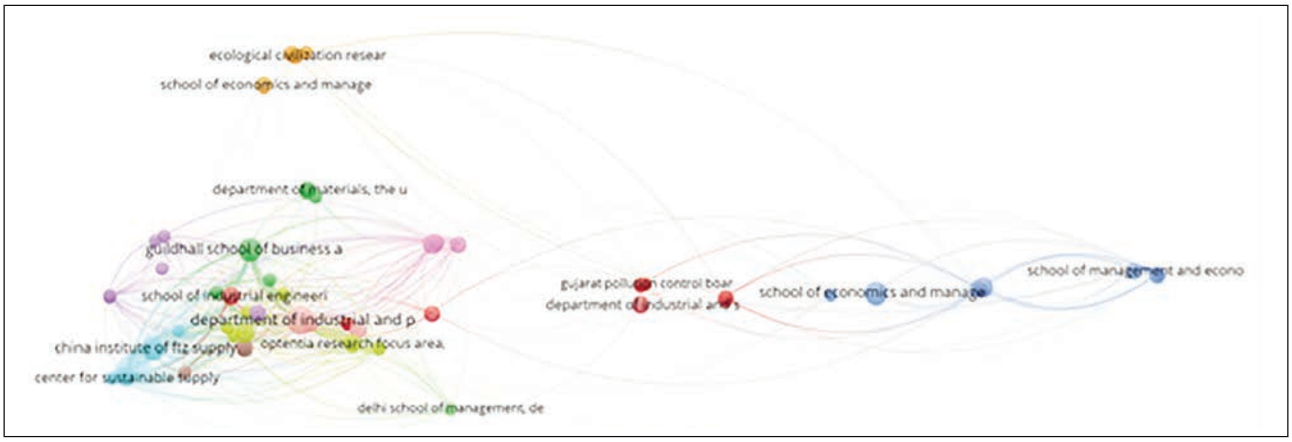

Fig. 9. Bibliometric coupling of organizations

Moreover, the emergence of trend topics, such as "energy conservation" and "environmental policy", underscores the industry's ongoing efforts to align with global environmental objectives. Data derived from the VOSviewer further enriches our understanding. The co-authorship analysis reveals vast networks of collaboration spanning authors, countries, and organizations. The expansive collaboration, particularly among nations like China, India, and the US, corroborates findings noted in the global nature of textile research [46]. The frequent co-occurrence of keywords, including "sustainability" and "textile industry", accentuates the growing convergence of environmental concerns with industry practices. This trend is consistent with observations which highlighted the industry's shift towards green manufacturing processes [47, 48]. Lastly, the bibliometric coupling analysis affirms the interconnectedness in this research domain. The dominant role of institutions like the "Department of Industrial and Production Engineering" at the Bangladesh University of Engineering and Technology illustrates the global spread and collaborative nature of research endeavours. However, the decision-making process represents a challenging issue in the modern era [49]. The comprehensive analysis of literature on the textile and apparel industry reveals an evolving narrative centred around sustainable practices, global collaborations, and innovative methodologies, reflecting broader global trends and imperatives. On the other hand, according to [50] in the emerging country of India, the "fintech segment is currently one of the most rapidly growing industries".

CONCLUSION

In synthesizing the vast volume of data unearthed from our meticulous analysis, it becomes lucidly clear that sustainability transitions in the textile and apparel sector have evolved to occupy a dominant space in academic discourse. The intellectual structure, elucidated via co-citation and co-word analyses, underlines the intertwining of sustainable development with the intricate workings of this industry, effectively addressing our first objective. Moreover, by navigating the gender and ethical dimensions, an intriguing observation emerges regarding the representation and thematic focal areas within the research. Not only does this help grasp the diversity of voices and perspectives in this field but also underscores the imperative to foster a more inclusive research environment, adhering to the second objective.

Geographically, a compelling concentration of research has emanated from countries like China, India, and the United States. This distribution not only reflects the region's inherent industrial prowess but also pinpoints both the leading lights and the existing lacunae in sustainability research. Institutions from Bangladesh, for instance, have showcased commendable research contributions, emphasizing our pursuit of highlighting works from lesser-known institutions and developing regions, encapsulating objectives three and seven. Technological and interdisciplinary innovations have left an indelible mark on sustainable practices within the industry. Through analysis, we note an upswing in research themes focusing on technological integrations, such as supply chain management and waste management, solidifying our fourth objective. When delving into the real-world impacts, the pertinence of case studies and policy reforms becomes unmissable. The emphasis on "sustainable development" and "sustainability" as recurring keywords lends credence to the industry's efforts in translating academic insights into tangible practices, manifesting the sixth and eighth objectives. Additionally, the influence of significant global events and challenges on research trends underscores the adaptive and responsive nature of sustainability research in this realm, ticking off our sixth objective. The recurring focus on "sustainable practices" and the emphasis on innovative topics such as "circular economy" in the literature reveals the industry’s effort to embed sustainability holistically. It resonates to quantify real-world impacts, specifically looking at environmental metrics and policy shifts, as outlined in our fifth objective.

The textile and apparel industry, as mirrored in the analysed literature, stands at the crossroads of sustainability, innovation, and inclusivity. The academic landscape, populated by myriad voices and perspectives, not only chronicles the sector's past endeavours but also charts a promising roadmap for the future. This comprehensive study effectively bridges the academic-industry nexus, offering actionable insights while fulfilling its objectives, from understanding the intellectual underpinnings to spotlighting tangible industry successes and challenges in the domain of sustainability.

POLICY IMPLICATIONS

In light of the comprehensive bibliometric analysis, several crucial policy implications emerge. Firstly, the literature underscores the urgency of sustainable development and overall sustainability in the textile and apparel industry. Policymakers are urged to enact regulations that nudge industries towards more sustainable practices, whether through positive incentives for eco-conscious operations or stiffer penalties for environmental transgressions.

Moreover, an observation from the study indicates a potential gap in inclusive research, particularly in gender and ethical dimensions. This points to the need for policy guidelines that ensure research grants and platforms embrace diversity. By ensuring an equitable distribution of research opportunities, we can cultivate a more comprehensive academic discourse enriched by varied perspectives.

Additionally, considering the geographical distribution of research, there's a clear indication that one-size-fits-all strategies might be suboptimal. Policymakers must craft region-specific strategies, considering the unique challenges, strengths, and cultural nuances of each region. This not only enhances the efficacy of policies but also ensures localized relevance.

Technological innovation emerges as a strong theme, signifying the convergence of technology and sustainability. Policymakers could capitalize on this by channelling resources into interdisciplinary research, spurring the growth of technological solutions tailored for the textile and apparel sector. Furthermore, the dynamic nature of the industry, especially its agility in reacting to global events, implies that static policies could be obsolete in a short span. Policymakers must cultivate a culture of adaptability, revisiting, and recalibrating policies based on the current global context and the latest research findings. Lastly, a pivotal observation is the necessity to bridge the academia-industry divide. Policymakers can be instrumental in catalysing this by endorsing and facilitating partnerships between academic researchers and industry professionals. This symbiotic relationship ensures that academic discoveries don't remain ensconced in journals but find palpable expression in the industry, driving tangible change.

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