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Discussion on key issues of carbon footprint quantification of silk products

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ABSTRACT – REZUMAT

Discussion on key issues of carbon footprint quantification of silk products

In this study, to accurately calculate the carbon footprint of silk products, key issues were analysed and discussed, including accounting boundary, accounting data, sequestration of greenhouse gases (GHG) and calculation of results. The results support the feasibility of "cradle to gate" or "gate to gate" as the accounting boundary for the carbon footprint of silk products. Accordingly, the quality of accounting data may be improved by determining the key emission sources of GHG within the accounting boundary, selecting the appropriate data allocation methods and maintaining the consistency of the allocation methods within the accounting boundary when necessary. The GHG sequestration of silk is explained separately in the results, which report on the carbon footprint of silk products. The carbon-neutral actions taken by silk enterprises are also discussed and quantified in the results of the carbon footprint calculation. Ultimately, it is found that a consistent accounting boundary and emission factors constitute two key prerequisites for the feasibility of carbon footprint quantification of various silk products.

Keywords: *silk products, carbon footprint, accounting boundary, carbon neutralization, allocation*

Discuții privind problemele cheie de cuantificare a amprentei de carbon a produselor din mătase

În acest studiu, pentru a calcula cu exactitate amprenta de carbon a produselor din mătase, au fost analizate și discutate aspecte cheie, inclusiv limitele contabile, datele contabile, captarea gazelor cu efect de seră (GES) și calculul rezultatelor. Rezultatele susțin fezabilitatea „de la producţie până la livrare“, ca limită contabilă pentru amprenta de carbon a produselor din mătase. În consecință, calitatea datelor contabile poate fi îmbunătățită prin determinarea surselor cheie de emisie a GES în limitele contabile, selectând metodele adecvate de alocare a datelor și menținând consistența metodelor de alocare în limitele contabile, atunci când este necesar. Captarea GES din mătase este explicată separat în rezultate, care raportează amprenta de carbon a produselor din mătase. Acțiunile neutre în ceea ce priveşte carbonul întreprinse de companiile producătoare de mătase sunt, de asemenea, discutate și cuantificate în rezultatele calculului amprentei de carbon. În cele din urmă, se constată că o limită contabilă consecventă și factorii de emisie constituie două premise cheie pentru fezabilitatea cuantificării amprentei de carbon a diferitelor produse din mătase.

Cuvinte-cheie: *produse din mătase, amprentă de carbon, limită contabilă, neutralizarea carbonului, alocare*

INTRODUCTION

In China, industrial green low-carbon development and consumption of green and low-carbon products constitute key elements of the carbon peaking and carbon neutrality goals. The calculation of the carbon footprint of products throughout their life cycle provides an important reference conducive to carbon mitigation in industrial production and progress concerning consumption. In this regard, in China, the Ministry of Industry and Information Technology published the 14th Five-Year Plan for Green Development of the Industry Sector, which has listed the calculation of the carbon footprint of products among the main tasks assigned to green development in the industry. Moreover, the Implementation Plan for Promoting Green Consumption has set exploring and establishing the standards of the carbon footprint of key products over the whole life cycle as a priority.

Around 2005, discussions commenced concerning the concept and calculation methods of a carbon footprint. At the outset, Carbon Trust published Carbon Footprint Measurement Methodology Version 1.1 in 2007, after which, several institutions, including the British Standards Institution (BSI), the International Organization for Standardization (ISO), the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) have promoted the enactment of carbon footprint accounting standards [1, 2]. In addition, in 2008, BSI published “PAS 2050:2008 Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services”; in 2011, an updated version was released. In 2011, WRI and WBCSD co-published “GHG Protocol: Product life cycle accounting and reporting standard”. While the carbon footprint of products was not explicitly identified in this document, general requirements for the quantification of the life cycle of emission of greenhouse gases were set out, and conditions for evaluation and reporting were stipulated in general terms. Published by ISO in 2013, "ISO/TS 14067:2013 Greenhouse Gases – Carbon Footprint of Products – Requirements and Guidelines for Quantification and Communication", defined the concept of the carbon footprint of a product (CFP) and stipulated requirements of boundary setting for the CFP, in addition to accounting data inventory and accounting methods; to establish international standards, this document was subsequently updated to ISO 14067:2018. When calculating, evaluating and reporting the carbon footprint of silk products in the life cycle based on the above three general standards and technical specifications, accounting personnel frequently demonstrate varying understandings about key elements of carbon footprint accounting, including boundary setting, data collection and allocation methods, leading to high uncertainty and poor comparability of accounting results [3]. Published by BSI in 2014, "PAS 2395:2014 Specification for the Assessment of Greenhouse Gas (GHG) Emissions from the Whole Life Cycle of Textile Products", and T/CNTAC 11-2018 "General requirements for Quantifying Greenhouse Gas Emissions of Textile Products", specified the transformation of international general standards and technical specifications about the textile industry. Meanwhile, in both China and around the world, several institutions are at work developing Product Category Rules (PCR) for carbon footprint accounting in the interest of standardizing the accounting of the CFP in detail. Meanwhile, China's textile industry standards have been in the process of formulation, as demonstrated by such documents as the following: "Carbon Footprint of a Product: Product Type Rules for Textile Products", "Carbon Footprint of a Product: Product Type Rules for Woolen Yarn", "Carbon Footprint of a Product: Product Type Rules for Woolen Fabric" and "Carbon Footprint of a Product: Product Type Rules for Woolen Knitted Products".

Due to their high quality, silk products constitute a popular textile product category among consumers. The production of cocoons and raw silk in China accounts for more than 80% of global production [4], and China ranks first in the world in the production and processing of silk fabrics, silk garments, and silk home textiles. Therefore, the carbon footprint of silk products is of great significance for the sustainable development of the silk industry. At present, studies on the environmental performance of silk products throughout their life cycle largely focus on cocoons, raw silk, silk fabrics, silk garments, and other craft products, as shown in figure 1. For example, Barcelos et al. [5] conducted a life cycle assessment of the core processes of mulberry and silk cocoon production along with upstream processes of raw material production. Accordingly, the number of opportunities for improving the environmental profile of mulberry and silk cocoon production under Brazilian conditions was determined. Additionally, in southern India, Astudillo et al. [6] constructed a life cycle inventory of the production of high-quality silk and compared best practice recommendations with observed farm practices. The results demonstrated that GWP_{100} values of 1 kg raw silk under farm practices and recommended practices were 80.9 kg CO_2eq/kg and 52.5 kg CO_2eq/kg respectively. Also in India, Vollrath et al. [7] conducted an LCA of silk yarn production, focusing on cumulative energy demand

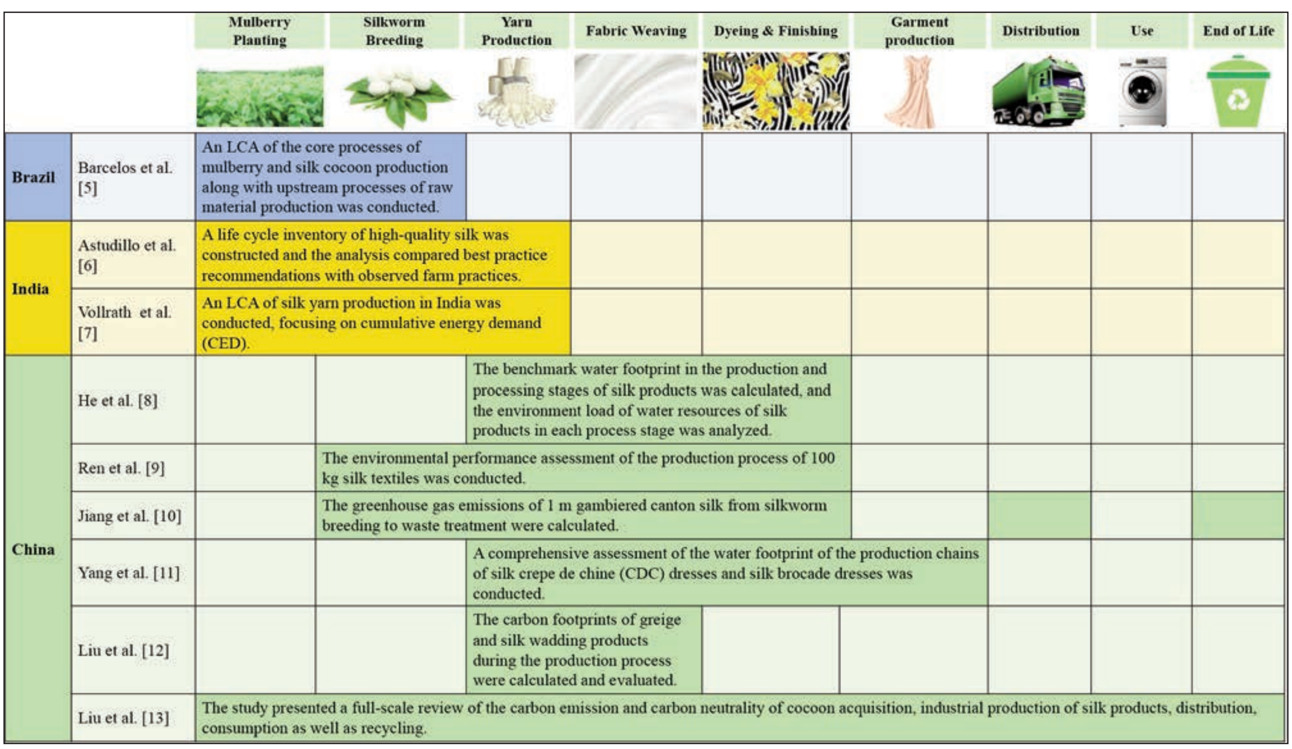

Fig. 1. Literature review on life cycle assessment of silk products

(CED), rendering calculated CED values above 1800 MJ/kg. In China, He et al. [8] calculated and assessed the benchmark water footprint in the production and processing stages of silk products. The results demonstrated that the benchmark water discharge footprint of the silk reeling stage, dyeing stage, and weaving stage was 682.7 m^3 H_2O eq/t, 297 m^3 H_2O eq/t and 252.5 m^3 H_2O eq/t. Ren et al. [9] conducted an environmental performance assessment of the production process of 100 kg silk textiles, and the calculated GWP value came to 20.253 kg CO_2 in total. Meanwhile, Jiang et al. [10] calculated the greenhouse gas emissions of 1 m gambier canton silk, delivering a result of 1.88 kg CO_2e/m. On top of these, Yang et al. [11] conducted a comprehensive assessment of the water footprint of the production chains of silk crepe de chine (CDC) dresses and silk brocade dresses utilizing the ISO 14046 and the life cycle assessment polygon method. Similarly, Liu et al. [12] calculated and evaluated the carbon footprint results of greige and silk wadding products during the production process, turning out that the carbon footprints of greige products made from fresh cocoons and dry cocoons were 24.93 kg CO_2e/kg and 27.84 kg CO_2e/kg respectively, and the CF result of silk wadding product was 10.14 kg CO_2e/kg. On the whole, Liu et al. [13] reviewed the research progress in terms of the environmental performance assessment of silk products, reflecting upon and reconsidering the research methods, calculation boundary, data inventory and result evaluation. Notwithstanding, the life cycle chains of various silk products prove long and complicated, involving a great many contributory and productive elements. Accordingly, the key issues of the carbon footprint of silk products need to be fully analysed. Nevertheless, few studies have systematically analysed the standards relating to accounting as pertains to the carbon footprint produced during the life cycle of silk products. Accordingly, this work discusses and makes recommendations regarding key issues in the quantification of the carbon footprint of silk products, including boundary setting, data collection and distribution, and result in acquirement.

Specifically, this study provides references and suggestions for evaluating the accounting of the carbon footprint of silk products and the development of related standards.

ACCOUNTING BOUNDARY

The carbon footprint of a product constitutes the quantification of global climate change in the life cycle of a product; thus the accounting of the carbon footprint requires an assessment of the entire life cycle of the product [14]. As such, the entire life cycle of silk products may be divided into five stages, namely the acquisition of silkworm cocoons, the manufacturing, the sales and use of products, the disposal of products, as well as recycling. In turn, each stage is divided into several segments. The initial stage, that of silk cocoon acquisition, essentially pertains to silkworm breeding. Depending on the species of silkworm, the breeding methods include traditional mulberry silkworm breeding, sericulture breeding, factory mulberry silkworm breeding, etc.

Subsequently, the manufacturing stage includes reeling, weaving, whitening, dyeing, printing, sewing and so on. In addition, the sales and use stage encompasses trade and retail, laundry care, etc. Finally, the disposal stage represents the terminus of the life cycle of silk products, while the recycling stage constitutes the beginning of the life cycle of recycled silk products.

According to the definition of the carbon footprint of a product in ISO 14067:2018, the carbon footprint represents a quantification of the impact on climate change resulting from the sum of greenhouse gas emissions and sequestration over the full or partial life cycle of a product (one or more life cycle segments). The accounting boundaries of a partial CFP vary by circumstances, including “cradle to grave”, “cradle to gate” and “gate to gate”. To set a specific accounting boundary is to determine the range of carbon footprint quantification. The selected boundary directly affects the involved inputs and outputs, which in turn affects the GHG assessment results of the target product [15]. Multiple types of by-products may be generated during the whole life cycle process of silk products (such as white silk, silk fabrics and silk apparel). If the entire life cycle assessment is conducted, accounting for the carbon footprint is usually impracticable due to the uncertainty of the subsequent applications of by-products. For example, white silk may be used to produce dyed fabrics and then to create silk garments, or be used to produce printed fabrics and then silk scarves. As a consequence, it is practical to select “cradle to gate” or “gate to gate” as the accounting boundary of the carbon footprint of silk products. When the specifics of distribution, use, disposal and recycling are confirmed, including the modes of transport, distance from factory to retail store, whether sales are to be online or offline, methods and frequency of laundry, methods of disposal (landfill or incineration), and recycling, it becomes feasible to set “cradle to grave” as the accounting boundary for calculating the carbon footprint of silk products over the whole life cycle. The boundary of “cradle to gate” and “gate to gate” can be adjusted flexibly, based upon the accounting purpose of the carbon footprint of silk products, as shown in figure 2. The process of “cradle to gate” can start with silk eggs and proceed to different product stages, such as silkworm cocoons, white silk and silk fabrics. The progress of “gate to gate” may commence from silkworm cocoons and extend to white silk or silk fabrics. On the other hand, it can also start from white silk to silk fabrics or silk apparel. Although the setting of an accounting boundary for the carbon footprint of silk products is highly flexible, the selected accounting boundary should be explained clearly when reporting the carbon footprint accounting results and comparing the carbon footprint of specific products. The prerequisite for the accounting carbon

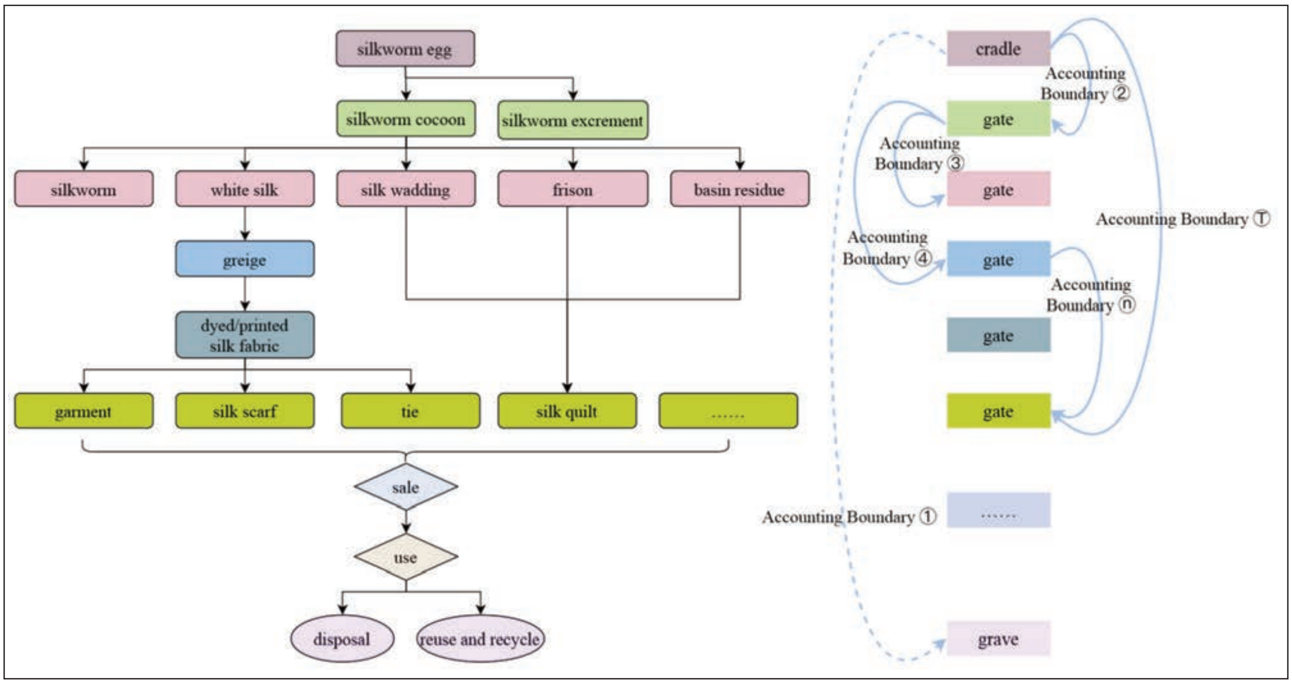

Fig. 2. Accounting boundary of the carbon footprint of silk products

footprint of silk products is the consistency of the accounting boundary. The selected boundary has a direct bearing on the input and output within the studied system, further influencing the final results. For instance, Giacomin et al. [16] unearthed a positive correlation between silk garments and carbon footprint mitigation when including the cultivation of mulberry trees in the computation. According to the calculation conducted by Giacomin et al. [16], the carbon footprint per tonne of silk fibre was 25,425 kg CO_2e from fibre production to the end of the life cycle. Besides, Barcelos et al. [5] conducted a life cycle assessment for the core processes of mulberry and silk cocoon production and upstream processes of raw material production, turning out that the GWP result of mulberry production was 0.21 kg CO_2e per kg of silk cocoon. The average content of Brazilian silk in cocoons is approximately 17%, which means 1 tonne of silk fibre requires 5.88 tonnes of cocoons, with the GWP value of 1 tonne of silk fibre during the mulberry production of 12,348 kg CO_2e. Thus, based on their research and the above calculations, the carbon footprint result of 1 tonne of silk in the whole life cycle is about 37,773 kg CO_2e, without taking the carbon sequestration effect of mulberry trees into consideration. However, the ability of mulberry trees to sequester carbon is significant, and by planting a field of mulberry trees, the correspondingly mitigated CO_2e is approximately 735 times the weight of the produced silk fibre [16]. Taking a tonne of silk fibre for instance, the mitigated CO_2 by mulberry trees is about 735,585 kg CO_2e, which far surpasses the carbon footprint of the whole life cycle (37,773 kg CO_2e). Therefore, when the starting point of the accounting boundary of silk products is “cradle”, it is an essential account for the role of mulberry trees and explains the selected boundary separately. Any change in the accounting boundary brings about the volatility of the accounting results [1].

ACCOUNTING DATA

Within the accounting boundaries of carbon footprint, the sources of greenhouse gas (GHG) emission include direct GHG emissions and indirect GHG emissions. Specifically, GHG emissions from fuel burning (e.g., natural gas boiler combustion emissions), chemical reactions (e.g., carbon dioxide produced by carbonate reactions), and wastewater treatment (e.g., methane and nitrous oxide) [17] constitute direct greenhouse gas emission data. On the other hand, the off-site combustion energy consumed within the accounting boundaries (such as electricity), and materials (e.g., dyes, auxiliaries packing materials, etc.) fall under indirect GHG emission data.

Accounting data forms a basis for evaluating the carbon footprint of products. In this regard, ISO 14067: 2018 classifies accounting data into primary data, site-specific data and secondary data. Primary data refers to the data directly measured in the progression of the life cycle of a product or calculated from direct measurements. Site-specific data refers to the primary data obtained within the accounting boundary of the carbon footprint of a product, covering direct GHG emissions, activity data (AD) and emission factors. Outside of primary data, data not directly collected, measured or estimated, but rather sourced from published literature or an industry database, are collectively referred to as secondary data. Although personal respiration, as a basic physiological activity, is affected by labour intensity, its carbon dioxide emissions are usually not included in accounting data of the carbon footprint. The fixed assets include production equipment and factories

Table 1

CARBON FOOTPRINT ACCOUNTING DATA FOR SILK PRODUCTS			
Process/stage	**Sources of GHG emissions and sequestration**		**Data inventory**
Acquisition of silk cocoons	Direct emissions	Fuel combustion	Wood, coal, natural gas and diesel
	Indirect emissions	Energy and heat production	Electricity, steam
		Material production	Mulberry leaves, fodder, paper, plastic film, lime, bleaching powder, packing material
Production of silk products	Direct emissions	Fuel combustion	Wood, coal, natural gas and diesel (transportation)
		Chemistry reaction	Sodium carbonate, baking soda
		Wastewater treatment	Wastewater quantity, influent COD concentration, effluent COD concentration
	Indirect emissions	Energy and heat production	Electricity, steam
		Material production	Cord material, paper, packing material, tags, fresh water, textile chemicals (dyes, aids, et al.), chemicals for wastewater treatment
	Direct sequestration	Wastewater treatment	Methane recovery
Sale and use of silk products	Direct emissions	Fuel combustion	Diesel (transportation)
	Indirect emissions	Energy production	Electricity
		Material production	Paper, packing material, fresh water, detergent
Disposal	Direct emissions	Fuel combustion	Diesel (transportation)
		Combustion, landfill	Waste silk products
	Indirect emissions	Energy production	Electricity
Recycle and reuse	Direct emissions	Energy combustion	Diesel (transportation)
	Indirect emissions	Energy production	Electricity
		Material production	Packing material, fresh water, chemicals

generating GHG emissions directly or indirectly. However, as they constitute long-term assets not limited to the production of a specific silk product, they are also not included in the carbon footprint accounting data of silk products. The main list of accounting data for the carbon footprint of silk products is displayed in table 1.

Depending on the varying measurement levels of enterprises, some of the data relating to GHG emission sources can be accurate concerning a specific silk product or a specific workshop section, while other data constitutes overall data falling within a certain period, such as the monthly lighting expenditures of a workshop. If the workshop produces multiple silk products at the same time in a particular month, the monthly lighting expenditures need to be allocated to the silk products and co-generation products according to product characteristics, such as production volume or value [18]. If there are several segments involved in data allocation within the accounting boundary, the chosen allocation methods should be consistent. For example, if the lighting power consumption of greige fabric in the pre-processing workshop is allocated according to value, the lighting power consumption of the printed fabrics should also be allocated according to value in the subsequent printing workshop. When by-products are generated in a chain segment, the accounting data in this chain segment also needs to be allocated. For instance, in the reeling stage, where silk, basin residue and silkworms are generated concurrently, the data in the reeling stage should be allocated among the three products. If the usefulness of by-products is low (such as solid waste) or the output of by-products is small (such as less than 1% of production), there is no need to allocate accounting data to this segment.

In addition to collecting input and output data for the accounting of the carbon footprint of silk products, the moisture content of products in each stage needs to be addressed. For instance, the moisture content of silk in the reeling stage is different from that of the re-reeling stage, so the output data in both stages should be separately rectified based on moisture content data.

GHG SEQUESTRATION

The definition of the carbon footprint of a product by ISO 14067:2018 includes the GHG emission and sequestration of a product during the life cycle. The related methods of GHG sequestration include plant absorption of carbon dioxide and conversion into biochar during photosynthesis, artificial carbon capture, storage and utilization, etc. Naturally, silk is not directly obtained from plants. However, the necessary mulberry leaves as well as oak leaves fed in a traditional sericulture mode along with the feed raised in modern industrial sericulture mode (including mulberry leaves, soybean meal, etc.) are plant-derived products. Moreover, the carbon they contain is traceable to carbon dioxide in the air. In addition to mulberry leaves, oak leaves or artificial feed are eaten by silkworms, and the carbon contained in leaves or feed is then converted into carbon dioxide and released into the atmosphere. The remaining carbon absorbed by the silkworms is eventually transferred to the silkworm excrement, silkworm chrysalis as well as the silk. Consequently, the carbon sequestration of mulberry leaves, oak leaves or artificial feed is not equivalent to the carbon sequestration of silk.

The quantification unit of the carbon footprint of a product is also carbon dioxide equivalent, which in turn refers to the total radiative forcing of methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride (SF_6), etc. in a given period (such as 50 years, 100 years) to an equivalent amount of carbon dioxide (CO_2) [19]. The impact of silk in terms of carbon fixation is impacted by the duration of the use of silk products. The greater the duration, the more significant the carbon fixation effect, and vice versa. Generally, the use of silk products does not extend more than fifty years. Consequently, while the carbon dioxide sequestration of silk biochar may not be included in the calculation of the carbon footprint of silk products, it can be explained in the form of a data list in the carbon footprint accounting report. When the carbon footprint accounting boundary is set as “cradle to grave”, burning waste silk products releases carbon into the atmosphere but generates heat concurrently. If this heat is utilized, the use of corresponding fossil fuels can be conserved and the measurement of GHG emissions can be reduced, which is equivalent to greenhouse gases sequestered.

If the silk product manufacturers sequester greenhouse gases from the atmosphere by purchasing carbon sinks or using artificial carbon capture, the greenhouse gases sequestered should be calculated into the carbon footprint results during accounting. To provide an example, if a manufacturer purchases a certain amount of carbon sinks and declares the share allocated to the silk products whose carbon footprint is to be accounted for, this amount can be used to offset the GHG emissions within the accounting boundary.

CALCULATION OF RESULTS

The quantification of the carbon footprint of various textile products during the production process is associated with complex and changeable production technologies and different processing modes [20]. As a result, depending on the production scenarios, the calculation for the carbon footprint of silk products involves different emission sources and calculation methods. Chemical reaction emissions of direct greenhouse gas emissions within the accounting boundary can be calculated through a chemical equilibrium equation, and GHG emissions incurred through the burning of energy can be calculated based on factors such as carbon content of energy, carbon oxidation factor, low calorific value and so on. Indirect greenhouse gas emissions within the accounting boundary can be calculated according to the method of GHG emission = AD * EF (AD represents activity data, and EF represents emission factor). AD consists of input data of off-site combustion energy (such as purchased electricity) and materials (such as dyes, auxiliaries, packaging materials, etc.), but the calculation of EF is relatively complex. When deriving the carbon footprint, EF data released by relevant institutions, as found in the literature and commercial databases, can be utilized. When choosing EF data, time and geographical differences should be fully addressed. For instance, if a certain silk product is manufactured in Zhejiang Province, and the electricity used in production is supplied by the East China Power Grid, the EF data for the power should be corresponding data released by the East China Power Grid.

Until now EF data remains a key factor restricting the calculation of carbon footprint results of products, and it is mainly manifested in incomplete data, poor timeliness, and incomplete geographic coverage. The lack of integrity of data refers to the fact that, for some materials, the EF data remains unavailable. For example, a portion of EF data concerning dyes that are utilized in the dyeing process of silk fabrics is still missing. Meanwhile, poor timeliness signifies that some of the existing EF data are outdated. For example, some data were obtained five years ago, ten years ago or even earlier. Incomplete geographic coverage refers to the fact that EF data only includes information relating to several specific areas. For instance, EFs for output power from grids prove dissimilar from one country or region to another, while published or researched EF data on electricity do not cover all countries and regions. With the deepening and expansion of research in the field of carbon footprint, EF data is still being dynamically updated. While calculating the carbon footprint of silk products, the selected EF data should be described in detail, as the consistency of EF data constitutes a key prerequisite for the comparability of different silk products within the same accounting boundary.

The results of the calculation regarding the carbon footprint of silk products equal the sum of carbon footprints in each process within the accounting boundary, and it is reported as the carbon footprint of the functional unit product. Different functional units should be set according to different product categories. For example, in the reeling stage, the unit weight of white silk is normally set as the functional unit; in the weaving stage, the unit weight or the unit meter of greige fabric is normally set as the functional unit; in the manufacturing stage of the finished product, a silk garment, a silk scarf or a silk quilt is generally set as the functional unit. When a functional unit is a non-weight unit, such as a meter, piece or bar, the weight information should be noted to facilitate the accurate conversion if the carbon footprints of different processes are compiled.

CONCLUSIONS

As the life cycle chain of silk products is long and comprises numerous contributory and productive elements, it is necessary to completely and systematically analyse the key issues of carbon footprint accounting of silk products to ensure the validity and comparability of carbon footprint accounting results. In this study, we discussed key issues such as accounting boundary, accounting data, GHG sequestration and calculation of results in the process of assessment of the carbon footprint of silk products.

Accordingly, when accounting for the carbon footprint of silk products, the accounting boundary should be set according to accounting needs. In this regard, it is usually feasible to choose a "gate" as the endpoint of the accounting boundary. The integrity and accuracy of accounting data constitute a key basis for carbon footprint accounting. In addition, the key GHG emission sources within the accounting boundary should be identified as well. Meanwhile, to ensure the quality of the accounting data collected, the data distribution method needs to be selected appropriately. Moreover, the GHG sequestration effect of silk is affected by the duration of usage of silk products. When reporting the carbon footprint of silk products, the GHG sequestration amount corresponding to biochar can be separately stated. Besides, the carbon neutralization actions of silk enterprises can be incorporated into the carbon footprint quantification results of silk products. On top of that, EF data affects the accuracy of calculation results of the carbon footprint of silk products. Finally, a consistent accounting boundary and consistent EF data constitute the two key prerequisites for the comparability of the calculated results expressing the carbon footprint of different silk products.

The accounting of the carbon footprint of silk products provides an important reference for the low-carbon design of silk products, carbon emission reduction in the manufacturing process, and green and low-carbon consumption by consumers. It is also of great significance for the green and low-carbon development of the silk industry and other textile products.

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Development of nano ferrite coated miniaturised jute antenna for wireless applications

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ABSTRACT – REZUMAT

Development of nano ferrite coated miniaturised jute antenna for wireless applications

In this work, a microstrip patch antenna is designed using a novel Ytterbium doped Cu-Mn Nano ferrite coated jute substrate for S band (2-4 GHz) applications. The prepared material is characterised by structural and electromagnetic properties to examine and analyse the effect of material factors on antenna substrate suitability. The antenna is designed and simulated using Computer Simulation Technology (CST) software. The antenna parameters such as gain are improved by employing super formula and meander line techniques. The fabricated antenna also shows better performance with return loss, Voltage Standing Wave Ratio (VSWR) and gain values.

Keywords: *coating, composites, technical textiles, textile, thermal conductivity*

Dezvoltarea antenei din iută în miniatură acoperită cu nanoferită pentru aplicații wireless

În această lucrare, a fost proiectată o antenă cu patch-uri cu microbandă folosind un nou substrat de iută acoperit cu nanoferită de Cu-Mn, dopat cu iterbiu pentru aplicații în bandă S (2-4 GHz). Materialul realizat este caracterizat pentru proprietăți structurale și electromagnetice, cu scopul de a examina și a analiza influența factorilor de material asupra adecvării substratului antenei. Antena este proiectată și simulată folosind software-ul Computer Simulation Technology (CST). Parametrii antenei, cum ar fi amplificarea, sunt îmbunătățiți prin folosirea tehnicilor cu superformule și a liniilor tip spirală. În plus, antena fabricată prezintă performanțe superioare în raport cu pierderile de retur, raportul undei staționare de tensiune (VSWR) și valorile de amplificare.

Cuvinte cheie: *acoperire, compozite, textile tehnice, textil, conductivitate termică*

INTRODUCTION

New and innovative materials are being developed continually in the field of materials science [1]. This leads to the advancement of existing products and technologies or the introduction of new technologies for the development of society and the environment, either directly or indirectly. Among various materials, Nano ferrites attracted the attention of researchers, scientists and technologists due to their wide range of applications in the fields of electronics, communication, drug delivery, sensors, actuators etc. The size of the antenna in electronics is a major bottleneck in further reducing communication package sizes at the very high-frequency band (VHF) [2]. The growing demand for small antennas in defence, aerospace, and mobile devices necessitates antenna miniaturisation. Antenna miniaturisation is a difficult problem because antenna gain and bandwidth [3] are constrained by fundamental limits based on antenna size.

Because of the wide extent of the field of composites, the necessity to discover a replacement for glass fibre-reinforced composites, which are non-biodegradable, is essential. A primary component of interest has been the development of a high-performance composite employing natural fibres.

RELATED WORKS

The following are some of the works focussed on flexible antennae using Nanomaterial material as substrate.

Xu et al. [4] prepared LiZnTiBi ferrites with high permeability dispersed into a PDMS film to use as a flexible substrate for the patch antenna. The ferrite material is ground and synthesized. After dispersed on the Polydimethylsiloxane film, shows desirable normalized characteristic impedance ($(\mu'/\varepsilon')1/2\eta_0 = 0.95\eta_0$) and miniaturization factor ($(\mu'\varepsilon')1/2 = 5.26$) for miniaturized flexible antenna application at 100 MHz. However, there is no simulation-level design of an antenna with such a substrate for miniaturization.

Hasan et al. [5] prepared a nanomaterial mixture consisting of nickel zinc ferrite (NZF) nanopowder with linseed oil, m-xylene and α-terpineol. The final nanopowder is sonicated and in liquid form applied on the surface of FR-Material. Then the square patch antenna is designed using the nano-composite substrate and silver patch. The simulated results show there is a significant reduction in Return loss (–10.97 dB at 6.42 GHz) and bandwidth for patch antenna using Nano-composite substrate when compared to patch antenna with FR-4 substrate which has higher return loss (–8.2 dB at 6 GHz) and reduced bandwidth.

Nevertheless, considerable challenges still need to be addressed before nano composite substrate-based patch antennas can be widely used in various wireless applications. The nano-composite substrate possesses the following issues: the cost of the composite material such as FR4, epoxy glass, RT-Duroid etc., is high, and there are more rigidity, and design issues when applicable to conformal antennas, wearable antennas etc. These issues can be overcome by employing nanomaterials on flexible substrate materials such as textiles, foam etc.

In addition to this, Nano ferrite materials have an impressive dielectric strength and negligible losses at high frequencies, making them suitable for high-frequency applications. Microstrip patch antennas mounted on ferrite substrates have several advantages over dielectric materials. On the other hand, the nano ferrites mixed with textile materials can do even better when comes to bending applications. Thus, the designed antenna can even be applicable for wearable applications. For this reason, this work focuses on the development of Nano ferrite materials and their mixing in the flexible substrate jute for the miniaturized design and performance improvement for wireless applications. For further improvement of the antenna performance, enhancement techniques like Super shape and meander line techniques are proposed.

The main contributions of the proposed work include:

- Primary approach to use nano-ferrites coated on the jute fabric as a substrate for the patch antenna.
- Antenna miniaturization with reduced return loss, better Voltage Standing Wave Ratio (VSWR) and improved gain by employing super formula and Meander line techniques.

The rest of the paper has been organised as follows: 3rd section deals with the steps involved in the development of flexible antennae such as material synthesis and characterisation, antenna design, simulation, fabrication and measurement. 4th section involves the results and discussions. The simulated and measured values under various conditions are plotted and analysed. Finally, 5th section provides a conclusion and suggests the future work that can be done in the proposed work.

PREPARATION OF NANO-FERRITE MATERIAL

Researchers investigated that the combination of Copper and Manganese nano ferrites has developed a non-conducting behaviour [5, 6]. Moreover, when added with rare earth metal, the combination will further improve the dielectric property overall. The choice of rare earth metal chosen is Ytterbium. Ytterbium is being used in a variety of applications, including memory devices and optoelectronic applications [7]. It can also serve as an industrial catalyst and is increasingly being used to replace conventional catalysts which are too toxic and polluting [8, 9].

Synthesis and characterisation of nano ferrites

The synthesis procedure is done using the sono chemical reactor process as shown in figure 1. For this process, metal nitrates are employed as a source material. Metal nitrates and citric acid were initially dissolved 1:1 in deionized water. For two hours, the blended solution was sonicated. The sonication process was conducted at a constant temperature of 80°C. The pH value was adjusted to 7 using NH_4OH after sonication, which was added drop-by-drop to the produced solution by stirring at room temperature, and then dried for 24 hours at a constant temperature of 80°C in a hot-air oven. As a result, the

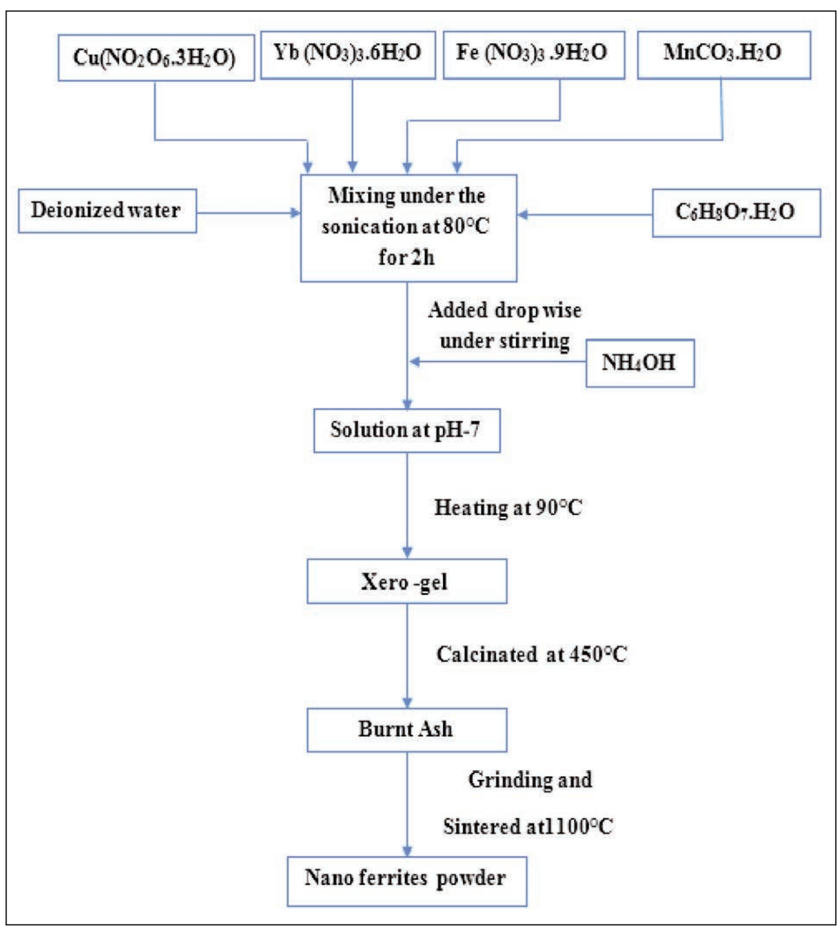


Fig. 1. Synthesis of nano ferrites

residue formed was collected and subjected to calcination at 400°C for three hours before it was ground into a homogenous mixture and sintered for 24 hours at 1000°C in atmospheric air. Further characteristic studies were performed with sintered powders. To meet the objectives of this research, the following materials were prepared using the above-mentioned sono chemical methods:

$Cu_{0.5} Mn_{0.5} Yb_X Fe_{1.8} O_4$ (X = 0.2, 0.4 and 0.8) nano ferrites

Characterisation of nano ferrites

The Ytterbium doped Cu-Mn Nano ferrite particles are characterized for structural and electromagnetic properties to examine and analyse the effect of material factors on antenna substrate suitability.

The phase formation of the synthesized ytterbium-doped manganese copper nano ferrite is confirmed by their X-ray diffraction patterns, which were recorded on a Schmadzu 7000S powder X-ray diffractometer (XRD). The crystallite sizes of $Mn_{0.5}Cu_{0.5}Yb_{0.15}$ $Fe_{1.85}O_4$ (MCYFO) nano ferrites were determined from the unit cell software. The XRD pattern of the MCYFO nano ferrite is shown in figure 2, *a*.

The observed XRD peaks are matched with the JCPDS card No: 74-1482 (orthorhombic structure) and 74-2072 (cubic structure) for $YbFeO_3$ and $MnCFe_2O_4$, respectively [10]. The crystallite size of MCYFO nano ferrite is 97.57 nm. Moreover, the lattice constant and volume of the prepared nano ferrite is 8.417 Å and 596.51 $(Å)^3$. Thus, the prepared $Mn_{0.5}Cu_{0.5}Yb_{0.1}5Fe_{1.8}5O_4$ nano ferrite is at the nano level.

Morphology, size and elements of the MCYFO nano ferrite were analyzed by scanning electron microscopy (SEM) [11] with energy-dispersive X-ray spectroscopy (EDS) (ULTRA 55; Zeiss, Germany). The SEM image of the MCYFO nano ferrite is shown in figure 2, *b*. This SEM image exhibited a condensed arrangement of regular material with a spherical shape. The nanoferrite size is 97.14 nm which is in good agreement with the crystallite size calculated from the XRD pattern. However, a lot of voids are seen in the SEM image. This may be due to delamination or accumulation of active impurities. This can be minimized by careful synthesis of the nanomaterials.

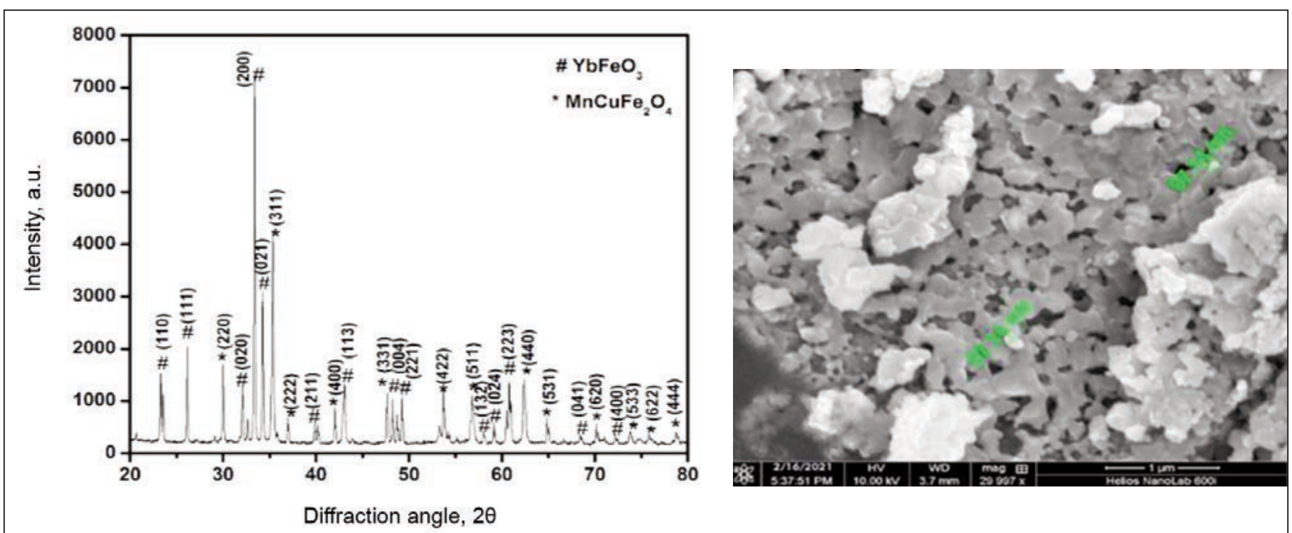
Preparation of antenna substrate material

As mentioned earlier, Microstrip patch antennas mounted on ferrite substrates have several advantages over other dielectric materials. On the other hand, the nano ferrites mixed with textile materials can do even better when comes to bending applications. The textile material chosen is jute fabric. Even though jute is a significant fabric, its application in microwave antennas has been limited [12]. It is one of the cheapest natural fibres and the second most commonly used fibre after cotton [13]. Jute has the advantage of not wrinkling as easily or wearing away as cotton. It also eliminates pollutants from the environment [14].

The process involved in the development of the nano-ferrite-coated jute material is shown in figure 3. In this process, the first step is to prepare the nano ferrites powder in liquid form by mixing it with deionized water and leaving it for 24 hours and then continuously stirring using a magnetic stirrer as in figure 3, *a*. Then the jute sheet is dipped with the solution using dip coating equipment as in figure 3, *b*. Using this method, the solution will be evenly mixed and coated into the jute sheet. After dipping, the fibre is dried for 24 hours. The resultant material is a nanocomposite fibre material as shown in figure 3, *c* which is flexible, unlike nanocomposite glass material.

Measurement of dielectric properties of the nanocomposite substrate material

The dielectric properties of the Nano-ferrite Jute substrate are tested using a Broadband Dielectric Spectrometer (BDS) of NOVOCONTROL Technologies GmbH & Co. Germany and model Concept 80. The



a *b*

Fig. 2. Images of: *a* – RD pattern of the MCYFO nano ferrite; *b* – SEM image of MCYFO nano ferrite

a *b* *c*

Fig. 3. Steps involved in the development of nano-ferrite doped Jute substrate: *a* – preparation of the nano ferrites powder in liquid form; *b* – jute sheet dipping; *c* – nanocomposite fibre material

dielectric constant and the tangent loss for the prepared substrate are measured in the range of 1 MHz to 3 GHz as shown in figures 4 and 5.

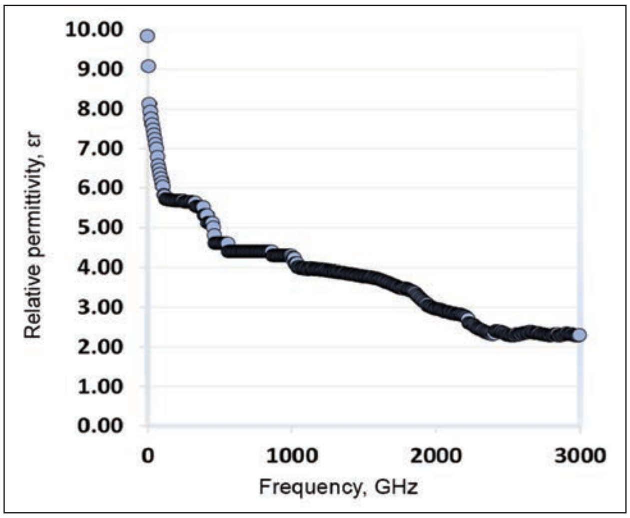


Fig. 4. Relative permittivity vs Frequency

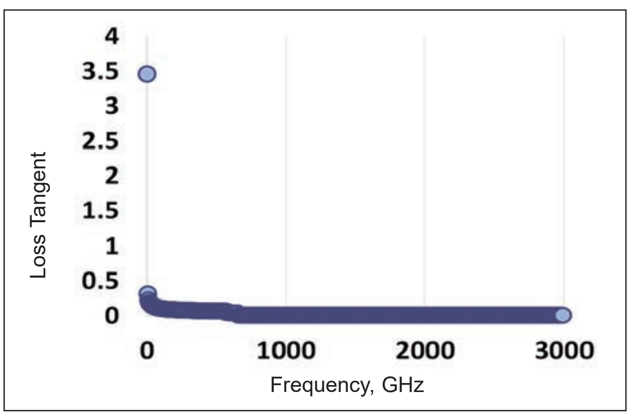


Fig. 5. Loss tangent vs Frequency

From figure 4, the relative permittivity is taken as 2.306. From figure 5, the loss tangent is reducing from 0.00102 beyond 1 GHz. The final value i.e., loss tangent is taken as 0.00102.

Thermal conductivity (K)

The thermal conductivity (K) of any material is a parameter that determines how well it can conduct heat. This term refers to the amount of heat, Q that passes through a thickness L in a plane normal to its surface area A with temperature difference T under steady state when the temperature gradient is the only factor affecting heat transfer. It is given by equation 1:

$$K = \frac{Q \times L}{A \times \Delta T} \qquad (1)$$

By substituting the thickness of the substrate, L = 1 mm, heat transfer as 27 W, temperature difference (2 K to 400 K) as 398 K and Area (circle sheet of 13 mm diameter) as A = 132.66 mm^2, the K = 0.511 W/K/m.

Table 1 shows the comparison of the values of dielectric properties i.e., relative permittivity and loss tangent and patch dimensions of Jute and nano-ferrite doped Jute material. This shows that the higher loss tangent value jute is compensated which is reduced by dipping it with nano ferrite material. Even though the dielectric constant is higher for new substrate material, there is no compromise in the flexibility of the substrate. From the patch dimensions also, it is understood that the patch size is minimized.

Design and simulation of antenna

Microstrip patch antennas [15] were chosen for the antenna design because they have several advantages over traditional microwave antennas in terms of simple design, smaller dimensions, low profile, and ease of fabrication. The width and length of the patch

Table 1

DIELECTRIC PROPERTIES AND PATCH DIMENSIONS OF JUTE AND NEW SUBSTRATE MATERIAL

Substrate	Dielectric Constant	Frequency (GHz)	Loss tangent	Material density (Kg/m^3)	Thermal conductivity (W/K/m)	Length of the patch (mm)	Width of the patch (mm)
Jute	1.87	3.2	0.052	0.0015	0.4273	33.66	39.10
Nano ferrite coated Jute material	2.306	3.2	0.00102	0.0021	0.511	30.44	36.47

Table 2

COMPARISON OF ANTENNA PARAMETERS OF PATCH USING JUTE AND NANO FERRITE COATED JUTE					
Antenna structure	**Frequency (GHz)**	**Return loss S_{11} (dB)**	**VSWR**	**Gain (dB)**	**Directivity (dBi)**
Rectangular patch with Jute as substrate	3.22	–15.465	1.40	–2.34	6.77
Rectangular patch with Nano ferrite coated Jute as substrate	3.19	–17.17	1.32	5.351	7.057

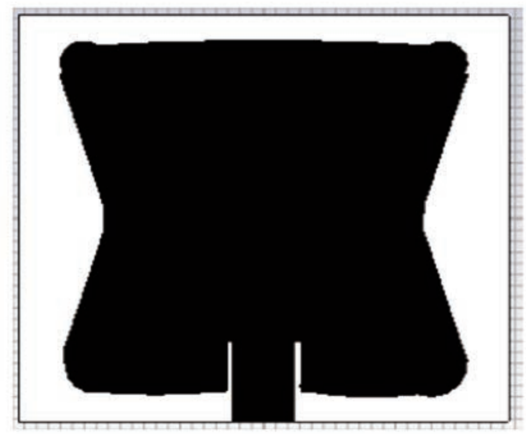
are calculated from the standard design equation of the rectangular patch antenna [16] as 36.44 mm and 30.44 mm respectively.

The structure of a conventional rectangular patch antenna with new material as substrate at 3.2 GHz with inset feed [17], layout of the antenna structure with dimensions simulated in Computer Simulation Technology (CST) Studio Suite® 2019 version software as shown in figure 3. The length and width of the substrate and ground plane as 36.46 mm and 42.49 mm respectively. The thickness of the copper sheet used for the patch and ground plane is 0.035 mm.

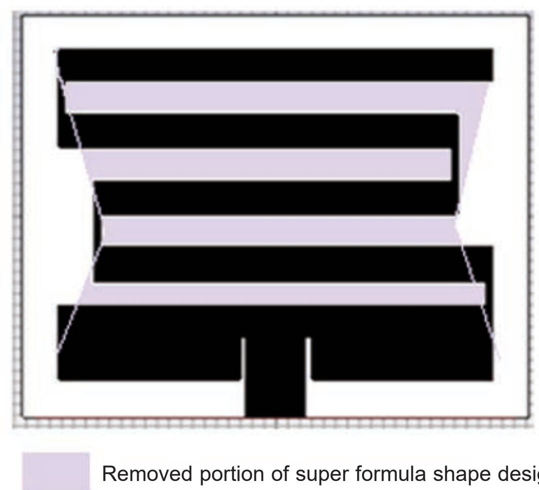
Table 2 shows the comparison of antenna parameters of the rectangular patch using Jute and Nano ferrite coated Jute. The result shows that all the parameters are improved when the jute substrate is coated with ferrite material compared to simply jute. This result shows that the antenna parameters can be improved further when employing some enhancement techniques such as meander line, super formula techniques etc.

The superformula technique [18] on microstrip antennas allows for reduced size and high-gain antenna designs by developing new structures. The meandering line technique in antennae is nothing but the design made by a succession of sets of right-angled compensating bends [19]. Electrically, a meander antenna is a compact antenna. Meander line antennas [20] are made up of horizontal and vertical lines. Turns are formed by combining horizontal and vertical lines. As the number of turns rises, so does the efficiency. Figure 6 shows the step-by-step process of the proposed antenna. The size of the superformula shape as in figure 6, *a* can be reduced by employing meandered lines with the remaining portion in the superformula shape removed as shown in figure 6, *b*. The horizontal and vertical lines are adjusted such that the operating frequency will be 3.2 GHz. Using the meandering line, nearly 50% patch size is reduced as shown in figure 7.

Table 3 shows the dimensions of the antenna. An Inset feed line is used for better antenna performance. Its advantages are its ease of fabrication, simplicity of modelling, and ability to match impedances. Figure 8 shows the simulation results of the antenna parameters of the proposed antenna. Using the Meander line technique, the antenna resonates at dual frequencies 2.19 GHz and 3.2 GHz. The S_{11} value was also very much reduced to –35 dB



a



b

Fig. 6. Step-by-step process of proposed antenna: *a* – antenna structure 2 using super formula shape; *b* – meandered line in antenna structure 3

Table 3

DIMENSIONS OF THE PROPOSED ANTENNA	
Parameters	**Dimensions (mm)**
Width of the patch Wp	36.47
Meander line M1	3
Meander line M2	0.5
Meander line M3	2
Meander line M4	6
Length of the patch Lp	30.44
Feed line width F1	5
Inset feed gap	0.5

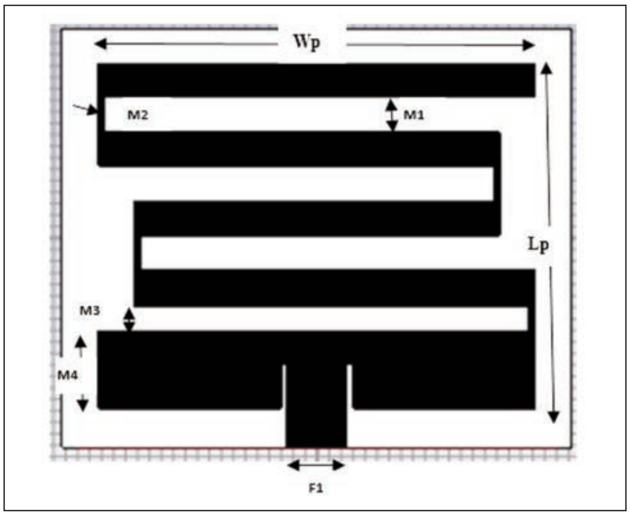


Fig. 7. Proposed Antenna Structure

at 3.2 GHz which is very low compared to a rectangular patch antenna (–17.17 dB) using the same substrate material. Overall, the gain also improved from 5.351 dBi to 8.366 dBi.

Equivalent circuit model

The proposed antenna design is modelled using a Lumped network equivalent model with capacitor and Inductor and simplified as shown in figure 9. In this, by using the resonant frequency equation as in equation 2, the frequency is calculated as 2.13 GHz and 3.169 GHz.

$$f_r = \frac{1}{2\Pi\sqrt{L_{eq} \cdot C_{eq}}} \tag{2}$$

Antenna fabrication and measurement

The proposed antenna is fabricated with the same dimension as in the simulated model and measured. To assess the values of performance parameters acquired with the antenna designed using simulation software, the fabricated antenna is connected with the Vector Network Analyzer (VNA) for *S* parameter measurement and microwave set up for gain measurement as shown in figure 10. The *S* parameter is measured as –26.42 dB. The gain of the test antenna is calculated as 5.47 dB.

COMPARATIVE RESULT ANALYSIS

Table 4 shows the comparison of the simulated and measured results of the various antenna parameters of nano-ferrite doped flexible patch antenna with flat as well as bending of 20 degrees. The measured values are very well matched with the simulated values. The gain obtained in the fabricated antenna is also greater than 5dB. Moreover, the results indicate that the proposed antenna has achieved better performance when compared to the works done in [5] in which the nanomaterial is deposited on FR-substrate which is rigid and in [4] that employs oil palm empty fruit fibre (OPEFF) mixed with nickel oxide (NiO) nanoparticles reinforced with polycaprolactone (PCL) which has return loss of –11.93 dB, –14.2 dB and –16.3 dB for three patch antennas designed. In the above table, the results show that there is a gradual deviation in the performance of the antenna when it undergoes bending. The performance also depends on the dimension of the antenna. Because for a compact antenna, it is enough to bend the antenna to a certain limit. No need to bend the antenna fully due to the small size of the antenna. The overall performance of the nano ferrite mixed jute antenna is very much improved when compared to the performance of the jute-only antenna. The length and width of the proposed antenna are smaller than those of the conventional rectangular microstrip antenna.

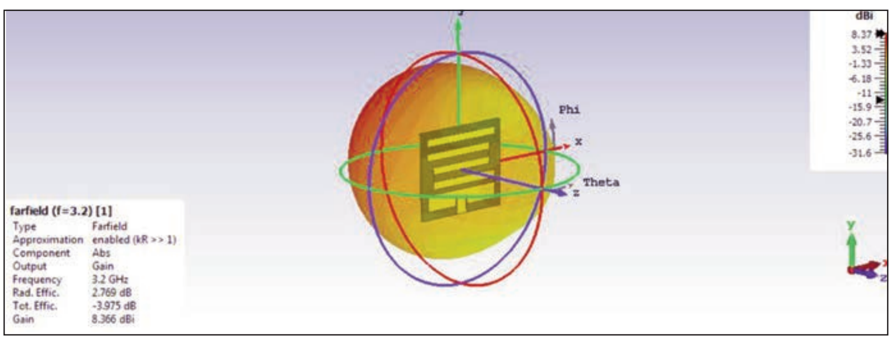


Fig. 8. The simulated gain value of the proposed antenna

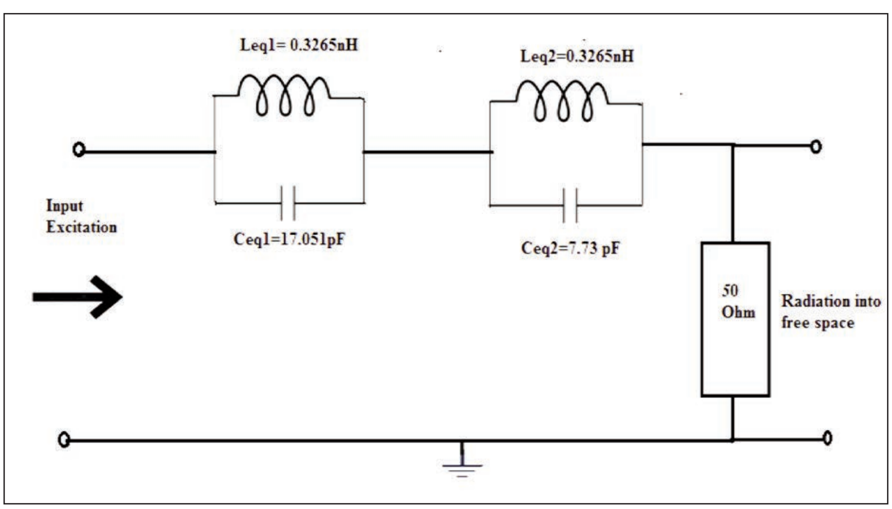


Fig. 9. Equivalent circuit model of the proposed antenna

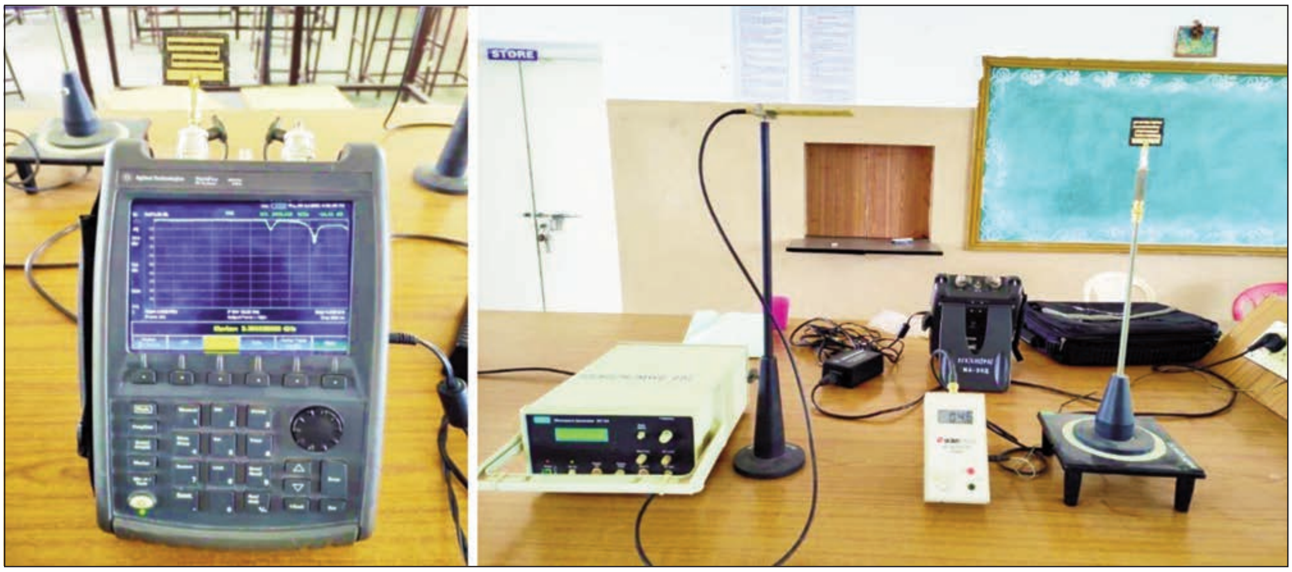


Fig. 10. Testing of fabricated antenna – S_{11} (left) and Gain(right) measurements

Table 4

COMPARISON OF SIMULATED AND MEASURED PARAMETERS OF THE PROPOSED ANTENNA		
Parameter	**Simulated values**	**Measured values**
Resonant frequency (GHz)	3.20	3.30
Return loss (dB)	–35.07	–26.42
VSWR	1.03	1.23
Bandwidth (MHz)	20	250
Gain (dB)	8.366	5.47

CONCLUSION AND FUTURE WORKS

The patch antenna is designed by depositing the newly prepared strong dielectric nanomaterial Ytterbium doped Copper-Manganese Nano Ferrites in the jute fabric for miniaturization, to avoid the air gap and for better performance. Also, the antenna is designed with varied meandered line patches using a super formula technique for improving the antenna performance. The performance is improved with reduced reflection coefficient, VSWR, Directivity and gain.

Comparatively, the gain of the antenna is enhanced to a very good level (greater than 5 dB) than the previous approaches. The fabricated antenna also shows better under free space and bending conditions. This paves the way to achieve the needs and develop portable devices for various applications such as aircraft, spacecraft, satellites, missiles, mobile, GPS, Wi-Max and radio locations, especially in Ground Radar (3.1–3.4 GHz) with the help of a low-cost flexible antenna. In future, the antenna can be designed using thin film nanomaterial as a substrate with flexible properties for wearable applications.

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Multimodal perception of digital protective materials

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ABSTRACT – REZUMAT

Multimodal perception of digital protective materials

The online clothing industry has gained popularity among consumers, and the perception of materials and equipment plays a crucial role in their purchasing decisions. Therefore, accurately representing their appearance in real-time is essential. This study aimed to subjectively evaluate 20 protective textile materials by translating their tactile characteristics into virtual prototypes. This was accomplished by scanning physical materials with an x-Tex scanner and processing them in KeyShot rendering software. Consequently, four scenarios featuring digital materials were created: S1-image, S2-video animation, S3-3D object, and S4-physical materials. Digital visual subjective evaluations were conducted for sensory analysis. Participants were asked to assess four visual and seven tactile characteristics using a seven-point Likert scale. Statistical analysis was employed to evaluate the sensory data collected through subjective testing. The results indicated that agreement values for the four scenarios ranged from 1.25 to 7.0, as illustrated in boxplot diagrams representing the subjects' agreement with the perceptual attributes.

Pairwise comparisons of the S4-S1, S4-S2, and S4-S3 scenarios concerning the difference in means revealed that attributes FR with values of 0.045 (S1), RM with values of 0.063 (S1), CR with values of 0.028 (S1), CR with values of 0.039 (S2), and 0.052 (S3) are closely aligned with the actual values, as the values obtained from these scenarios closely approximate 0. In contrast, the values of the remaining attributes were close to 1, indicating the difficulty of translating these attributes into digital format and achieving accurate perception. Assessing textile material properties through digital images remains a challenging task that requires in-depth subjective analysis.

Keywords: *scanning, digitization, rendering, subjective perception, tactile attributes, visual attributes*

Percepția multimodală a materialelor textile digitale cu rol de protecție

Industria de îmbrăcăminte online a câștigat popularitate în rândul consumatorilor, iar percepția materialelor și echipamentelor utilizate în transpunerea caracteristicilor acestora joacă un rol crucial în deciziile de cumpărare a potențialilor clienți. Prin urmare, reprezentarea cu acuratețe a aspectului materialelor textile în timp real este esențială. Acest studiu și-a propus să evalueze subiectiv 20 de materiale textile cu rol de protecție, prin transpunerea caracteristicilor tactile în prototipuri virtuale. Acest lucru a fost realizat prin scanarea materialelor fizice cu scanerul x-Tex și procesarea digitală a acestora cu software-ul de randare KeyShot. În consecință, au fost create patru scenarii de reprezentare a materiale digitale: S1-imagine, S2-animație video, S3-obiect 3D și S4-materiale fizice. Au fost efectuate evaluări subiective vizuale digitale pentru analiza senzorială. Participanții la experiment au fost rugați să evalueze patru caracteristici vizuale și șapte caracteristici tactile folosind metoda de evaluare Likert cu șapte puncte. Analiza statistică a fost folosită pentru a evalua datele senzoriale colectate prin testare subiectivă. Rezultatele au indicat că valorile de acord pentru cele patru scenarii au variat de la 1,25 la 7,0, așa cum este ilustrat în diagramele boxplot, reprezentând acordul subiecților cu caracteristicile perceptuale.

Comparațiile în perechi ale scenariilor S4-S1, S4-S2 și S4-S3 cu privire la diferența de medii au arătat că anumite caracteristici FR cu valori de 0,045 (S1), RM cu valori de 0,063 (S1), CR cu valori de 0,028 (S1), CR cu valori de 0,039 (S2) și 0,052 (S3) sunt strâns aliniate cu valorile reale, deoarece valorile obținute din aceste scenarii sunt aproximativ 0. În schimb, valorile caracteristicilor rămase au fost apropiate de valoarea 1, indicând dificultatea de transpunere a acestora în format digital și de a obține o percepție exactă a caracteristicilor materialelor. Evaluarea proprietăților materialelor textile prin intermediul imaginilor digitale rămâne o sarcină provocatoare care necesită o analiză subiectivă aprofundată.

Cuvinte-cheie: *scanare, digitizare, randare, percepție subiectivă, caracteristici tactile, caracteristici vizuale*

INTRODUCTION

Due to the urgent necessity for a sustainable environment, all companies are striving to find the most efficient process for production optimization [1]. Different strategies must be applied to achieve a smooth transition to a sustainable textile industry [2]; in this regard, the textile industry must have a robust digital arsenal [2]. In their creative endeavours, companies have embraced the concept of Digital Product Creation (DPC), which streamlines the prototyping process through virtual 3D simulations [3], enabling compliance with increasingly stringent environmental standards. By using digital galleries of textile materials in the DPC process, a sustainable future is supported by reducing waste through the elimination of physical materials [4–6]. To support a sustainable textile industry, the adoption of digital technologies has posed several challenges to material digitalization [7]. There is still a gap in translating the appearance from visual and tactile qualities into a digital environment and their physical counterparts [8, 9].

Standardized methods for representing materials in a digital format, even when based on images, are still lacking. Consequently, the investigation of existing databases is approached through subjective evaluation to enhance the quality of these databases [10]. Regarding the perceptual evaluation of material appearance, numerous studies have focused on analysing the perception of smart materials [11], such as knitwear made of wool, cotton, or synthetic fibres [12, 13], as well as functional textiles [14, 15]. Only a limited number of reference papers have provided concise information on the subjective appearance evaluation of protective materials. Research in the evaluation of protective textile materials has primarily centred on evaluating their comfort properties [16]. In this paper, we aim to investigate the disparity in appearance between digitized protective materials and their physical counterparts by assessing how perceptual material information is transmitted through tactile and visual stimuli. Additionally, it's important to note that current databases cover only a limited range of isotropic and anisotropic materials [17–19], and there are only a few databases specifically focusing on protective textiles [20]. This research assesses twenty digital protective textile materials obtained through scanning [21]. Our proposal suggests a standardized set of procedures for analysing materials using different techniques to conduct perceptual quality ratings across 11 selected attributes. The proposed method for evaluating protective materials is an extension of the research work conducted by Martin et al. [22]. The evaluation of digital materials' appearance is based on spatially varying BRDFs when compared to physical materials at the perceptual level, utilizing various stimuli.

The human brain has the innate ability to recognize materials and their properties merely by visual observation [23], without the need for physical contact [24]. This theory forms the basis for the evaluation proposed in this research, involving the examination of rendered materials as images on a screen in scenario S1. Motion is considered a crucial aspect in the perceptual evaluation of digital material surfaces [25, 26], which led to the creation of video animations in scenario S2. When it comes to testing protective materials, advanced evaluations can be conducted by simulating them on specific three-dimensional shapes. This process heavily relies on perceiving the fabric's properties to accurately assess their effectiveness. According to Xiughui Dong's study [27], subjects can perceive the textures of digital materials more easily when allowed to increase the resolution of objects. Therefore, scenario S3 was created to present materials as three-dimensional interactive objects, allowing for object rotation and resolution enhancement to improve texture visualization. Studies on the subjective analysis of textile materials suggest that visual and tactile senses play a crucial role in describing their properties [28]. To address this, scenario S4 was introduced, enabling subjects to interact with physical materials and answer the same questions as in the digital material evaluation scenarios (S1–S3). This paper aims to expand on the reference works by combining the main methods of subjective evaluation of textile materials. Starting with the multi-modal digital representation of materials in scenarios S1–S3 and having scenario S4 as a reference, we seek to answer the key question of whether subjects can obtain sufficient information to perceive the real characteristics of materials in digital format.

MATERIALS AND METHODS

Materials

In this paper, twenty textile materials were subjected to a subjective evaluation. These materials were chosen by the standards governing industrial products crafted from specialized fabrics, as dictated by European and national legislation. Among the materials examined, fourteen fall under the category of protective textile materials, specifically designed for waterproof equipment intended to shield against various environmental conditions, including precipitation in the form of rain or snow. These materials adhere to the ISO EN 343 standard and find utility as both inner and outer layers of protection in various sectors, encompassing roles such as firefighting, traffic policing, and hunting. Furthermore, one material was assessed for its suitability in the production of ballistic protection equipment, aligning with European regulations such as Standard EN166. Additionally, four materials were analysed in terms of their appropriateness for the manufacturing of protective equipment used in forestry applications, in compliance with standards including EN 381, EN ISO 20471, and EN 343. Lastly, a textile material intended for military product manufacturing was also included in the evaluation. The following protective materials, each characterized by its composition, were evaluated in this paper: 100% Polyester + 100% Polyurethane (film layer); 100% Polyamide + 100% Polyurethane (film layer); 32% Polyamide + 68% Polyester + 100% Polyurethane (film layer); 100% Nylon + 100% Thermoplastic Polyurethane (film layer); 100% Polyester; 45% Polyamide + 55% Polyester; 100% Polyester; 45% Polyamide + 55% Polyester; 32% Polyamide + 68% Polyester; 60% Polyamide + 32% Polyester + 11% Elastane; 100% Polyurethane; 89% Polyester + 11% Elastane. This paper provides a comprehensive evaluation of these materials within the scope of the research.

Method of scanning and digitizing materials

The scanning procedure for the twenty protective material samples was conducted using the x-Tex system, developed by Vizoo. Each fabric was scanned using the x-Tex [29] system, resulting in the acquisition of a synthetic SVBRDF (Spatially Varying Bidirectional Reflectance Distribution Function) dataset comprising six uniform texture maps: Base Colour, Normal, Volumetric, Metallic, Opaque, and Rough. The output format is compatible with rendering applications such as Key Shot [30] software, which was employed to generate four scenarios utilized in this study, namely S1-image, S2-video animation, S3-3D object, and S4-physical materials. The geometry of the materials was approximated from the set of photographic texture maps within a virtual scene, using an illumination algorithm. For scenario S1, the output format was JPEG, with an image size of 2560 pixels in width by 1440 pixels in height, and a resolution of 300 dpi. In scenario S2, which involved an animated scene, the camera was rotated at –45 degrees, the camera focus distance was set to 800 mm, and the scene was rendered at 60 FPS (frames per second) to create a clip lasting 15 seconds, with a resolution of 2560 pixels by 1440 pixels. For scenario S3, the materials were rendered as interactive 3D objects, with the following settings: 26 frames of horizontal rotation and 16 frames of vertical rotation, resulting in a total of 416 frames for each 3D object, with a zoom factor of 200%. The results of the three scenarios used in the subjective evaluation are depicted in figure 1.

Visual and tactile attributes of materials for evaluation

To ensure the feasibility of this study, the primary objective was to analyse the key characteristics of protective materials. The selection of visual characteristics was based on relevant literature, encompassing a set of attributes focused on recognizing and perceiving material qualities, particularly those related to general text attributes. The descriptive attributes for visual properties of materials included gloss, colour, roughness, and transparency/opacity [31–37]. Similarly, the tactile attributes encompass softness, drape, elasticity/stretch properties, abrasion, thermal sensation, and moisture sensation/hygroscopicity [38–46].

Questionnaire evaluation

The subjective evaluation of protective fabrics was conducted using visual assessment techniques within digital/rendered scenarios. The assessment involved 24 subjects from Romania, comprising 6 males and 18 females, whose ages ranged from 22 to 59 years. All participants have higher education and extensive professional experience in the textile industry, which made them more critical and objective in their evaluation of textile materials. Before the assessment commenced, the subjects received instructions on the assessment procedures and processes. For data collection, a questionnaire based on a Likert scale was utilized [47]. This method was chosen because it is widely regarded as the most effective approach for assessing data in product analysis,

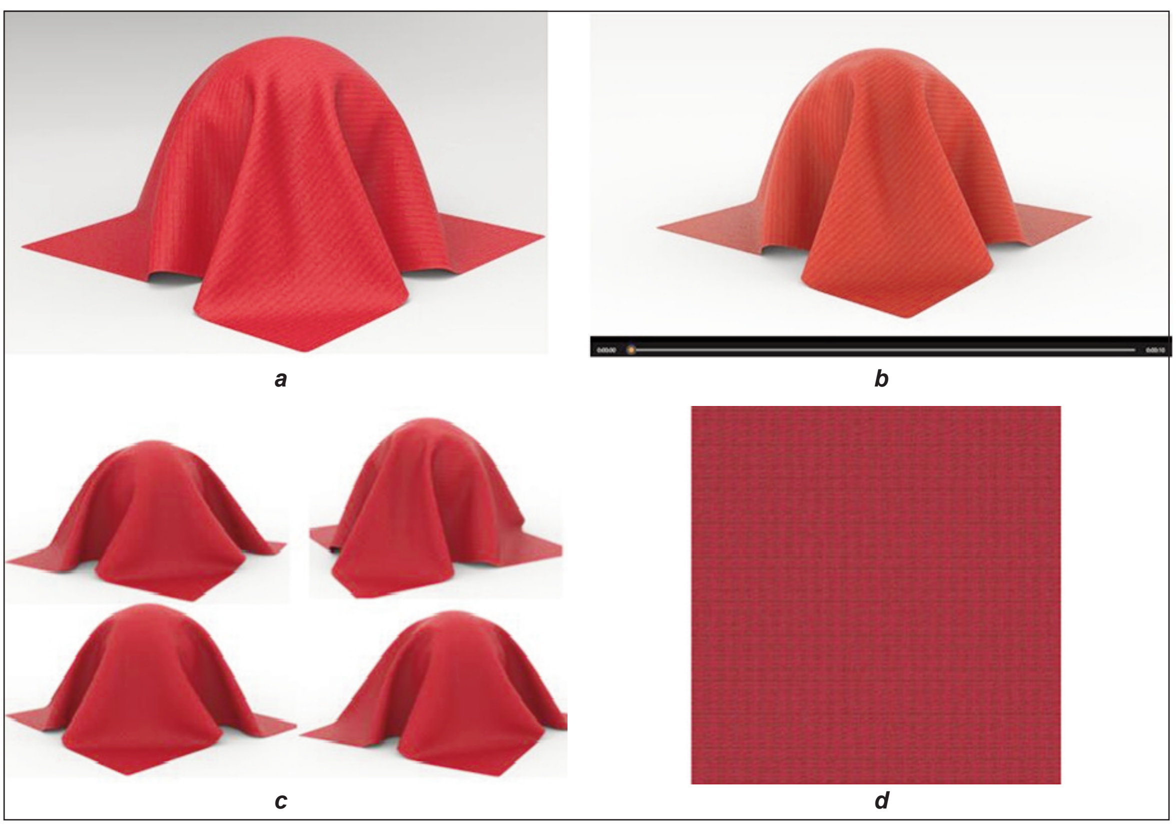

Fig. 1. Evaluation scenarios for the subjective evaluation of scanned textile materials:
a – S1 – image; *b* – S2 – video; *c* – S3 – 3D object; *d* – S4 – physical material

service evaluation, and the perception of specific products [37]. The subjects' task was to evaluate each digital representation of materials displayed on a monitor. The monitor used had a resolution of 3840 × 2160 pixels. To maintain consistency with the perception of potential buyers of textile protective materials or products made from these materials, the monitors were deliberately not calibrated. A total of twenty rendered protective textiles were assessed, employing a seven-point Likert rating scale, as detailed in table 1, where 1 indicated the lowest intensity and 7 represented the highest intensity of the attributes in question. This design was applied consistently across rendered images (S1), video (S2), 3D objects (S3), and physical materials (S4). To ensure that subjects did not experience confusion regarding the authenticity of digital materials in the first three scenarios, they were not permitted to touch or view the physical samples until scenario S4. Materials were to be evaluated solely within the digital context. After evaluating the first three digital scenarios, subjects were allowed to physically touch and examine the materials. They were then asked to respond to the same set of questions as in the previous three scenarios. A complete evaluation session for each corresponding scenario lasted approximately 4 hours and 30 minutes per person.

RESULTS AND DISCUSSIONS

The applied statistical analyses

In this research, boxplot diagrams were employed to assess the subjects' level of agreement regarding the perception of material characteristics. Additionally, the Friedman test was applied to evaluate and compare the perception across the three digital scenarios with the perception of physical materials in the fourth scenario. The final phase of the study involved establishing correlation coefficients to observe the associations between the scenarios.

Subjective evaluation of the perception of bipolar attributes regarding experts' degree of agreement

Subjective judgments involving human experts were employed to conduct sensory evaluations of the protective materials. All data obtained through the visual subjective evaluation technique were analysed using the statistical analysis software XLSTAT, a statistical tool integrated into Excel designed for sensory and visual analysis. The subjective evaluation of bipolar attributes, in relation to the degree of agreement among the experts, included the calculation of statistical indicators to measure the variation of textile material attributes. These indicators were then visually presented using boxplot diagrams. When considering the distribution of minimum and maximum values, the highest degree of agreement was observed in scenario S4 (8 out of 11 attributes), followed by S1 (8 out of 11), while the lowest degree of agreement was found in scenario S2 (6 out of 11). Regarding the symmetry of the distribution, a high level of agreement among the subjects was evident for attributes ML, UM, and NA (asymmetric to the right), as well as for attribute TO (asymmetric to the left). In the case of the remaining attributes, the distribution was approximately central. As for the height of the box, it appeared reduced for most bipolar attributes across all four scenarios, indicating that responses tended to cluster around the median. The results indicated that agreement values for the four scenarios ranged from 1.25 to 7.0, as represented in the boxplot diagrams, which illustrate the subjects' agreement with the perceptual attributes. Minimum agreement values were found in S1 for attribute NA, while the maximum agreement value was observed for attribute TO. This disparity suggests varying levels of agreement among subjects regarding the perception of attributes. Figure 2 depicts the boxplot diagram illustrating the subjects' level of agreement on the perception of the analysed materials, along with the minimum and maximum values obtained for all scenarios.

Table 1

QUESTIONNAIRE STRUCTURE REFERRING THE VISUAL AND TACTILE ATTRIBUTES

Abr.	Evaluated attributes	1	2	3	4	5	6	7
ML	Gloss	Mat						Glossy
UM	Colour	Uncoloured						Multi-coloured
RM	Roughness	Rough						Silky
TO	Transparency	Transparent						Opaque
FR	Softness	Flexible						Rigid
GU	Drape	Heavy						Easy
ER	Elasticity	Elastic						Rigid
SG	Thickness	Thin						Thick
AA	Friction	Slippery						Adherent
CR	Thermal sensation	Warm						Cold
NA	Hygroscopicity	Non-absorbent						Absorbent

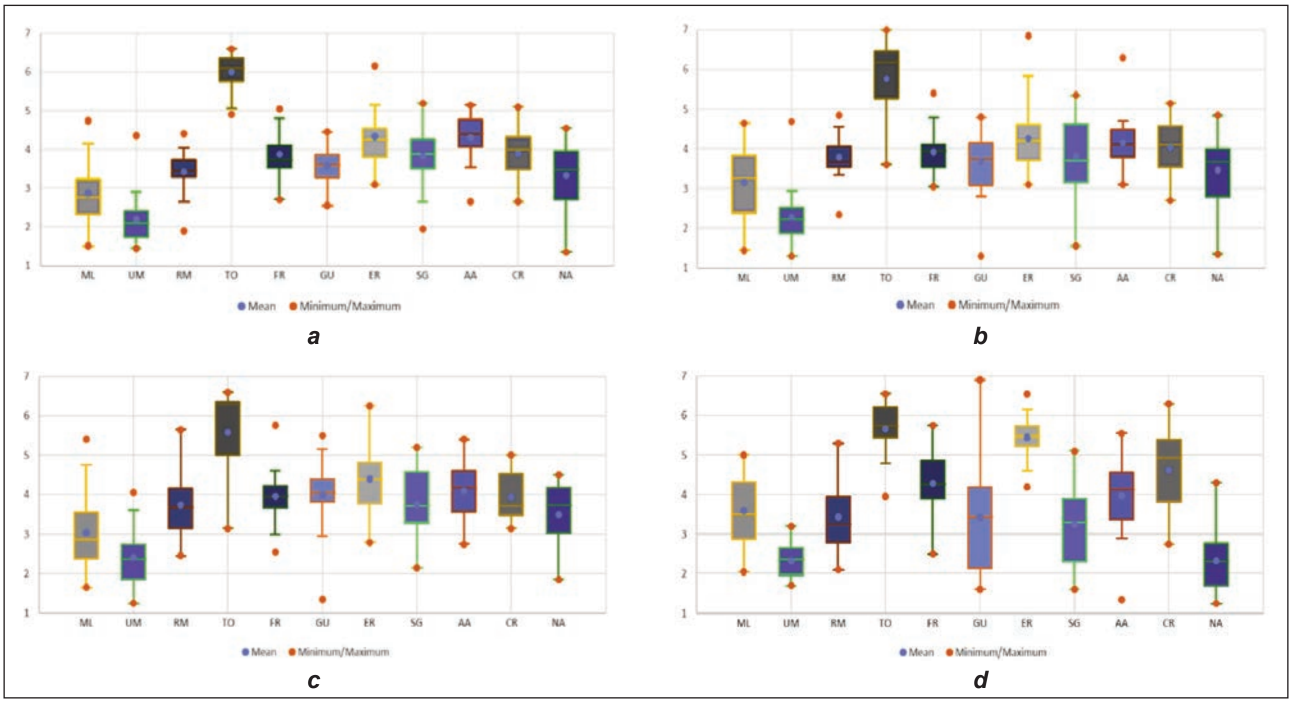

Fig. 2. Boxplot diagram on materials properties perception in scenario S1, S2, S3, S4: *a* – S1 Min = 1.35 (NA), Max = 6.6 (TO); *b* – S2 Min = 1.3 (UM,GU), Max = 7 (TO); *c* – S3 Min = 1.35 (GU), Max = 6.6 (TO); *d* – S4 Min = 1.25 (NA), Max = 6.9 (GU)

Comparative analysis between scenarios of the bipolar attributes

The subsequent phase of this study involved an analysis of scenarios, specifically a comparison between scenarios S1, S2, and S3, representing digital materials, and scenario S4, featuring physical materials. This analysis aimed to elucidate the differences in perception between digital and physical materials. The Friedman test was employed to evaluate and compare the four scenarios. All data analyses for all materials were conducted in pairs, with S4 serving as the reference scenario. The closer the difference in means is to 0, the more closely aligned the S1–S3 scenarios are with the S4 scenario. The results are presented in table 2, with significant differences from the S4 scenario highlighted in bold. The pairwise comparison of the S4–S1, S4–S2, and S4–S3 scenarios, concerning the difference in means, reveals that attributes FR with values of 0.045 (S1), RM with values of 0.063 (S1), CR with values of 0.028 (S1), CR with values of 0.039 (S2), and 0.052 (S3) closely approximate the truth. This is evident as the values obtained for these scenarios closely approach the value of 0. Conversely, the values for the remaining attributes were closer to 1, underscoring the challenge of translating these attributes into digital format and perceiving them accurately.

Table 3 presents a comparison of pairs of scenarios, namely S4–S1, S4–S2, and S4–S3, concerning the p-values. The closer the "p" values are to 1, the more closely aligned the S1–S3 scenarios are with S4. Significant differences from the S4 scenario are highlighted in bold in the results.

The challenge in translating attributes like ML, FR, ER, SG, CR, and NA may be attributed to technical scanning and rendering conditions. The disparities in ER, SG, AA, and NA attributes underscore the complexity of translating tactile attributes into a digital format. For ML and FR attributes, significant differences are observed in scenario S1 only. These differences indicate that the representation of static three-dimensional materials in scenario S1, as opposed to scenarios S2 and S3 where materials are depicted in three-dimensional motion, didn't allow for the identification of the degree of material transparency. In the case of attributes UM, RM, and GU, significant differences are evident in scenarios S1–S3 when compared to scenario S4. Additionally, for attributes UM, RM, and GU, significant differences are highlighted between scenarios S1–S2–S3 compared to scenario

Table 2

COMPARING SCENARIOS BASED ON THE MEAN DIFFERENCE

Attribute		**Mean difference**		
	Scenario	**S1**	**S2**	**S3**
ML	S4	0.917	0.583	0.833
UM	S4	0.646	0.333	0.104
RM	S4	**0.063**	–0.542	–0.188
TO	S4	–0.729	–0.458	–0.479
FR	S4	**0.045**	0.208	0.230
GU	S4	–0.250	–0.500	–0.750
ER	S4	1.583	1.958	1.458
SG	S4	–1.083	–0.938	–0.729
AA	S4	–0.563	–0.479	–0.458
CR	S4	**0.028**	**0.039**	**0.052**
NA	S4	–1.125	–1.229	–1.313

Table 3

COMPARISON BETWEEN SCENARIOS BY REFERENCE TO "P" VALUES				
Attribute		**"p" value**		
	Scenario	**S1**	**S2**	**S3**
ML	S4	0.069	0.400	0.117
UM	S4	0.309	**0.808**	**0.992**
RM	S4	**0.998**	0.467	**0.958**
TO	S4	0.208	0.609	0.573
FR	S4	0.045	0.208	0.230
GU	S4	**0.908**	0.537	0.186
ER	S4	0.000	<0.0001	0.001
SG	S4	0.021	0.060	0.208
AA	S4	0.433	0.573	0.609
CR	S4	0.028	0.039	0.052
NA	S4	0.015	0.006	0.003

S4. Concerning the UM attribute, the results are similar for scenarios S2 and S3, with a value close to 1, indicating a similar perception of material colour in both digital representation scenarios. Regarding the GU attribute, the values are similar and close to 1 in scenario S1, with lower values in scenarios S2 and S3. This reflects the challenge of conveying the draping of materials through a static image. Finally, for the RM attribute, the values are similar and close to 1 in scenarios S1 and S3, but significant differences are observed in scenario S2, indicating that roughness was harder to perceive in scenario S2.

Calculating correlation coefficients to observe the associations between scenarios

Correlation coefficients were calculated to observe the associations between scenarios S1, S2, and S3 in relation to scenario S4. The resulting data are presented in table 4. Upon reviewing the data in the table, it becomes apparent that there are no very high correlations for the UM attribute in scenario S1, the TO attribute in scenario S3, and the SG, AA, and CR attributes in scenario S2. Instead, medium correlations are observed for the ML attributes in scenario S1, RM and NA in scenario S3, ER in scenario S2, as well as the UM and FR attributes in scenario S2. In contrast, only low and very low correlations are found for the S3 scenario. The majority of statistically dependent bipolar attributes concerning S4 are found in the case of scenario S2.

Table 4

CORRELATION COEFFICIENTS BETWEEN SCENARIOS			
Attribute	**Scenarios**		
	S1–S4	**S2–S4**	**S3–S4**
ML	0.350	0.220	0.041
UM	**0.539**	–0.170	0.055
RM	0.147	0.138	0.320
TO	0.106	0.188	**0.562**
FR	–0.137	–0.107	0.146
GU	0.042	0.139	–0.119
ER	0.062	0.254	–0.050
SG	0.291	**0.585**	0.225
AA	0.176	0.478	0.330
CR	0.194	**0.516**	0.105
NA	–0.035	–0.030	0.207

Correlation coefficients intervals interpretation:
- 0.0 < 0.1 – very low correlation
- 0.1 < 0.3 – low correlation
- 0.3 < 0.5 – average correlation
- 0.5 < 0.7 – high correlation
- 0.7 < 1 – very high correlation.

CONCLUSIONS

Research on the perception of protective textile fabrics has been extended through the use of subjective fabric assessment. This method is considered non-traditional due to the absence of established standards for deviations in textile perception in digital images. Interpreting and predicting the exact margin of error for these deviations has proven challenging. The questionnaire on the characteristics of protective textile materials aimed to assess the following bipolar attributes: Gloss (matt-glossy), Colour (unicolour-multicolour), Roughness (rough-matt), Transparency (transparent-opaque), Softness (flexible-rigid), Drape (heavy-light), Elasticity (elastic-rigid), Thickness (thin-thick), Friction (slippery-sticky), Thermal sensation (warm-cool), and Hygroscopicity (non-absorbent-absorbent). The complexity involved in transposing textiles into a digital format is evident in the results obtained from the bipolar attribute evaluation experiment. The results display a wide distribution for all attributes represented digitally. As expected, the subjects exhibited the highest level of agreement when assessing materials' physical and tactile attributes in the S4 scenario, where they could see and touch the physical sample. The highest degree of agreement was found in the case of the S4 scenario (8 out of 11 attributes). Surprisingly, an equal number of agreements (8 out of 11 attributes) were obtained from scenario S1 (rendered image). The lowest agreement was observed in the case of the S2 scenario (6 out of 11). In the comparative analysis between scenarios for the bipolar attributes, significant differences were noted for the ML, ER, SG, and NA attributes in all three scenarios (S1-S3) compared to scenario S4. These differences underscore the difficulty of translating these attributes into a digital format. The challenge in translating the ER (elastic-rigid) attribute, a tactile attribute, may be attributed to certain technical factors influencing its digital representation. This is compounded by variations in subjects' interpretations, often influenced by diverse prior experiences related to material perception. Similar difficulties were encountered with the SG (thin-thick) and NA (non-absorbent-absorbent) attributes. The data obtained significantly deviates from the truth concerning the S4 scenario, indicating the complexity of perceiving these characteristics. Furthermore, numerous challenges in multimodal perceptions of protective materials remain to be addressed, emphasizing the need for further research in this direction.

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Green HRM practices in textile sector of Pakistan and its impact on green innovation and environmental sustainability

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ABSTRACT – REZUMAT

Green HRM practices in textile sector of Pakistan and its impact on green innovation and environmental sustainability

The issue of Environmental sustainability is getting more attention from academia over the last few years. Green Human Resource Management Practices (GHRM) are important in every aspect of environmental sustainability. This research study examines the impact of Green Human Resource Management Practices on environmental sustainability through the mediating role of green innovation in the textile sector of Pakistan. This study is quantitative in nature, and data was collected through a survey questionnaire. The data was analysed with the help of SPSS and Smart PLS. The findings indicate that GHRM practices significantly contribute to green innovations. Green innovations such as green product innovation and green process innovation significantly contribute to environmental sustainability.

Keywords: *green human resource management, green product innovation, green industry innovation, green process innovation, environmental sustainability*

Practici privind managementul verde al resurselor umane în sectorul textil din Pakistan și impactul acestora asupra inovației ecologice și sustenabilităţii mediului

Problema sustenabilităţii mediului a primit din ce în ce mai multă atenție din partea mediului academic în ultimii ani. Practicile ecologice de management al resurselor umane (PEMRU) au un rol important în fiecare aspect al sustenabilităţii mediului. Acest studiu de cercetare examinează impactul practicilor ecologice de management al resurselor umane asupra sustenabilităţii mediului prin rolul de mediere al inovației ecologice în sectorul textil din Pakistan. Acest studiu este de natură cantitativă, iar datele au fost colectate prin metoda sondajului. Datele au fost analizate cu ajutorul programelor SPSS și Smart PLS. Rezultatele empirice indică faptul că practicile ecologice de management al resurselor umane contribuie în mod semnificativ la inovațiile ecologice. Inovațiile ecologice, cum ar fi inovarea produselor „verzi” și inovarea proceselor ecologice, contribuie în mod semnificativ la sustenabilitatea mediului.

Cuvinte-cheie*: managementul verde al resurselor umane, inovare de produse ecologice, inovare verde în industrie, inovare de procese ecologice, sustenabilitatea mediului*

INTRODUCTION

Globalization has brought new environmental challenges, and governments and businesses both increasingly understand how important environmental sustainability is for long-term social and economic well-being [1]. A growing number of businesses are turning to green human resource management (GHRM) to improve their image and meet environmental objectives as a result of government mandates, environmental regulations, and stakeholders [2]. To improve environmental performance and obtain a competitive edge, GHRM practices are becoming more important [3]. It is an emerging perspective for the researchers. GHRM are the methods executed to eliminate the negative environmental facets to upgrade the positive environmental footprints of the organizations. GHRM allows employees to take an active part in sustainable applications and urges others to take active participation in sustainability problems. These factors apply human resource practices to the viable usage of resources of the organization to enhance environmental sustainability. More and more, GHRM is seen as a critical instrument for adopting green initiatives and environmental management practices [4]. By “the HRM elements of environmental management”, we mean anything that has to do with people management [5]. Economic growth is the most important factor in ensuring the long-term viability of businesses [6]. One of the elements that contribute to climate change is economic growth [7]. As a result, businesses must be accountable for environmental protection as economic actors [8]. All business players, from SMEs to corporations, must exercise environmental control. Innovative choices are linked to frontline workers' knowledge, abilities, and behaviours that generate value, according to [9] and

[10]. Employees' green skills, motivation, and opportunities will be difficult to apply in a company with no green innovation culture.

MOTIVATION OF THE STUDY

To investigate and explain the HRM-performance connection in the context of Pakistan's textile industry, the study used the resource-based view (RBV) of the business and the ability-motivation-opportunity (AMO) theory. The connection between human capital and business performance is not new, and it may be found in existing HRM and strategy literature [11]. According to the resource-based view (RBV) of the business, competitive advantage and performance are determined by how companies utilize strategic resources that are valuable, uncommon, and difficult to duplicate by market competitors [12].

Current research shows that human resource management (HRM) has evolved from antiquated practices like those that saw little participation from employees to ones that allow employees to improve their skills, knowledge, and attitudes via participation and support [13–15]. When we look at the literature on sustainable HRM, we see GHRM as an important addition since it focuses on corporate environmental management practices and connects HRM practices with the company's environmental management activities via green HRM [16, 17].

Innovation, for all means and purposes, ensures not just a competitive edge, but also environmental and social benefits [18]. Related core ideas have arisen when environmental innovation, eco-innovation, GI, and sustainable innovation are assigned to various corporate divisions [19]. According to prior research, the phrases ecological innovation, eco-innovation, environmental innovation, and GI are equivalent [20]. Sustainable innovation includes both social and environmental components [21].

Green innovation is defined as the adoption of organizational practices such as green and sustainable raw materials, the use of fewer materials during product design using eco-design principles, and the goal of reducing emissions, water, electricity, and other raw materials consumption [22]. Several studies have found that green innovative organizations are more successful [23] and have better overall performance than their competitors because they use their green resources and capabilities to respond quickly and appropriately to customer needs [24] and add intangible values and assets [25]. HR management techniques that focus on building a commitment culture rather than compliance have a positive effect on a company's creative mindset [13, 26]. Furthermore, strategic HRM has a positive influence on product innovation in organizations with a dynamic culture and a flat organizational structure, as stated by Wei, Liu and Herndon [27].

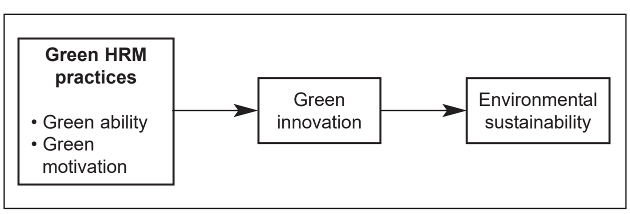

Fig. 1. Research framework

RESEARCH METHODOLOGY

The research work trails applicable research techniques and numerical methods that are reinforced by the value of aggregations and extent [28]. The suggested agenda in figure 1 is deductively explored to quantify the connection between proposed ways and start the submitted results. The research is cross-sectional since the data around variables A and B were collected to represent happening at a unique point in time [29]. Due to limited, time, resources and budgetary constraints, this study focused on those textile units that also have outlets and offer brands. A structured questionnaire was used to gather the essential data from textiles. Questionnaires were distributed to the Managers (Top level to bottom level) of the textiles sectors of Faisalabad. Data was collected from middle-level managers and operation managers from the textile sector from Lahore and Faisalabad cities of Pakistan.

Data analysis

Microsoft Excel (2016), PLS Smart 3.0, and IBM SPSS Statistics 23 bundle were utilized to conduct the required information results. For the approval of an instrument validity of the variables examination were decided

Demographics of the respondents

Table 1 depicts the demographic information of respondents which included gender, age, work experience, and designation. The details are presented in the table.

Common method bias

Harman's single factor score, in which all items (testing latent variables) are put into one common factor, is one of the easiest techniques to determine whether CMB is present in your research. If the overall variance for a single element is less than 50%, CMB is not affecting your data, and hence the findings [30]. The test released rotated arrangements of eleven variables with one factor clarifying 24.08% of the variance, and eleven elements clarifying 67.96% of the fluctuation (table 2). The un-rotated arrangements did not produce a general factor, recommending that 'common method variance' does not seem to be risky.

Measurement model

The measurement model analysis explains how dimensions of latent variables are dignified regarding their measurement properties and perceived (observed) items [31]. This specific section highlights the evaluation of the outer model (measurement) by assessing the internal consistency, item reliability, discriminant validity and convergent reliability [22].

Table 1

DEMOGRAPHIC VARIABLES OF THE TEXTILE MANUFACTURING INDUSTRY		
Demographic variables	**Frequency**	**Percentage (%)**
Gender		
Male	216	94.3
Female	13	5.7
Age		
21 – 25 years	53	23.1
26 – 30 years	29	12.7
31 – 35 years	128	55.9
Above 35	19	8.3
Work Experience		
Less than 5 years	62	27.1
5 to 10 years	72	31.4
10 to 15 years	49	21.4
15 to 20 years	43	18.8
Above 20 years	3	1.3
Designation		
Senior Officer	15	6.6
Assistant Manager	56	24.5
Deputy Manager	17	7.4
Manager	67	29.3
General Manager	74	32.3

Including 45 items to explain the four constructs of the model. Using the PLS algorithm for all reflective constructs was accomplished. The reflective scale's reliability was assessed by the SMART-PLS algorithm, through the estimations of convergent reliability and discriminant validity. The following model depicts latent variables (circles) and their measuring items (rectangles) appear in figure 2.

Table 2

HARMAN'S ONE-FACTOR TEST COMMON METHOD BIAS			
Component	**Initial Eigenvalues**		
	Total	**% of Variance**	**Cumulative (%)**
1	10.836	24.080	24.080
2	4.607	10.239	34.319
3	2.929	6.509	40.828
4	2.239	4.976	45.803
5	1.835	4.079	49.882
6	1.727	3.838	53.721
7	1.550	3.444	57.165
8	1.426	3.169	60.333
9	1.264	2.809	63.142
10	1.162	2.583	65.725
11	1.007	2.238	67.963

Note: Extraction Method: Principal Component Analysis.

The results show that all latent variables in the model are reflective by nature and it is defined by results that all-inclusive quality of the reflective variable's measure of PLS loadings, Cronbach's alpha, constructs 'AVE & composite reliability which is shown in table 3.

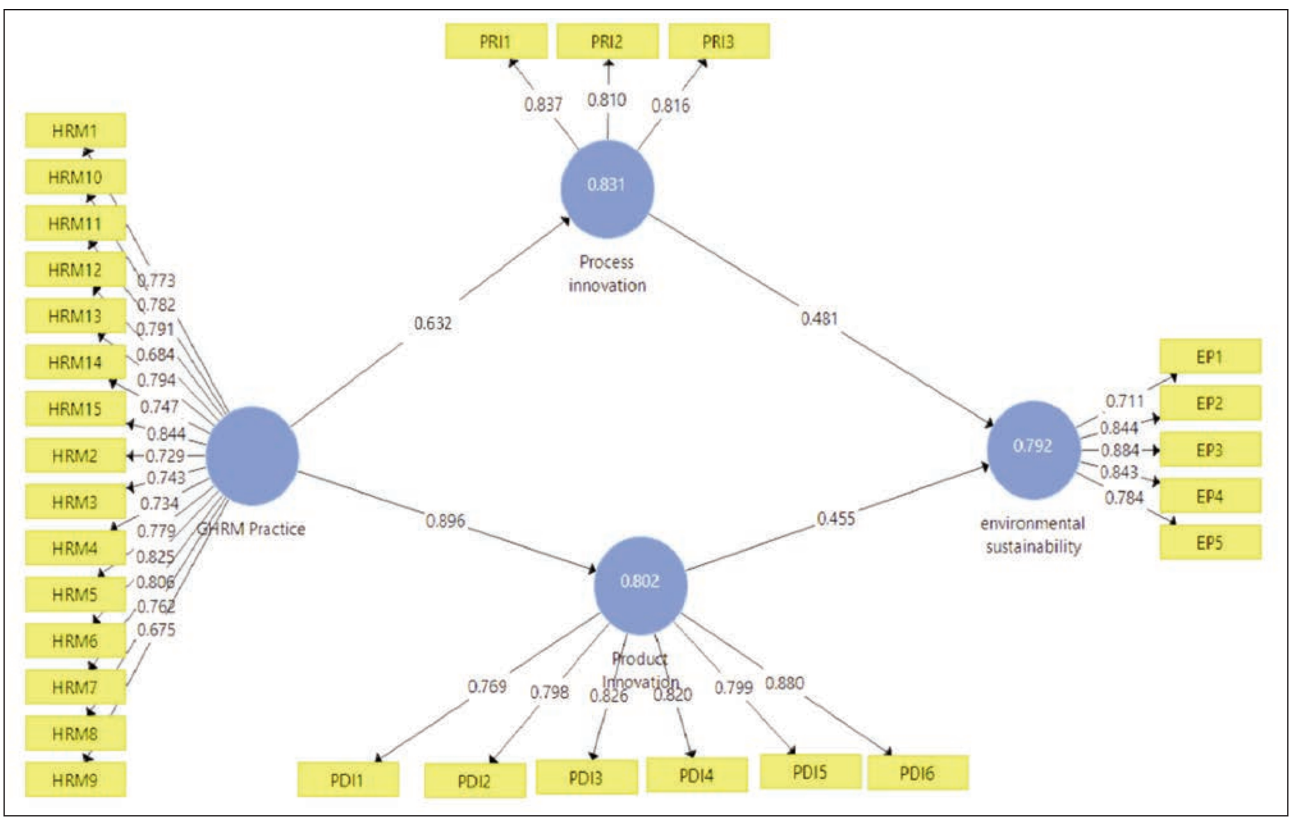

Fig. 2. Measurement model

Table 3

MEASUREMENT STATISTICS OF CONSTRUCTS				
Constructs, Dimensions, Items	**Item loading**	**AVE**	**CR**	**A**
Environmental sustainability (ES)		0.872	0.908	0.665
ES1	0.711			
ES2	0.844			
ES3	0.884			
ES4	0.843			
ES5	0.784			
Human Resource Management		0.949	0.955	0.587
HRM1	0.773			
HRM2	0.729			
HRM3	0.743			
HRM4	0.734			
HRM5	0.779			
HRM6	0.825			
HRM7	0.806			
HRM8	0.762			
HRM9	0.675			
HRM10	0.782			
HRM11	0.791			
HRM12	0.684			
HRM13	0.794			
HRM14	0.747			
HRM15	0.844			
Product Innovation		0.899	0.923	0.666
PDI1	0.769			
PDI2	0.798			
PDI3	0.826			
PDI4	0.820			
PDI5	0.799			
PDI6	0.880			
Process Innovation		0.759	0.861	0.675
PRI1	0.837			
PRI2	0.810			
PRI3	0.816			

First order constructs

By evaluating the first-order construct the item's loading was assessed (table 3). Regarding Green HRM practices, it consisted of fifteen items. The outer loadings fluctuated from 0.675 to 0.844 for the concerned items, and all items are significant at the level of 0.5 which is shown by the *t*-value results. Product innovation with no dimension but it comprises six items. The outer loadings fluctuated from 0.769 to 0.880 for the concerned items, and all items are significant which is shown by the *t*-value results. Process innovation is assessed by three items with no dimension. The outer loadings fluctuated from 0.816 to 0.837 for the concerned items, and all items are significant at the level of 0.5 which is shown by the *t*-value results. Environmental Sustainability was assessed by five items and it has no dimension as well, the outer loadings fluctuated from 0.711 to 0.884 for the concerned items, and all items are significant at the level of 0.5 which is shown by the *t*-value results.

Item reliability

All item's reliability is robust, as can be seen in table 3, Cronbach's alpha (α) is greater than 0.7. Moreover, composite reliability (CR) fluctuated from .861 to .955, which surpasses the prescribed limit of 0.70, affirming that all loadings used for this research have shown satisfactory indicator reliability.

Ultimately, all item's loadings are over the 0.6 cutoff [32].

Structural model

The Structural equation model (SEM) was assessed dependent on five criteria: (1) Path coefficient (β) that shows either relationship is weak or strong between constructs; (2) level of variance clarified or R square (R^2) which generally was called regression score; (3) standardized root mean square residual (SRMR); (4) *t*-values significance which clarify the relationship among variables are significant or not; (5) The Q2 that estimates how well the model reproduced the perceived values and its estimates of parameters [33].

Model fit

The SRMR of the model was 0.077, which demonstrates a sufficient model fit. An SRMR value under 0.08 was prescribed to be appropriate for PLS path models [34].

Parh coefficient (β) and t-value

In this study, the path coefficient was led to assess the relationship of the variables as hypothesized [35]. The resampling criteria of bootstrapping were run in accordance to induce statistical inference and to observe the influence of confidence intervals of path coefficients [36]. Table 4 indicates the results of the sample bootstrap analysis like (1) standardized path co-efficient (β), and (2) corresponding *t* and *p* values results.

SEM analysis was used with Smart-PLS to test all the Hypotheses. Latent variables were entered into the model and connected in a path, internal brand management as independent variable, employee brand building behaviour as mediation, and perceived brand ethicality as moderator and brand performance as dependent variable.

The first hypothesis shows Green human resource management practices will have a significant impact on Product innovation. The results show there is a significant relationship between GHRM practices and process innovation ($\beta = 0.632$; $t = 43.537$, $p < 0.0000$), supporting H1. Moreover, findings showed that GHRMS practices have a significant impact on product innovation ($\beta = 0.896$; $t = 23.459$, $p < 0.000$) supported H2. The third hypothesis shows there is a positive relationship between Product innovation and environmental sustainability ($\beta = 0.481$; $t = 4.888$, $p < 0.000$) accepting H3. The four hypotheses show there is a positive relationship between Process

Table 4

RESULT OF STRUCTURAL MODEL AND HYPOTHESES TESTING

Hypothesis	B	|*t* value|^	*p* value	Decision
GHRM Practice → Process innovation	0.632	43.537	0.000	Supported
GHRM Practice → Product Innovation	0.896	23.459	0.000	Supported
Process innovation → environmental sustainability	0.481	4.848	0.000	Supported
Product Innovation → environmental sustainability	0.455	4.328	0.000	Supported

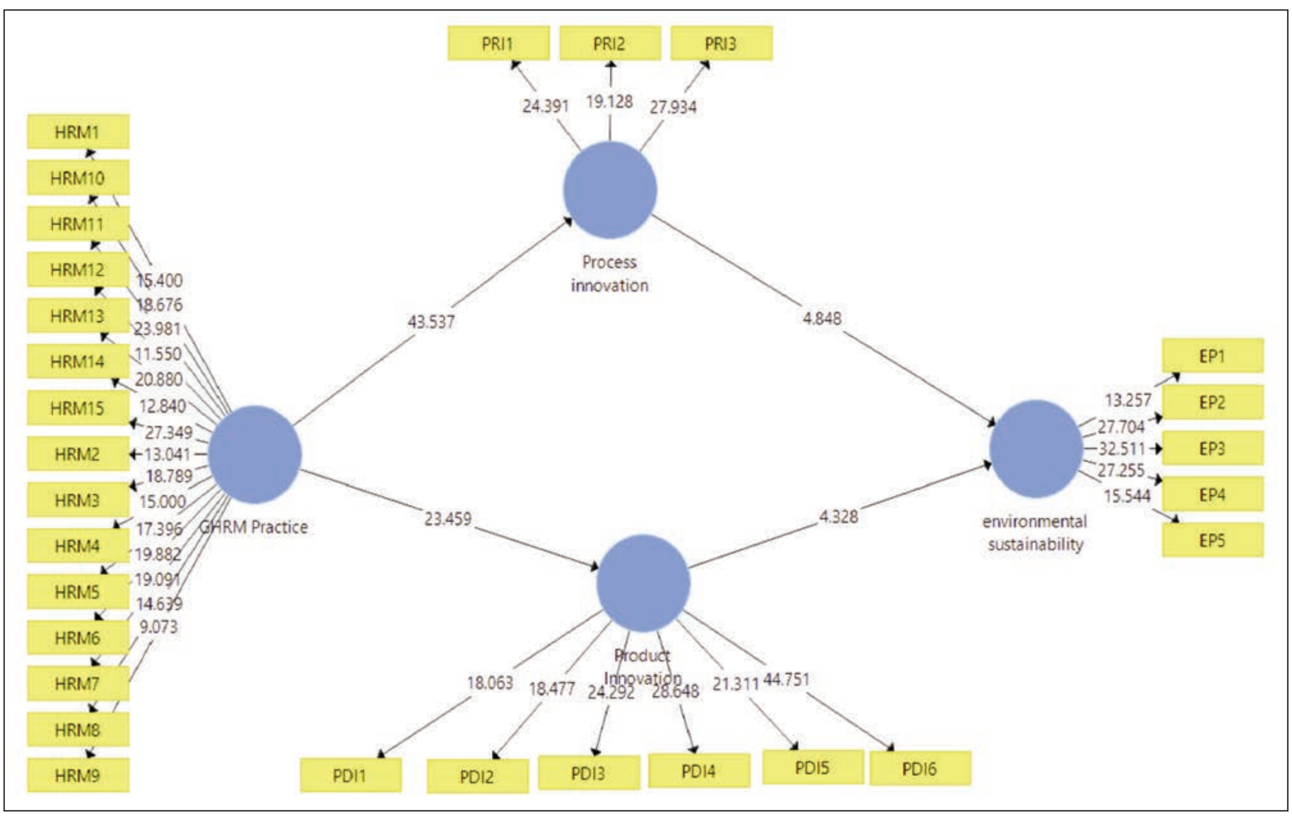

Fig. 3. Bootstrapping

Table 5

DIRECT INDIRECT EFFECTS MEDIATIONS						
Hypothesis	**Relationship**	**Direct effects**	**Indirect effects**	**Total effects**	**VAF**	**Mediation**
H4	GHRM → PDI → ES	β = 0.325 *p*-value = 4.325	β = 0.407 *t* = 3.759 *p*-value = 0.000	β = 0.846 *t*-value = 23.349 *p*-value = 0.000	55%	Partial
H4	GHRM → PRI → ES	β = 0.325 *p*-value = 4.325	β = 0.407 *t* = 3.759 *p*-value = 0.000	β = 0.734 *t*-value = 8.320 *p*-value = 0.000	60%	Partial

Note: β values and P values are shown in table VAF = Variance Accounted For. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$ (two-tailed).

innovation and environmental sustainability (β = 0.455; $t = 4.328$, $p < 0.000$) accepting H4.

TESTING THE MEDIATING EFFECTS

MacKinnon and Luecken [37] characterize 'Path Analysis' as an unpredictable measurement of relations among constructs which contain mediating as a significant component. The mediation effect issue is essential in any 'path analysis' and SEM. The construct is taken as a mediator considered as an arbitrate between the independent and dependent constructs [38]. The causal advances approach created by [39] has turned out to be most prevalent in testing mediation impacts. The fifth hypothesis indicates that Green innovation has two dimensions such as process innovation and product innovation mediating the relationship between GHRM practices and Environmental sustainability. Process innovation has a significant mediating impact (β = 0.438; $t = 4.684$, $p < 0.000$) on accepting H4. The β value of the direct effect of GHRM practices had a significantly positive effect on product innovation (β = 0.896, $t = 23.459$, *p*-value = 0.000) and had a significantly positive effect on environmental sustainability (β = 0.325, $t = 4.325$, *p*-value = 0.045). As shown in table 5 indirect effect of GHRM Practices on environmental sustainability (β = 0.407, $t = 3.759$, *p*-value = 0.000) showed Partial mediation and supporting hypothesis (4).
The β value of the direct effect of IBM had a significantly positive effect on Process Innovation Environmental sustainability (β = 0.632, $t = 43.537$, *p*-value = 0.000) and had a significantly positive effect on environmental sustainability (β = 0.325, $t = 4.325$, *p*-value = 0.045). As shown in table 5 indirect effect of GHRM Practices on Environmental sustainability (β = 0.407, $t = 3.759$, *p*-value = 0.000) showed Partial mediation and supporting hypothesis (5). In this, the variance accounted for (VAF) describes the size of the indirect effect about the total effect. According to Nitzl et al. [40] and Zhao, Lynch and Chen [41] a partial mediation indicated where the direct and indirect effects are significant.

The explanatory power of the model (r^2)

To evaluate the explanatory power of the model the R^2 value was analysed for every predicted variable. It shows the degree to which independent variables illustrate the dependent variables. R^2 in between 0 and 1 with higher values shows a higher level of predictive accuracy. Subsequent values of R^2 describe 0.25 for weak, R^2 0.50 for moderate and R^2 0.75 for substantial. Table 6 displays the percentage of variance clarified for every variable. 80.1% of employee brand-building behaviour and the items related to the variable. Also, 83% of Process innovation was elaborated by GHRM practices. In general, results demonstrate that values of R^2 endogenous variables fulfil the minimum criteria for the 0.10 cut off 'value, which is a sign of a moderately 'parsimonious' mode [42]. Most importantly, the outputs give significant validity to the model.

Table 6

PREDICTIVE RELEVANCE FOR ENDOGENOUS CONSTRUCTS			
No.	**Endogenous variables**	R^2	Q^2
1	PDI	0.801	0.550
2	PRI	0.830	0.523
3	ES	0.790	0.512

Predictive relevance

For this research, Q^2 was acquired by utilizing cross-validated redundancy systems as proposed by Chin [43]. A Q^2 larger than 0 infers that the model has predictive significance, while a Q-square under 0 proposes that the model needs predictive importance. As appeared in table 6, Q^2 for product innovation is 0.550 and 0.523 for process innovation and for environmental sustainability is 0.512. In this study, Q^2 values are greater than 0 which demonstrates the stability of the model, and the predictive significance of the inner model was satisfactory. The finding recommended that the proposed model has great predictive capacity. Thus, the results of the model fit, path coefficients, t-statistics, R^2, and Q^2 recommended the proposed model is substantial enough to clarify relations among variables, supporting all hypotheses.

CONCLUSION

The study's objective was to determine whether or not GHRM practices influence the environment by examining the mediating impact of green innovation.

According to the study's results, green innovations in the textile industry are very beneficial. Moreover, the study investigated whether the textile industry needed a green innovation to become a more viable economic sector and whether GHRM practices have a positive impact on environmental sustainability, which is in line with previous literature. This is especially true when the impact of GHRM practices on environmental sustainability increases as a result of green innovation, green process innovation, and green product innovation. The study revealed that GHRM practices in organizations contributed to environmental sustainability. The findings of the study contribute to the growing body of literature that shows that green product and process innovation leads to better environmental performance for companies.

LIMITATIONS

The current study is limited to Pakistan's textile sector. As a consequence, we recommend that future studies include the non-manufacturing sector. Second, this study did not look at the effect of environmental attitudes and values on HRM performance outcomes on the level of employees. Third, only internal factors impacting the execution of SMEs' environmental strategy were examined in this study. To better understand how to create, implement, and sustain proactive environmental plans in the non-manufacturing sector, we advise future studies to look at both internal and external elements.

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A new approach for predicting seam strength

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ABSTRACT – REZUMAT

A new approach for predicting seam strength

Owing to a high amount of stress, seam failure in workwear fabrics makes the fabric unsuitable although the fabric strength is high. It is therefore important to predict the seam strength to ascertain the performance of the garments during use and determine the required thread strength to match the required seam strength. An assembly is composed of a sewing thread and a fabric. The thread forming the seam undergoes several stresses during its passage from the sewing machine to the formation of the loop and when wearing the garment: these are mechanical stresses. Therefore, it is necessary to evaluate the strength of the seam. But, in the bibliography, most researchers have studied the strength of the seam concerning a single type of stitch. This work aimed to examine the seam's strength from the resistance to the loop of the thread for all types of stitches. In all of the earlier predictive equations, seam strength is predicted from thread loop strength with some multiplicative factors. The thread loop strength is measured without considering the stitch type. During the sewing process, threads loop differently from one stitch to another, therefore, the standard thread loop strength becomes unfit to predict the seam strength. In this paper, the effects of loop thread length and configuration are studied on thread loop strength and seam strength. The seam strengths predicted from the loop strength before and after considering the new loop configurations and the real seam strength are compared. So, new clamps for loop strength are configured and carried out. It is observed that there is a closer match between experimental and predicted seam strength with new loop configurations. The loop configuration has a significant effect on the thread loop strength and improves the accuracy of seam-strength prediction.

Keywords: *sewing thread, thread loop strength, seam strength, loop configuration, loop strength clamps*

O nouă abordare pentru preconizarea rezistenței asamblărilor prin coasere

Din cauza tensiunilor crescute, asamblările țesăturilor pentru îmbrăcămintea de lucru cedează, ceea ce face ca materialul să fie inadecvat, deși rezistența țesăturii este ridicată. Prin urmare, este important să se preconizeze rezistența asamblărilor prin coasere pentru a stabili performanța articolelor de îmbrăcăminte în timpul utilizării și pentru a determina rezistența necesară a firului, în concordanță cu rezistența necesară a cusăturii. Un ansamblu este compus dintr-un fir de cusut și o țesătură. Firul care formează cusătura suferă mai multe solicitări în timpul trecerii sale de la mașina de cusut până la formarea buclei și la purtarea îmbrăcămintei: acestea sunt solicitări mecanice. Prin urmare, este necesar să se evalueze rezistența asamblării prin coasere. Dar, în bibliografie, majoritatea cercetătorilor a studiat rezistența cusăturii în ceea ce priveşte un singur tip de cusătură. Scopul acestei lucrări a fost de a studia rezistența cusăturii de la rezistență la bucla firului pentru toate tipurile de cusături. În toate ecuațiile de predicție anterioare, rezistența cusăturii este preconizată din rezistența buclei de fir cu unii factori multiplicatori. Rezistența buclei firului este măsurată fără a lua în considerare tipul de cusătură. În timpul procesului de coasere, firele se desfășoară diferit de la o cusătură la alta, prin urmare, rezistența standard a buclei de fir devine inadecvată pentru a preconiza rezistența cusăturii. În această lucrare, influența lungimii și configurației buclei firului este studiată în ceea ce priveşte rezistența buclei firului și rezistența cusăturii. Se compară rezistența cusăturii estimată din rezistența buclei înainte și după luarea în considerare a noilor configurații de bucle și rezistența reală a cusăturii. Prin urmare, noi elemente de fixare pentru rezistența buclei sunt configurate și realizate. Se observă că este o concordanță mai strânsă între rezistența experimentală și cea preconizată a cusăturii cu noile configurații de bucle. Configurația buclei are o influență semnificativă asupra rezistenței buclei firului și îmbunătățește precizia predicției rezistenței cusăturii.

Cuvinte-cheie*: fir de cusut, rezistența buclei de fir, rezistența cusăturii, configurația buclei, elemente de fixare a rezistenței buclei*

INTRODUCTION

The seam performance and quality depend on various factors such as seam strength, seam slippage, seam puckering, seam appearance and yarn severance [1, 2]. Sewing needle penetration forces and fabric deformation during sewing are effective factors for seam performance, too [3–5]. The appearance and performance of the seam are dependent upon the quality of the sewing threads. One essential requirement of any thread is that it must be compatible with the needle size, various sewing machine settings (sewing speed, thread tension) and the fabric on which it is being sewn. Seam damage can be a serious cost problem, often showing only after the garment has been worn. The most important parameters that influence seam damage tendency are

Table 1

PHYSICAL CHARACTERISTICS OF FABRICS					
Fabric	**Weave**	**Yarn density**		**Weight (g/m²)**	**Thickness (mm)**
		warp (ends/cm)	**weft (picks/cm)**		
1	Plain	25	25	165	0.36
2	Twill 3/1	40	30	250	0.31
3	Twill 3/1	30	20	268	0.48
4	Twill 2/2	30	20	275	0.46
5	Twill 3/1	30	25	280	0.51
6	Twill 2/2	30	20	300	0.55
7	Twill 3/1	30	20	225	0.42
8	Twill 3/1	42	30	255	0.27
9	Twill 3/1	30	30	265	0.35

fabric construction, chemical treatments of the fabric, needle thickness and sewing machine settings with sewing thread. Fibre content, yarn construction, tightness and density are important parameters for fabric construction on seam damage. A large number of studies [6–9] have determined the seam strength according to ASTM 1683-04 standards, which express the value of seam strength in terms of maximum force (in Newton (N)) to cause a seam specimen to rupture [10].

The majority of thread breaks in a seam occur at a looped part of a stitch, and the loop strength of a thread is related more closely to stitch strength than linear tensile strength. Loop strength is the load required to break a length of thread that is looped through another thread of the same length; it is influenced by stiffness, fibre or filament type, ply and twist construction and the regularity of these factors. Many studies have predicted the seam strength from thread loop strength, stitch density and other factors [11–14]. The thread loop strength is measured without considering the stitch type. During the sewing process, threads loop differently from one stitch to another, therefore, the standard thread loop strength becomes unfit to predict the seam strength. In this paper, the effects of loop thread length and configuration are studied on thread loop strength and seam strength. The seam strengths predicted from the loop strength before and after considering the new loop configurations and the real seam strength are compared. So, new clamps for loop strength are configured and carried out.

MATERIALS AND METHODS

The detailed experimental procedure involved in carrying out this study is described in the following sections.

Fabric sample

Ten commercial samples of woven fabrics with different weaves and weights, commonly used for clothing, were prepared. Since denim fabrics are generally made of cotton or a mixture of cotton and elastane, the composition fabric chosen in this study is made of 100% cotton warp yarn and weft yarn in 95% cotton and 5% elastane. The physical characteristics of fabrics are shown in table 1. The fabric weight, thickness and yarn density were measured according to French Standards EN 12127. (1997) [15], ISO 5084. (1996) [16] and BS EN 1049-2 (1993) [17].

Sewing thread characteristics

A large variety of sewing threads is used in the clothing industry. The majority of the sewing threads used by the clothing industry are made from cotton and polyester fibre [18]. Three commercially sewing threads (60% PES, 40% CO) are used and chosen according to French Standard NF G 07-117 [19]. The thread characteristics are shown in table 2. The tensile proprieties were determined according to ISO 2062 (2009); the specimen was subjected to tension until break using a suitable tester (dynamometer type ‘LLOYD Instruments’ Lloyd LRX 2.5 K) [20].

Table 2

PHYSICAL CHARACTERISTICS OF SEWING THREADS			
Thread	**1**	**2**	**3**
Yarn count (tex)	25	30	40
Twist (tpm)	700	750	850
Twist direction	Z	Z	Z
Tenacity (cN/tex)	40.8	41.93	35.5

Measurement of tensile seam strength

To evaluate the seam strength, we have used two methods:

- the grab test: This test method can also be used to determine the seam strength in woven fabrics by applying a force perpendicular to the sewn seams according to ISO standard ISO 13935-1 [21]. The seam specimens are prepared with three different stitch densities.
- a prediction function for the theoretical calculation of the real seam strength [22]:

$$Ss = Sl * ds * ls * \alpha \quad (1)$$

Where *Ss* is the strength of the seam (N), *Sl* – loop strength of the thread (N), *ds* – density of the stitch (cm^{-1}), *ls* – length of the seam (cm) and α – coefficient of the seam between 0.8 and 1.1.

For the measure of loop strength, the thread samples were tested at 200 mm gauge length (*L*) at a constant time to break of 20±3 s on Lloyd LRX 2.5 K tensile tester as per French Standard NFG 07-310 [23]. (Laboratory of Textile Engineering LGTex, higher institute of scientific and technology studies, Ksar Hellal, Tunisia). The thread samples are looped as shown in figure 1.

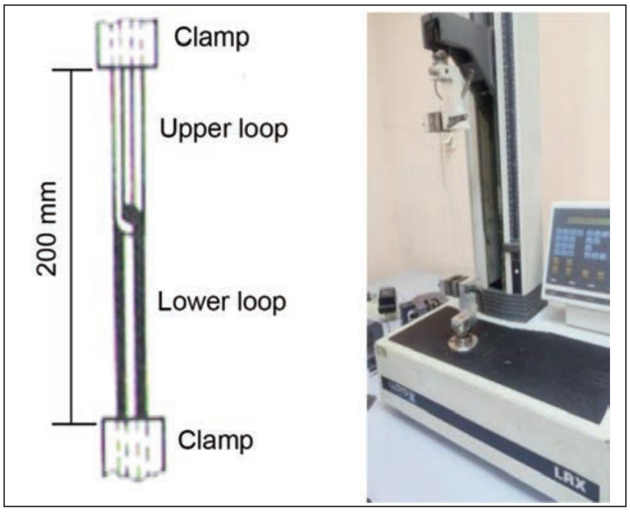


Fig. 1. Standard loop configuration (NFG 07-310)

To study the effect of the distribution of the length of the upper and lower loop on the loop strength and subsequently the seam strength, the loop strength is measured for three distributions ($L_{upper\ loop}$ = 1/2 *L*, $L_{upper\ loop}$ = 2/3 *L*, $L_{upper\ loop}$ = 3/4 *L*) in the new configuration corresponding the chain stitch type 401. This study is performed on thread 3.

Development of new loop configurations

The prediction function for the calculation of seam strength was developed basically for the lockstitch 301 the fact that the needle thread is looped through the bobbin thread of the same length as the standard loop configuration, however, it isn't the case for the other stitches. So, specific new configurations for each type of stitch were developed. For each stitch type, the behaviour of seam threads during a tensile test is determined. Therefore, two woven specimens (150 mm × 50 mm) are sewn by threads with different colours. Then these seam specimens are subjected to a constant maximum strain (tensile test). At this moment a photo (figure 2) is taken and analysed to develop the new loop configuration.

These configurations are developed for chain stitch type 401 and overedge stitch types 504, 514, 516, and 517. These stitches are mostly used in the apparel industry. To validate the new configurations, the real seam strength and the calculated seam strength for standard and new loop configurations are determined. Then, the coefficient α is calculated as follows:

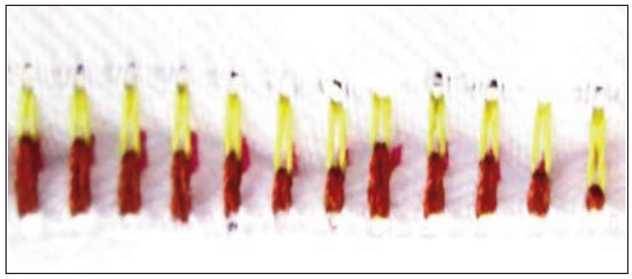


Fig. 2. Real seam behaviour to tensile test

$$\alpha = \frac{\textit{real seam strength}\ (N)}{\textit{calculated seam strength}\ (N)} \quad (2)$$

Conception and realization of news clamps for loop strength

The new clamps can be modelled as shown in figure 3.

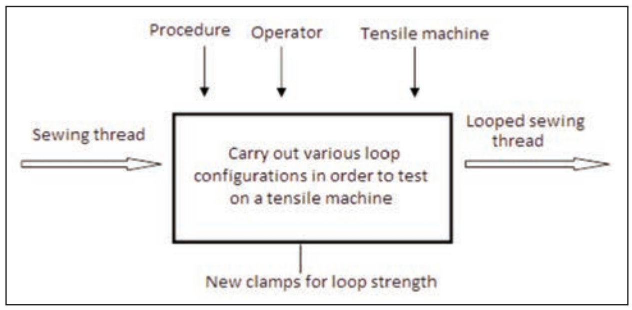


Fig. 3. New clamps modelling

The design of the clamps was performed on SolidWorks 2010 in a Windows environment.

RESULTS AND DISCUSSION

Thread loop strength

Table 3 shows that the size of the sewing thread is an important factor affecting loop strength. Higher sewing thread size leads to greater loop strength. This effect was proven by Sundaresan et al. who studied the effect of thread and fabric properties on sewing thread strength [24, 25].

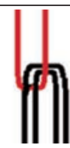
Table 3

SEWING THREADS LOOP STRENGTH			
Thread	Yarn count (tex)	Loop strength	
		Mean (N)	CV (%)
1	25	17.948	4.13
2	30	19.318	5.71
3	40	24.762	3.66

New loop configurations

Table 4 summarizes the standard and the new loop configurations for the studied stitches. The red loop is the upper loop(s) and the black one is the lower loop(s). The new loop configurations differ from the standard one, especially in several loops and several upper and lower yarns.

Table 4

STANDARD AND NEW LOOP CONFIGURATIONS		
Stitch type	**Standard loop configuration**	**New loop configuration**
Chain stitch 401		
Overedge stitch 504		
Overedge stitch 514		
Overedge stitch 516		
Overedge stitch 517		

New clamps

The new clamps can assemble and test several loops at once depending on the new configurations. These clamps contain three aligned cylinders donning (3), with a diameter of 3 mm, coated with a rubber material providing a good clamping of the yarns (figures 4, 5, 6).

Loop length effect on loop and seam strengths

The loop length distribution has an insignificant effect on the variation of the loop strength (table 5), but it minimizes the difference between the real seam strength and the calculated one (table 6). The minimum difference was visualized for the distribution Lupper loop = 3/4 *L*. This distribution is closer to the real configuration of chain stitch type 401. Stitch density was deemed to be an important attribute in seam quality because it assembles the fabric components. The change in stitch density exerts a great influence on seam strength (table 6).

The difference value is calculated per the following formula:

Table 5

EFFECT OF LOOP LENGTH DISTRIBUTION ON LOOP STRENGTH		
Loop length distribution	**Loop strength**	
	Mean (N)	**CV (%)**
$L_{upper\ loop}$ = 1/2 L	26.968	6.45
$L_{upper\ loop}$ = 2/3 L	26.959	11.17
$L_{upper\ loop}$ = 3/4 L	26.044	4.78

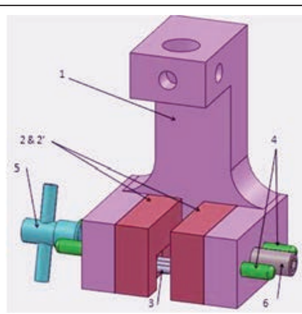


Fig. 4. 3-D view of a clamp: *1* – clamp; *2* and *2'* – two jaws; *3* – cylinders donning; *4* – pins; *5* – clamping screws; *6* – set screws

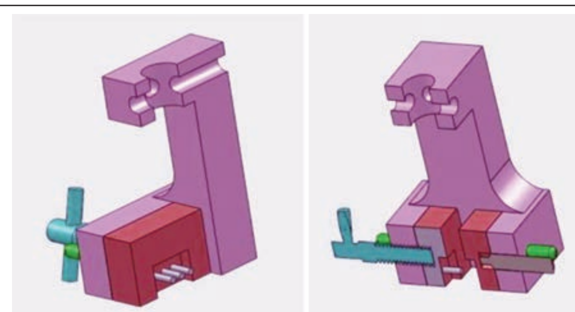


Fig. 5. Sectional view of a clamp

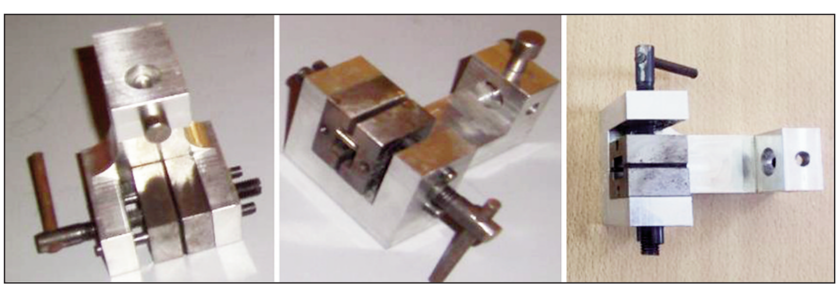


Fig. 6. Photos of carried clamps

Table 6

EFFECT OF LOOP LENGTH DISTRIBUTION ON SEAM STRENGTH				
Stitch density (cm^{-1})	**Real seam strength (N)**	**Difference (%)**		
		$L_{upper\ loop}$ = 1/2 L	$L_{upper\ loop}$ = 2/3 L	$L_{upper\ loop}$ = 3/4 L
2.5	291.380	3.95	3.92	0.55
3	315.840	13.2	13.2	10.16
4	386.273	10.47	20.39	17.6

$$Difference\ (\%) = \frac{Ss\ (calculated) - Ss\ (real)}{Ss\ (real)} \times 100 \quad (3)$$

New loop configuration effect

The difference between the loop strengths in the standard and new configurations for the chain stitch 401 is 8.77% against 48% for the overedge stitch 514 (table 7). These results show that the loop configuration has a very important effect on the loop strength. This can be explained by the fact that the new configurations for these stitches are very close to the standard ones. The difference value is calculated per the following formula:

$$Difference\ (\%) = \frac{Sl\ (new\ conf.) - Sl\ (standard\ conf.)}{Sl\ (standard\ conf.)} \times 100 \quad (4)$$

The overedge stitches are stronger than the chain stitch (table 8). The effect of stitch type on seam strength relates to the greater loss in strength that affects needle threads [4]. Variations in seam type can also affect seam strength with improved strength obtained in some of the lapped seams which have additional rows of stitching. Table 8 shows that the standard configuration gives values of α that exceed the limits given by the standard which are between 0.8 and 1.1 [1], except for the chain stitch 401. This can be explained by the fact that for this stitch, the loopback mode between the upper thread and lower thread is very close to the lockstitch 301. However, the loopback mode for the other stitches is very different. So the new loop configurations improve the accuracy of seam-strength prediction

CONCLUSION

In this study, the effects of loop thread length and configuration on thread loop strength and seam strength were investigated. The effect of the loop configuration on the accuracy of seam strength prediction is also studied. The results of this work are summarized below:

Table 7

EFFECT OF LOOP CONFIGURATION ON LOOP STRENGTH					
Stitch type	**Loop strength**				**Difference (%)**
	Standard configuration		**New configuration**		
	Mean (N)	**CV %**	**Mean (N)**	**CV %**	
401	24.793	5.12	26.968	6.45	8.77
504			26.968	6.45	8.77
514			36.811	8.15	48.73
516			46.247	10.20	86.53
517			42.442	10.80	71.18

Table 8

ASSOCIATIONS BETWEEN JOB STRAIN AND INDIVIDUAL AND ORGANIZATIONAL CHARACTERISTICS ACCORDING TO KARASEK'S MODEl					
Stitch type	**Calculated seam strength (N)**		**Real seam strength (N)**	**α**	
	S.C	**N.C**		**N.C**	**S.C**
401	371.460	404.52	368.66	0.91	0.99
504		404.52	450.63	1.11	1.21
514		552.165	436.85	0.79	1.17
516		693.705	516.35	0.744	1.39
517		636.63	458.33	0.719	1.23

Note: S.C – standard configuration; N.C – New configuration.

- New clamps for loop strength are configured and carried out.
- The effect of loop length distribution on the variation of the loop strength is not significant, but it minimizes the difference between the real seam strength and the calculated or predicted one (case of chain stitch 401).
- The loop configuration has a significant effect on the thread loop strength and improves the accuracy of seam strength prediction.
- The standard loop configuration gives values of α that exceed the limits given by the standard which are between 0.8 and 1.1, unlike the new loop configuration.

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Application of Kansei engineering in the innovative design of traditional fashion elements

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ABSTRACT – REZUMAT

Application of Kansei engineering in the innovative design of traditional fashion elements

Kansei engineering can quickly establish the relationship between human emotion and product composition, and it is expected to be an important method for design evaluation. This paper investigates the application of Yungang Grottoes Bodhisattva necklaces to modern attire, specifically the cheongsam, with a focus on the Kansei Engineering-based design approach. The study introduces sensory evaluation to analyse the suitability of various types of Yungang Grottoes Bodhisattva necklaces in cheongsam designs and the sensual style of high-fit cheongsam designs. Two experiments were conducted, with Experiment 1 assessing the suitability of Yungang Grottoes Bodhisattva necklaces on different traditional cheongsam, and Experiment 2 examining the overall style of cheongsam designs when combined with Yungang Grottoes Bodhisattva necklace designs. Fuzzy logic was employed in Experiment 1 to evaluate the suitability of each necklace element, while Experiment 2 incorporated sensory evaluation to determine the sensual style of high-fit cheongsam designs, assessed through subjective ratings by 50 industry experts and 50 evaluators (women aged 18 to 35). The investigation utilized standard procedures for subjective evaluation experiments, resulting in the determination of the suitability of three mainstream cheongsam designs with 24 Yungang Grottoes Bodhisattva necklaces, as well as the identification of high-fit cheongsam sensual styles. The paper concludes by providing recommendations for the design of Yungang Grottoes Bodhisattva necklaces on the cheongsam, utilizing the relative weight values of cheongsam designs as guidance for future applications. This research contributes to understanding the integration of cultural artefacts in contemporary fashion, offering insights into design considerations and potential enhancements of the cheongsam through the incorporation of Yungang Grottoes Bodhisattva necklaces.

Keywords: *Yungang Grottoes, Bodhisattva necklace, cheongsam design, sensory evaluation*

Aplicarea ingineriei Kansei în designul inovator al elementelor tradiționale de modă

Ingineria Kansei poate stabili rapid relația dintre emoția umană și compoziția produsului și este de așteptat să fie o metodă importantă pentru evaluarea designului. Această lucrare investighează aplicarea colierelor Bodhisattva din grotele Yungang la ținuta modernă, în special la rochia Cheongsam, cu accent pe abordarea de proiectare bazată pe ingineria Kansei. Studiul introduce evaluarea senzorială pentru a analiza adecvarea diferitelor tipuri de coliere Bodhisattva din grotele Yungang în modele de rochie Cheongsam și la stilul senzual al modelelor de rochie Cheongsam. Au fost efectuate două experimente, experimentul 1 analizând adecvarea colierelor Bodhisattva din grotele Yungang pe diferite tipuri de rochie Cheongsam tradiționale, iar Experimentul 2 analizând stilul general al modelelor de rochie Cheongsam, atunci când sunt combinate cu modelele de colier Bodhisattva din grotele Yungang. Logica de tip fuzzy a fost folosită în Experimentul 1 pentru a evalua adecvarea fiecărui element de colier, în timp ce Experimentul 2 a inclus evaluarea senzorială pentru a determina stilul senzual al modelelor de rochie Cheongsam, evaluate prin analize subiective de către 50 de experți din industrie și 50 de evaluatori (femei cu vârsta cuprinsă între 18 și 35 ani). Investigația a folosit proceduri standard pentru experimente de evaluare subiectivă, ceea ce a dus la determinarea adecvării a trei modele de rochie Cheongsam tradiţionale, cu 24 de coliere Bodhisattva din grotele Yungang, precum și identificarea stilurilor senzuale de rochie Cheongsam. Lucrarea se încheie cu recomandări pentru proiectarea colierelor Bodhisattva din grotele Yungang pe modele de rochie Cheongsam, utilizând valorile scorurilor relative ale modelelor de rochie Cheongsam ca ghid pentru aplicații viitoare. Această cercetare contribuie la înțelegerea integrării artefactelor culturale în moda contemporană, oferind perspective asupra considerentelor de design și potențialelor îmbunătățiri ale rochiei Cheongsam prin întegrarea colierelor Bodhisattva din grotele Yungang.

Cuvinte-cheie*: Grotele Yungang, colier Bodhisattva, design de rochie Cheongsam, evaluare senzorială*

INTRODUCTION

The research paper explores the application of Yungang Grottoes Bodhisattva necklaces to modern attire, particularly the cheongsam. The Yungang Grottoes, constructed during the Northern Wei Dynasty, house numerous statues, including over 3,000 Bodhisattva statues [1]. The Bodhisattva necklace, crafted with various jewels, is an iconic decorative object used for body adornment. These statues represent a blend of Indian Buddhist art, indigenous Chinese art, and Xianbei art, reflecting their cultural significance in China [2]. The rich variety of shapes and combinations of the Yungang Grottoes statues showcases exceptional carving techniques and traditional art styles, symbolizing prayers during tumultuous times. Therefore, incorporating the Bodhisattva necklace from the Yungang Grottoes into modern attire holds great importance for preserving traditional Chinese culture and art.

While traditional Chinese elements are highly suitable for traditional Chinese attire, their direct application to modern clothing can be challenging due to differences in dressing culture and habits [3]. However, the cheongsam, originating from the Republic of China, represents a blend of Chinese history and traditional culture. It has not only influenced the aesthetic style of the Republican era but also remains popular and wearable in modern times [4]. Thus, the cheongsam serves as a suitable sample for exploring the integration of traditional Yungang Grottoes Bodhisattva necklace elements.

The objective of this paper is to investigate the suitability of different types of Yungang Grottoes Bodhisattva necklaces in mainstream cheongsam designs. Experiment 1 employs sensory evaluation, [5] inspired by previous research on design elements in children's mackintoshes, to assess the compatibility of Yungang Grottoes Bodhisattva necklaces with cheongsam designs. Industry experts participate as subjects in this experiment. Experiment 2 selects the most suitable cheongsam designs based on the results of Experiment 1, utilizing expert interviews to identify appropriate sensual psychological words for the samples. Young women are chosen as evaluators to assess the sensual style of each cheongsam design. Through these experiments, the paper explores the application value of Yungang Grottoes Bodhisattva necklaces in modern clothing, specifically classic cheongsam designs.

The study is divided into four main parts: the description of the historical and aesthetic values of Yungang Grottoes Bodhisattva necklaces (2^{nd} section), the implementation of a questionnaire-based experiment (3^{rd} section), the discussion and analysis of the questionnaire findings (4^{th} section), and the overall conclusions drawn from the study (5^{th} section).

THE HISTORICAL AND AESTHETIC VALUES OF YUNGANG GROTTOES BODHISATTVA NECKLACES

The origins of Yungang Grottoes Bodhisattva necklaces can be traced back to the ancient South Asian subcontinent, where they were used by the nobility as body adornments. The term “Keyura” in Sanskrit refers to a jade ornament draped over the body, and it was worn by both male and female nobles in the Indian states [6]. As Buddhism originated in India, the necklace was frequently used to embellish statues of Buddha and Bodhisattvas. In ancient India, the wearing of necklaces held a hierarchical significance, and Bodhisattvas were privileged to wear them due to Prince Siddhartha Gautama, who later became the founder of Buddhism and was revered as the Buddha [14]. During his time as a prince, Siddhartha Gautama adorned himself with necklaces, which consequently became prominent ornaments in the design of Buddha and Bodhisattva statues.

Bodhisattva statues in India were often depicted topless, and adorned with three or four intricately decorated necklaces to symbolize their prestige [15]. Before the Han dynasty in ancient China, the term “yingluo” was not commonly used and was perceived as a foreign concept. “Yingluo” refers to accessories made of precious stones and jade, with “ying” and “luo” carrying their respective connotations of precious stones. Ancient texts describe the necklaces on Buddhist statues, specifying that they were composed of jewels and jade such as pearls, which could emit five colours of light in the Buddhist realm. These necklaces were frequently employed as neck ornaments for Bodhisattva statues, serving not only as decorative elements but also conveying solemn and beautiful symbolism.

From an aesthetic standpoint, the shape and function of Yungang Grottoes Bodhisattva necklaces can be understood as an expression of its content and form, influenced by cultural factors and artisanal skills within different historical contexts. The shape of the Yungang Grottoes Bodhisattva necklace reflects the aesthetic pursuits and cultural ideologies of its time. Three main aesthetic features are observed in these necklaces. First, balance and symmetry are evident in the visual equilibrium between the stylized components and the overall necklace. Research indicates that the three primary types of Yungang Grottoes Bodhisattva necklaces – short, medium, and long – are symmetrical, contributing to the visual balance of the overall statue and accentuating its dignity and prestige. Second, design aesthetics encompass the regular arrangement of points and dots, lines and curves, and surfaces and textures, resulting in a richer aesthetic experience and a sense of rhythmic interchange. Finally, variety and unity are observed, indicating the variation in necklace styles while maintaining formal cohesion or the divergence of forms based on unified components. This approach allows for a greater diversity of necklace shapes while maintaining visual harmony and balance [7]. The versatile design and aesthetic features of Yungang Grottoes Bodhisattva necklaces have influenced subsequent ornament and attire designs, with their balanced rhythmic beauty frequently employed in later artistic creations [17]. These traditional cultural elements have been widely adopted, demonstrating the significant aesthetic value brought forth by Yungang Grottoes Bodhisattva necklaces’ design elements and concepts to future generations [16].

Building upon these observations, this study conducts two experiments to investigate the practical application of Yungang Grottoes Bodhisattva necklaces in modern cheongsam designs.

EXPERIMENT 1: EVALUATING THE SUITABILITY OF YUNGANG GROTTOES BODHISATTVA NECKLACES APPLIED TO CLASSIC CHEONGSAM

Research methodology

Experiment 1 focused on assessing the suitability of Yungang Grottoes Bodhisattva necklaces when applied to classic cheongsam designs. The research employed a total of 24 representative Yungang Grottoes Bodhisattva necklaces and three classic cheongsams as research subjects. The aim was to investigate the overall compatibility of the 24 necklace types when paired with the three cheongsam designs. The research methodology encompassed three key phases: preparation, survey, and analysis.

During the preparation phase, several tasks were undertaken, including literature summarization, questionnaire development, and the creation of stimulus pictures. The literature summarization involved reviewing relevant scholarly sources to gather pertinent information. Subsequently, a well-designed questionnaire was developed to collect data on participants' perceptions of the necklace-cheongsam combinations. Additionally, stimulus pictures were created to visually represent the necklace-cheongsam pairings.

In the survey phase, the questionnaires were distributed to the participants. The participants were asked to provide their evaluations and preferences regarding the compatibility of each necklace concerning the three different cheongsam designs. The questionnaire responses were collected for further analysis.

Finally, in the analysis phase, the survey results were analysed using triangular fuzzy numbers. This analytical approach enabled a comprehensive assessment of the participant's responses, considering their preferences and perceptions regarding the necklace-cheongsam pairings. The use of triangular fuzzy numbers facilitated a more nuanced interpretation of the data, considering the inherent subjectivity associated with aesthetic evaluations.

The specific research technique route followed in Experiment 1 is presented in figure 1, outlining the sequential steps undertaken during the research process.

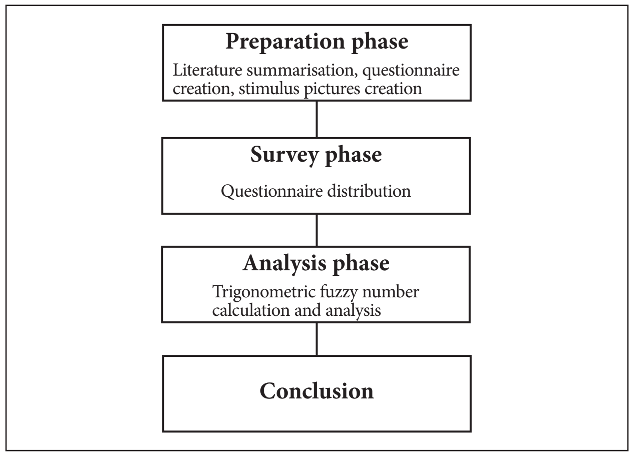


Fig. 1. Research technique route

Given the subjective nature of the evaluation in Experiment 1 and the need to capture relevant information for the design solution, the obtained results consist of semantic evaluations that cannot be directly quantified using conventional data analysis methods. To address this challenge, this research employs fuzzy logic as a means to quantify and process the subjective data, enabling the evaluation to be effectively analysed. By utilizing fuzzy logic, the data is defuzzified, transforming the fuzzy results into precise and scientifically grounded outcomes [8].

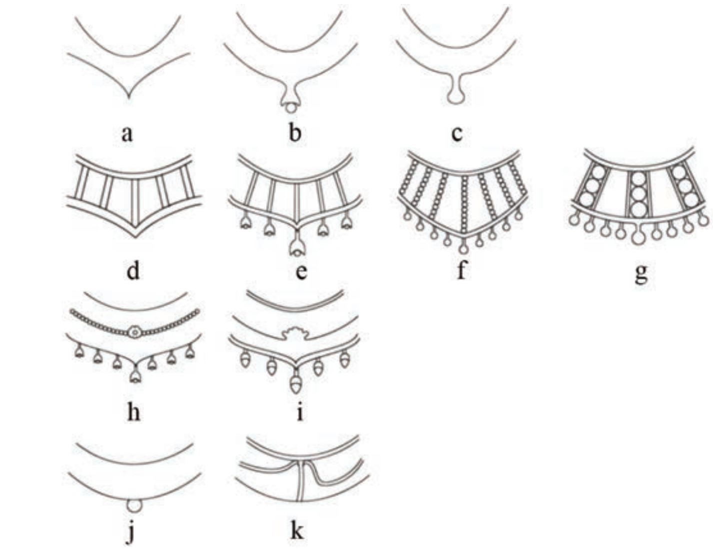
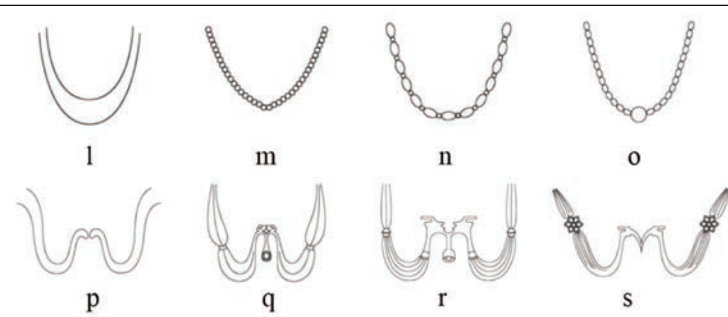
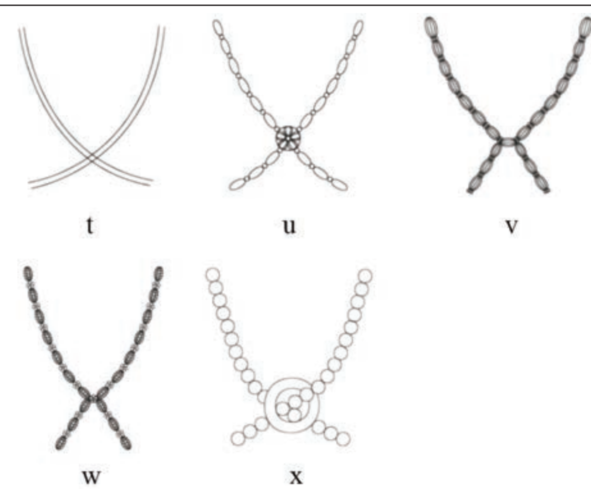
Fuzzy set tools, originally developed by Zadeh and Klaua [9], offer an alternative to classical set theory. In classical set theory, the membership of elements in a set is assessed in binary terms, where an element is either a member or not. However, fuzzy set theory allows for a gradual assessment of membership by employing membership functions that range within the real unit interval [0, 1] [10]. Fuzzy sets provide a generalization of classical sets, as the membership functions of fuzzy sets encompass the indicator functions of classical sets when the latter only take values of 0 or 1 [11]. Given its ability to handle uncertain data, fuzzy set theory finds wide application in sensory/subjective evaluation, offering distinct advantages in dealing with linguistic and clustering problems [12, 13].

In this study, evaluators tended to use sensory words rather than numbers, so quantifying the suitability of clothing became a problem. The fuzzy logic method can solve this problem very well, as it can quantify the sensory fuzzy words into data for calculation. By leveraging the principles of fuzzy set theory, this research applies fuzzy logic to analyse the subjective data obtained in Experiment 1. This approach allows for a more comprehensive and robust evaluation, enabling the translation of subjective assessments into quantifiable and meaningful outcomes, thereby enhancing the scientific rigour of the study.

Sample identification

A significant portion of the Yungang Grotto Bodhisattva necklaces are worn on the upper body of the Bodhisattva and can be categorized based on their length: short (neck), medium (chest), and long (cross). Among these categories, the short necklaces are the most abundant within the Yungang Grottoes and exhibit an overall 'V' shape. Medium necklaces can be further classified into two primary types. The first type is characterized by a 'U' shape and consists of round beads of varying sizes that are intricately strung together. The second type, known as the 'W' shape or animal chest ornaments, features two symmetrical animal heads positioned on the chest, facing upwards towards each other. Lastly, the long necklaces represent the longest style among the Yungang Grotto Bodhisattva necklaces, extending down to the waist and abdomen in a crossed manner. The diverse array of shapes and styles observed in the Yungang

Table 1

SHORT, MEDIUM AND LONG NECKLACE SHAPES	
The Yungang Grottoes Bodhisattva Necklace Categories	**Necklace stylized picture**
Short Necklaces	
Medium Necklaces	
Long Necklaces	

Grotto Bodhisattva necklaces led to the selection of 24 most representative types for investigation in Experiment 1, as depicted in table 1.

The 1930s and 1940s marked a significant period in the modern history of the cheongsam, characterized by its splendour. This era witnessed the influence of the historical phenomenon known as "Western Learning Spreading to the East", which led to transformations in the design of the cheongsam. Notably, the length of the cheongsam was shortened from the extravagant sweeping-hem style to a more modest length, reaching the mid-calf or knee. Concurrently, there was a tendency to eliminate or reduce the length of the sleeves and decrease the collar height, resulting in a simplification of the garment with fewer elaborate decorations. In Experiment 1, the selection of cheongsam designs drew upon the collection of cheongsams at the Jiangnan University Folk Costume Heritage Museum, as well as popular classic cheongsam styles from the twenty-first century. Three classic cheongsams were chosen for the research, each featuring a common high stand-up

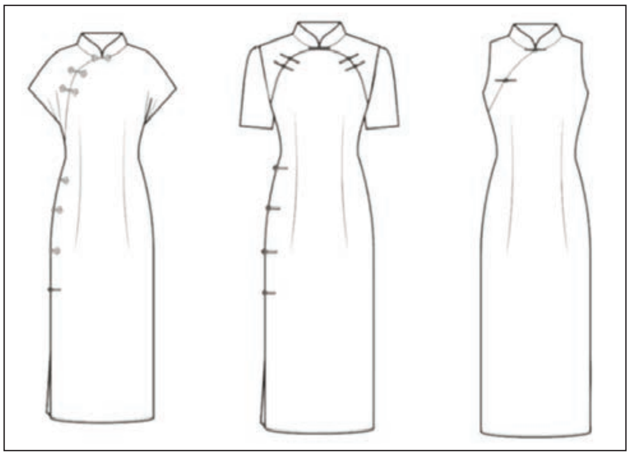


Fig. 2. Representative cheongsam design drawings

collar. Style A encompasses a large round front piece with raglan sleeves, while style B showcases a two-sided front piece with short sleeves. Lastly, style C exhibits an oblique front piece without sleeves. These selected cheongsam styles are illustrated in figure 2. Drawing upon a collection of 24 carefully chosen types of Yungang Grotto Bodhisattva necklaces and three representative classic cheongsams, the application of these necklaces to the basic cheongsam design was performed using Photoshop software. The resulting pairings were visually depicted and are presented in figures 3 to 5. Each pairing is assigned a unique identification number ranging from 01 to 24 for reference and analysis purposes.

Selection of survey respondents and determination of sample size

For Experiment 1, a carefully chosen group of experts within the apparel industry will serve as the survey respondents. The selection criteria for these respondents are as follows:

(1) They possess a minimum of five years of experience in working or conducting research within the clothing industry.

(2) They demonstrate a comprehensive understanding of traditional clothing, including consumer preferences and industry trends.

(3) They possess prior research or practical experience in the domain of incorporating traditional culture into modern clothing design.

A total of 57 questionnaires were distributed online for Experiment 1. The survey sample comprised 13 apparel designers, 20 apparel industry researchers, one fashion buyer, and 23 other professionals actively engaged in the apparel industry.

Questionnaire design

The online research was divided into two parts, the first part investigated the basic information about the subject such as gender, age and occupation. The second part introduced fuzzy terminology, throughout the fuzzy concept the evaluator el (l = 1, 2, ..., m, m = 20) will use the linguistic weight set Lk, Lk = {far more matched, more matched, a little more matched, moderate, a little less matched, less matched, far less matched} (k = 1, 2, 3, ..., 6, 7) to assess the relative suitability of the 24 Yungang Grottoes Bodhisattva necklaces to each cheongsam.

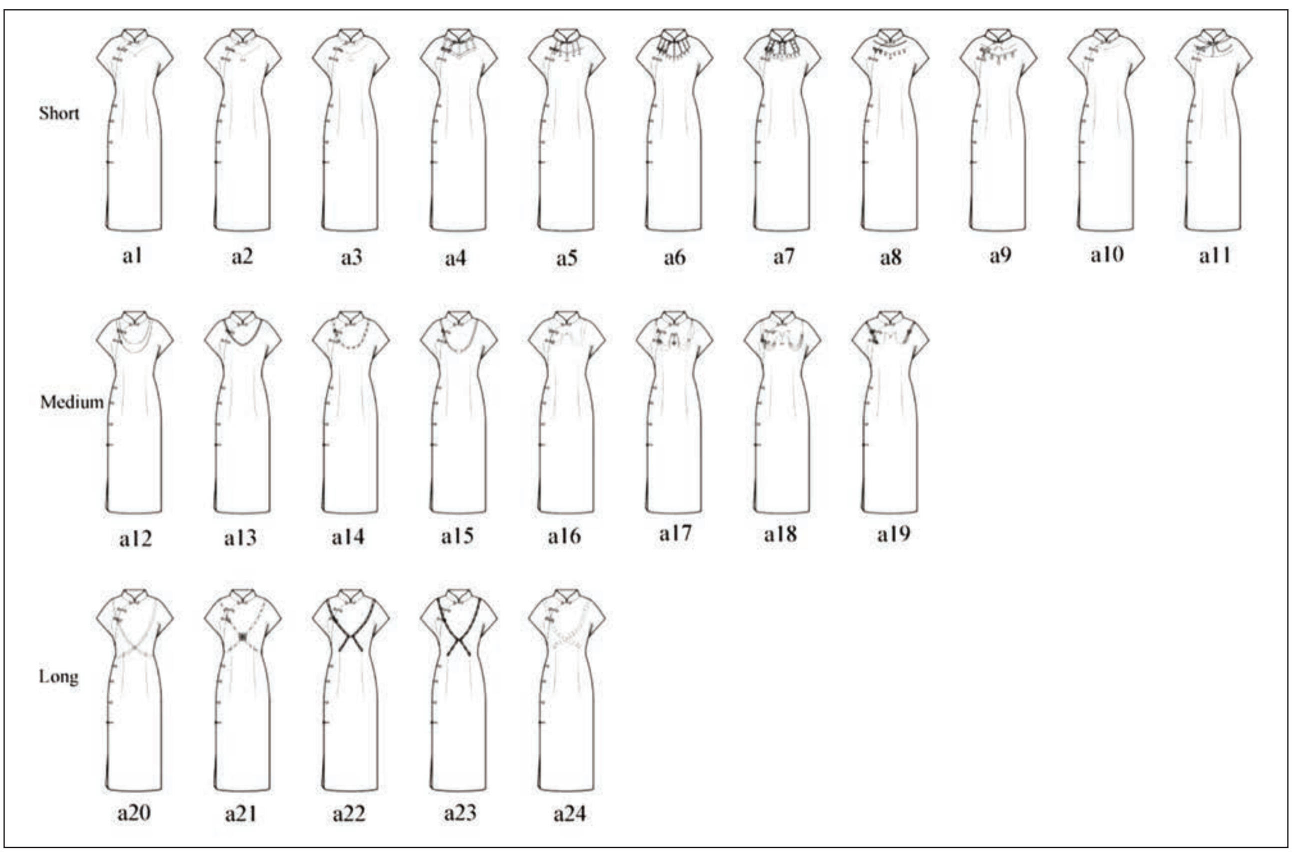


Fig. 3. Style A cheongsam with necklace designs

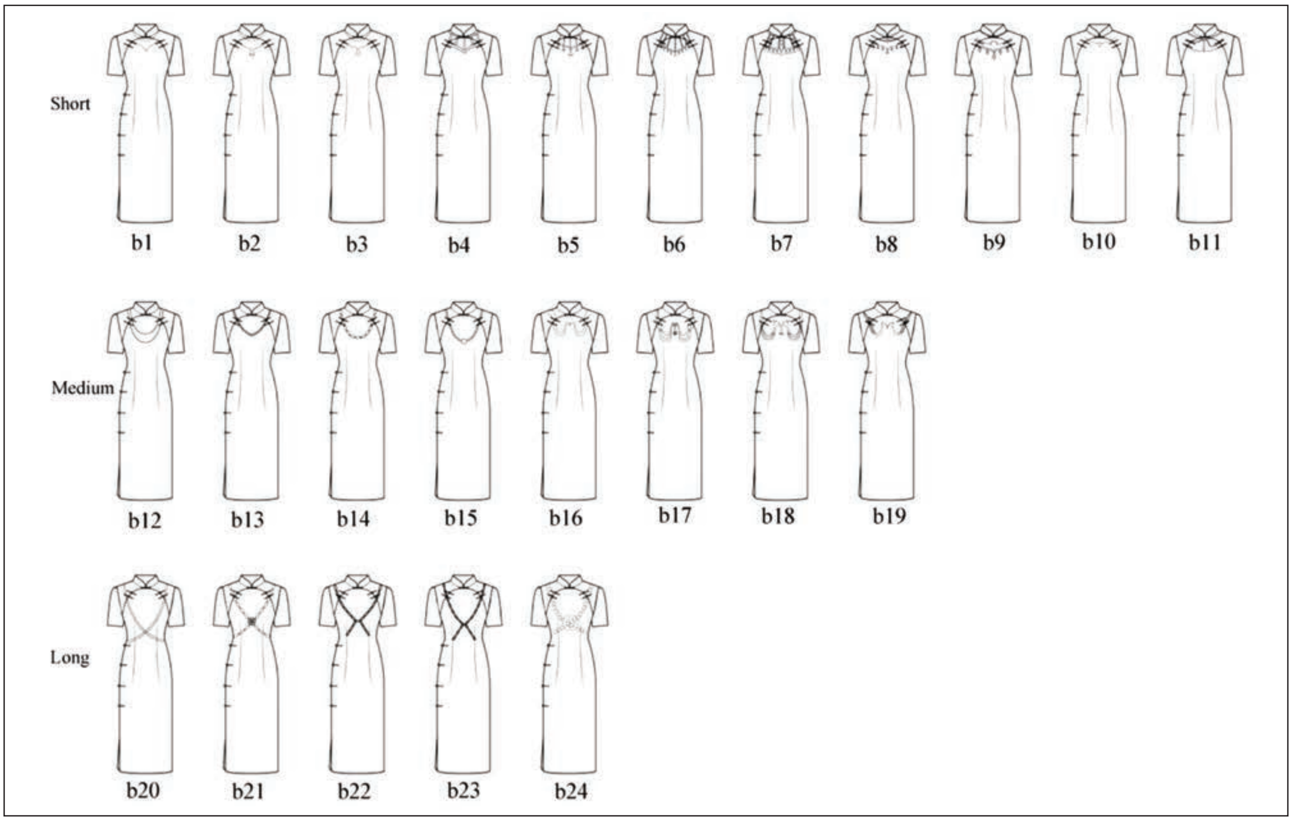


Fig. 4. Style B cheongsam with necklace designs

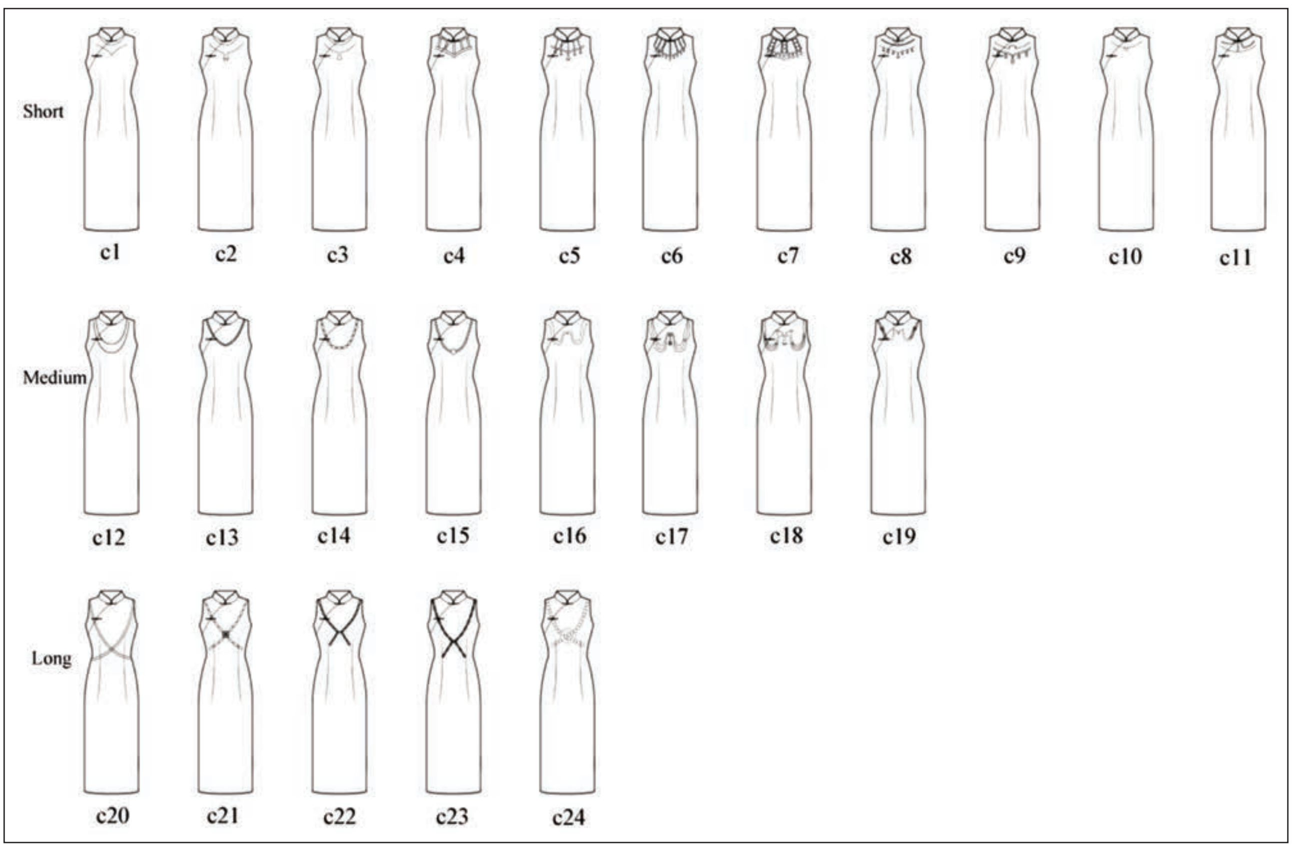


Fig. 5. Style C cheongsam with necklace designs

For example, evaluator el was asked to answer the following question: "The following is a drawing of each necklace with style A cheongsam, please evaluate the suitability of each necklace with this cheongsam based on your experience and aesthetic sense". To answer this question, evaluator el could choose an answer from *Lk*. The data collected by this process relies on the experience and knowledge of the evaluator, and the results of the experiment are subjective semantic data. To address this issue, we used the fuzzy set tool to quantify the results of the linguistic evaluation and then further processed these data.

Results discussion and analysis

Based on fuzzy set theory, linguistic terms of the linguistic rating scale *Lk* proposed can be quantified into Triangular Fuzzy Numbers (TFNs). A Triangular Fuzzy Number (TFN), *M*, can be denoted using tuples formalism as $M = (l/m, m/u)$ or $M = (l, m, u)$. Parameters l, m and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describes a fuzzy event. Each TFN has linear representations on its left and right side such that its membership function can be defined as:

$$u_M(x) = \begin{cases} 0, \ x \in [-\infty, 1] \\ \frac{x-1}{m-1}, \ x \in [1, m] \\ \frac{x-m}{m-u}, \ x \in [m, u] \\ 0, \ x \in [u, +\infty] \end{cases} \qquad (1)$$

If $M_1 = (l_1,m_1,u_1)$ and $M_2 = (l_2,m_2,u_2)$ are two TFNs, the operation laws between them can be defined as:

$$M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \qquad (2)$$

$$M_1 * M_2 = (l_1 * l_2, m_1 * m_2, u_1 * u_2) \qquad (3)$$

$$t * M_1 = (t * l_1, t * m_1, t * u_1) \qquad (4)$$

$$(l_1,m_1,u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1) \qquad (5)$$

Using TFNs, evaluation scores given by each of the evaluators can be quantified. Table 2 presents the quantified TFNs of the linguistic rating scale proposed.

Based on the operation rules given by equations 3, 4 and 5, the evaluation scores given by each evaluator e_l can be aggregated as $\{a_{ijh} \mid i = 1,\ldots,7, j = 1,\ldots,7, h = 1,\ldots,m\}$, where a_{ijh} represents the number of evaluators who choose one certain degree.

Therefore,

$$a_{ij} = \left(\frac{1}{m} \sum_j^1 a_{ijh} t_1, \frac{1}{m} \sum_j^1 a_{ijh} t_2, \frac{1}{m} \sum_j^1 a_{ijh} t_3 \right) \qquad (6)$$

where t_1, t_2, and t_3 correspond to the values of the triangular fuzzy numbers, the values of which are taken from table 2. Table 3 gives the triangular fuzzy numbers for the suitability of the three Cheongsam with the short, medium and long necklace designs. Table 4 gives the triangular fuzzy numbers for the suitability of the three cheongsam designs with necklace numbers 1 to 24.

The evaluation matrix is processed using extent analysis. It is assumed that the evaluators' values processed by the extent analysis are:

$$M_{E_i}^1, M_{E_i}^2, M_{E_i}^3, \ldots, M_{E_i}^m, \ i = 1, 2, \ldots, n \qquad (7)$$

where, $M_{E_i}^1 (i = 1, 2, \ldots, n)$ are all *TFNs*. The value of fuzzy synthetic extent concerning the *i*-th object is defined as:

$$S_i = \sum_{j=1}^m M_{E_i}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{E_i}^j \right]^{-1} \qquad (8)$$

Let $A(a_{ij})_{n \times m}$ be a fuzzy analytical matrix, where $(a_{ij}) = (l_{ij}, m_{ij}, u_{ij})$ are defined by the calculated values:

$$l_{ij} = \frac{1}{u_{ij}}; \ m_{ij} = \frac{1}{m_{ij}}; \ u_{ij} = \frac{1}{l_{ij}}$$

If $M_1 = (l_1,m_1,u_1)$ and $M_2 = (l_2,m_2,u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2,m_2,u_2)$ $M_1 = (l_1,m_1,u_1)$ is defined-by:

$$V(M_2 \geq M_1) = SUP_{y \geq x} \left[\min \left(\mu_{M_1}(x), \mu_{M_2}(y) \right) \right] \qquad (9)$$

and can be expressed as follows:

$$V(M_2 \geq M_1) = \text{hgt}\,(M_1 \cap M_2) = \mu_{M_1}(d) =$$

$$= \begin{cases} 1, \ \text{if } m_2 \geq m_1 \\ 0, \ \text{if } l_1 \geq u_2 \\ \frac{l_2 - u_1}{(m_2 - u_2) - (m_1 - l_1)}, \ \text{otherwise} \end{cases} \qquad (10)$$

Figure 3 illustrates equation 10, where 'd' is the ordinate of the highest intersection point. To compare M_1

Table 2

LINGUISTIC TERMS OF THE LINGUISTIC RATING SCALE PROPOSED AND THEIR RELATED TFN

Linguistic term	Related TFN
Far more matched	(0.84,1,1)
More matched	(0.67,0.84,1)
A little more matched	(0.5,0.67,0.84)
Moderate	(0.34,0.5,0.67)
A little less matched	(0.17,0.34,0.5)
Less matched	(0,0.17,0.34)
Far less matched	(0,0,0.17)

Table 3

TRIANGULAR FUZZY NUMBERS FOR THE SUITABILITY OF THE THREE CHEONGSAM WITH SHORT, MEDIUM AND LONG NECKLACES

Cheongsam	Style A	Style B	Style C
Short Necklace	(0.494,0.659,0.800)	(0.504,0.668,0.805)	(0.507,0.672,0.814)
Medium Necklace	(0.501,0.667,0.808)	(0.488,0.655,0.798)	(0.509,0.675,0.820)
Long Necklace	(0.422,0.588,0.739)	(0.430,0.593,0.746)	(0.457,0.624,0.776)

Table 4

TRIANGULAR FUZZY NUMBERS FOR THE SUITABILITY OF THE THREE CHEONGSAM WITH THE RESPECTIVE NECKLACES			
Cheongsam number	**Style A**	**Style B**	**Style C**
1	(0.495,0.658,0.804)	(0.555,0.720,0.857)	(0.556,0.719,0.848)
2	(0.559,0.725,0.865)	(0.521,0.684,0.825)	(0.551,0.716,0.848)
3	(0.535,0.702,0.845)	(0.523,0.687,0.831)	(0.524,0.690,0.828)
4	(0.339,0.494,0.641)	(0.360,0.512,0.652)	(0.407,0.564,0.714)
5	(0.515,0.681,0.822)	(0.547,0.713,0.842)	(0.558,0.725,0.863)
6	(0.480,0.646.0.790)	(0.456,0.620,0.757)	(0.495,0.661,0.807)
7	(0.384,0.550,0.699)	(0.439,0.603,0.751)	(0.442,0.608,0.755)
8	(0.585,0.749,0.876)	(0.580,0.746,0.871)	(0.571,0.734,0.862)
9	(0.524,0.691,0.828)	(0.532,0.699,0.836)	(0.462,0.629,0.781)
10	(0.562,0.728,0.862)	(0.562,0.728,0.856)	(0.532,0.699,0.846)
11	(0.454,0.620,0.763)	(0.465,0.632,0.775)	(0.483,0.649,0.798)
12	(0.617,0.784,0.918)	(0.570,0.737,0.875)	(0.591,0.758,0.886)
13	(0.512,0.678,0.822)	(0.506,0.673,0.819)	(0.533,0.699,0.842)
14	(0.495,0.661,0.801)	(0.501,0.667,0.810)	(0.524,0.690,0.830)
15	(0.541,0.708,0.839)	(0.535,0.702,0.834)	(0.536,0.702,0.842)
16	(0.468,0.634,0.781)	(0.439,0.605,0.755)	(0.471,0.638,0.793)
17	(0.460,0.625,0.772)	(0.448,0.614,0.758)	(0.479,0.646,0.799)
18	(0.442,0.608,0.752)	(0.442,0.608,0.757)	(0.474,0.640,0.787)
19	(0.471,0.637,0.781)	(0.465,0.632,0.778)	(0.462,0.629,0.782)
20	(0.474,0.641,0.786)	(0.479,0.644,0.790)	(0.489,0.655,0.807)
21	(0.425,0.590,0.743)	(0.442,0.606,0.760)	(0.457,0.623,0.772)
22	(0.399,0.564,0.716)	(0.413,0.576,0.728)	(0.465,0.632,0.787)
23	(0.410,0.576,0.732)	(0.416,0.579,0.734)	(0.442,0.608,0.757)
24	(0.402,0.567,0.719)	(0.398,0.562,0.716)	(0.434,0.600,0.754)

and M_2, we need both the values of $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$. The degree possibility for a convex fuzzy number to be greater than the k convex fuzzy M_i ($i = 1, 2, \ldots, k$) numbers can be defined as:

$$V(M \geq M_1, M_2, \ldots, M_k) = V[M \geq M_1 \text{ and } M \geq M_2 \text{ and } \ldots$$
$$M \geq M_k = \min V(M \geq M_i)] \quad i = 1, 2, \ldots, k \qquad (11)$$

Assuming that $d(A_i) = \min V(S_i \geq S_k)$ for $k = 1, 2, \ldots, n$; $k \neq i$, then the weight vector will be given by

$$W' = [d'(A_1), d'(A_2), \ldots, d'(A_n)]^T \qquad (12)$$

where, A_i and i = 1, 2,…, and n denotes the i-th element and n the number of elements, respectively.
A fuzzy number is a convex, normalized fuzzy set $A \subseteq R$ whose membership function is at least segmentally continuous and has the functional value $\mu_{\tilde{A}}(x) = 1$ precisely on the element. Using the classical normalization operation, the normalised weight vectors are obtained as follows.

$$W = [d(A_1), d(A_2), \ldots, d(A_n)]^T \qquad (13)$$

where W is a non-fuzzy number.
The triangular fuzzy numbers presented in table 3 were initially categorized based on Style A, Style B, and Style C, and subsequently subjected to processing using equation 8. By applying this equation, the initial weights indicating the suitability of short, medium, and long necklaces for each of the three cheongsam designs were computed. Subsequently, employing equations 9 to 13.
For example, in style A, the specific calculation steps of the suitable weight of medium, long and short necklaces are shown as follows. The numbers 1, 2, 3 represent short, medium, and long necklaces, respectively.
Using ***equation 8***:

$$\tilde{S}_1 = R_{R_1} \odot [R_{R_1} \oplus R_{R_2} \oplus R_{R_3}]^{-1}$$
$$= (0.494, 0.659, 0.800) \odot \left(\frac{1}{1.417}, \frac{1}{1.913}, \frac{1}{2.347}\right)$$
$$= (0.210, 0.344, 0.564)$$

Similarly,

$$\tilde{S}_2 = (0.213, 0.349, 0.571),\ \tilde{S}_3 = (0.180, 0.307, 0.522)$$

Thus, according to ***equation 11***, numerical values of the evaluation criteria were obtained as:

$$d(R_1) = V(\tilde{S}_1 \geq \tilde{S}_2, \tilde{S}_3) = \min\{0.987, 1\} = 0.987$$
$$d(R_2) = V(\tilde{S}_2 \geq \tilde{S}_1, \tilde{S}_3) = \min\{1, 1\} = 1$$
$$d(R_3) = V(\tilde{S}_3 \geq \tilde{S}_1, \tilde{S}_2) = \min\{0.894, 0.881\} = 0.881$$

Then, according to ***equation 12***, the ordering vector W'_R of C_1, C_2, and C_3 was obtained as W'_R = (0.987,

1, 0.881). Using classical normalization operations (***equation 13***), the normalized weight vector W_R can be defined as W_R = (0.344, 0.349, 0. 307).
The final suitability weights for short, medium, and long necklaces in each of the three cheongsam styles were determined, as outlined in table 5.

Table 5

SUITABILITY OF SHORT, MEDIUM AND LONG NECKLACES APPLIED TO THREE CHEONGSAM DESIGNS

Cheongsam	Style A	Style B	Style C
Short Necklace	0.344	**0.349**	0.341
Medium Necklace	**0.349**	0.342	**0.343**
Long Necklace	0.307	0.310	0.316

Analysis of table 5 reveals that the medium necklace exhibits the highest degree of suitability for both Style A and Style C, whereas the short necklace demonstrates the highest suitability for Style B. Conversely, the long necklace exhibits the lowest level of suitability across all three styles, namely A, B, and C.
The triangular fuzzy numbers provided in table 4 were subsequently categorized based on Style A, Style B, and Style C. Subsequently, the initial suitability weights of the 24 necklace types in each of the three cheongsam designs were subjected to processing using equation 8. By employing equations 9 to 13, the final suitability weights for each necklace type in the three cheongsam designs were calculated, and the results are presented in table 6.
Table 6 illustrates the suitability rankings for a cheongsam with a large round front piece and raglan sleeves. Among the Yungang Grotto Bodhisattva necklaces, number 12 demonstrates the highest suitability, followed by numbers 8 and 10. Conversely, the lowest suitability is observed for necklaces No. 22, No. 7, and No. 4. Obviously, the basic style of Cheongsam A is classical and mature, while the 8th necklace is short with three loops, with small bells similar to flowers evenly distributed at the bottom, and the overall style is fresh and elegant. The 10th and 12th necklaces are two loops of necklaces, and the overall style is simple and elegant. Therefore, it can be seen that when matched with the classical and mature style cheongsam of Style A, the simple and elegant necklace is more suitable for the fresh and elegant style.
The suitability assessment for the cheongsam with a two-side front piece and short sleeves is denoted as style B. It is evident that necklace No. 8 exhibits the highest level of suitability, followed by No. 12 and No. 10. Conversely, the necklaces with the lowest suitability are No. 22, No. 24, and No. 4. Style B cheongsam style is elegant and modern, is a younger style. The whole double-circle design of the 12th necklace is classical and simple. When matching style B cheongsam, it is well balanced with its modern

Table 6

SUITABILITY OF EACH NECKLACE TO THE THREE CHEONGSAM DESIGNS

Cheongsam number	Style A	Style B	Style C
1	0.044	0.055	0.052
2	0.060	0.049	0.051
3	0.055	0.049	0.046
4	0.006	0.014	0.023
5	0.049	0.054	0.053
6	0.041	0.036	0.041
7	0.019	0.033	0.031
8	0.065	**0.061**	0.055
9	0.051	0.051	0.036
10	0.061	0.057	0.048
11	0.035	0.038	0.039
12	**0.074**	0.059	**0.060**
13	0.049	0.047	0.048
14	0.045	0.045	0.046
15	0.055	0.052	0.049
16	0.039	0.034	0.037
17	0.037	0.035	0.039
18	0.032	0.034	0.037
19	0.039	0.039	0.036
20	0.040	0.041	0.040
21	0.029	0.034	0.034
22	0.023	0.028	0.036
23	0.026	0.029	0.031
24	0.024	0.026	0.030

sense, and at the same time adds a noble classical sense to it.
The evaluation of necklace suitability for the cheongsam with an oblique front piece and no sleeves is referred to as style C. It is observed that necklace No. 12 demonstrates the highest level of suitability, followed by No. 8 and No. 5. Conversely, the necklaces with the lowest suitability are No. 23, No. 24, and No. 4. Style C cheongsam style is modern simple and sexy. 12 necklace is elegant and light style with three circles, which is the most suitable for modern style cheongsam C. The next most suitable is a simple 8 necklace and an elegant and gentle 5 necklace. The second is the simple necklace No. 8 and the elegant and gentle necklace No. 5, which are more suitable for the modern cheongsam. It is worth noting that both necklaces #12 and #5 have a flower-shaped bell pendant at the bottom, which is a design element that can be well applied to cheongsam design.
Based on the findings, it is evident that the three main cheongsam designs exhibit stronger compatibility with the short Yungang Grotto Bodhisattva necklace variants, specifically No. 8 and No. 10, as well as the elegant and understated double-layered medium necklace, No. 12. No. 8 represents a C-shaped short

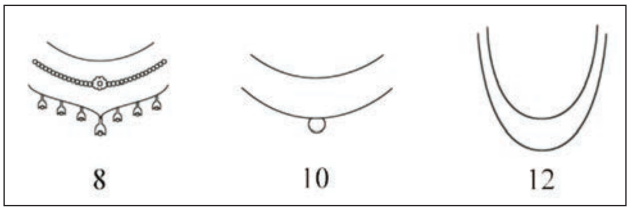


Fig. 6. Three best matches for the cheongsam

Yungang Grotto Bodhisattva necklace featuring a three-tiered structure characterized by a central floral scrolling motif and a pendant adorned with stones. On the other hand, No. 10 represents a D-shaped short Yungang Grotto Bodhisattva necklace resembling a collar design, consisting of two semi-circular arcs positioned above and below a 'U'-shaped collar embellished with a semi-circular decoration. These Yungang Grotto Bodhisattva necklace designs are visually depicted in figure 6.

EXPERIMENT 2: ANALYSIS OF THE OVERALL STYLE OF YUNGANG GROTTOES BODHISATTVA NECKLACES WHEN APPLIED TO CLASSIC CHEONGSAM

Research methodology

Sensory evaluation is a technique that integrates sensibility and engineering to design products by primarily analysing human sensory perception and incorporating human preferences [11]. In Experiment 2, it was essential to explore the subjective perceptions of the participants to determine the sensory style of each cheongsam design. The utilization of sensory evaluation allows for the conversion of subjective perceptions into objective data, facilitating the improvement of product design and development. By converting subjective data from experts and consumers into concrete data and parameters, the subjective evaluations within sensory evaluation render the evaluation outcomes more scientifically robust and convincing [8].

Experiment 2 employs cheongsam designs that incorporate elements of Yungang Grottoes Bodhisattva necklaces as the subjects of sensory evaluation to investigate consumers' sensory psychology towards different Yungang Grottoes Bodhisattva necklaces in cheongsam designs. Building upon the results of Experiment 1, the design drawings demonstrating high suitability will be selected as the focal points of the study. Consequently, activities such as adjective selection will be conducted, followed by the distribution of questionnaires and the analysis of mean values derived from the findings.

Sample identification

Based on the outcomes of Experiment 1, the cheongsam designs exhibiting the highest suitability were chosen for Experiment 2. These include style A, and style B paired with the No. 12 Yungang Grottoes Bodhisattva necklace, No. 8 and No. 10 short Yungang Grottoes Bodhisattva necklaces, and style C with the No. 12 Yungang Grottoes Bodhisattva necklace, No. 8, and No. 5 short Yungang Grottoes Bodhisattva necklaces. The designs are denoted by the numbers 1 to 9, as depicted in figure 7.

Sensory adjective identification

Fifty pairs of sensory adjectives were gathered to describe the cheongsam, with an initial selection of 26 adjective pairs based on relevant literature review and interviews conducted with cheongsam designers and consumers. Subsequent discussions were held with experts and professors specializing in ergonomics and traditional clothing research. Thirteen adjective pairs were selected based on their frequent usage in describing the overall aesthetics of the Yungang Grottoes Bodhisattva necklace when applied to cheongsam designs, while also exhibiting opposite meanings.

The selected 13 adjective pairs are as follows: classical - modern, casual - formal, simple - complicated, constricted - stretching, depressing - light, luxurious - plain, elegant - commonplace, fresh - flamboyant, mature - youthful, sexy - conservative, stable - lively, provocative - understated, like - dislike.

Survey participants and sample size determination

The survey participants consisted of young women aged 20 to 35, chosen due to their aesthetic capabilities, purchasing power, and enthusiasm for expressing their style and aesthetics through clothing. This demographic represents the primary consumer group for various clothing brands. For Experiment 2, a total of 52 questionnaires were distributed online via Questionnaire Star, out of which 20 responses were deemed valid.

Questionnaire design

The Semantic Difference (SD) method of sensory evaluation was employed for the questionnaire

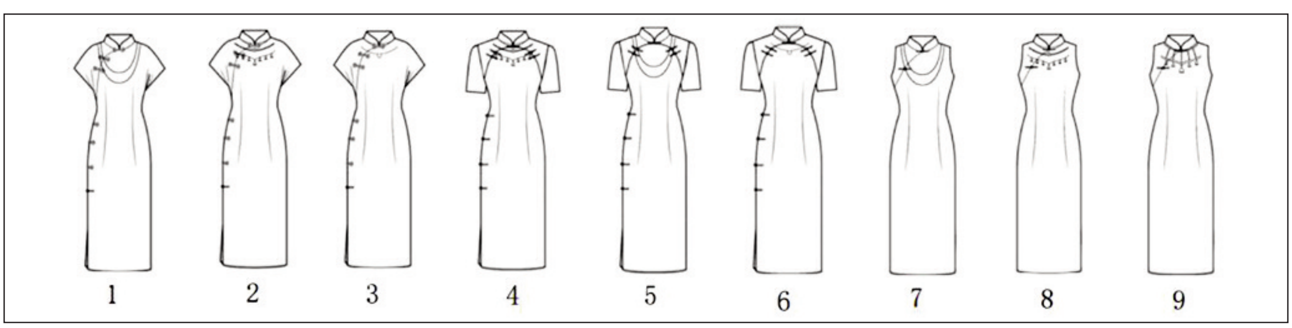


Fig. 7. The highest suitable cheongsam design drawings

design. The SD method is a widely used subjective evaluation technique that focuses on capturing the variability in individuals' understanding of a particular concept. It utilizes a 5-point Likert scale for scoring. For instance, the sensory adjective pair “classical-modern” is rated as follows: 1 indicates a significantly more classical perception, 2 represents a more classical perception, 3 denotes a neutral response, 4 signifies a more modern perception, and 5 indicates a significantly more modern perception.

Statistical analysis and results

Each cheongsam design received a total of 650 ratings (13 pairs of adjectives * 50 questionnaires) through the distribution of questionnaires. The scores for each adjective pair were initially calculated using the mean method, followed by the origin method. If the average score of an adjective pair is less than 3, the difference between 3 and the average score is taken, and the left adjective is associated with this value, representing a “classical” perception.

Conversely, if the average score is greater than 3, the difference between the average score and 3 is calculated, and the right adjective is associated with this value, indicating a “modern” perception. The resulting score represents the sensory psychological score of the stimulus image for that specific adjective pair. For example, a score of 0.98 for the “luxurious - plain” adjective pair assigned to cheongsam 01 indicates that the perception of plainness is particularly prominent in cheongsam 01, with a score of 0.98. The top three sensory adjectives were selected by ranking the extremes of the adjective scores for each stimulus image. The sensory psychological scores of the cheongsam designs are presented in table 7.

Table 7 displays the characteristics of each cheongsam design based on the sensory adjectives. Cheongsam 1, 3, and 6 are perceived as plain and understated, while Cheongsam 2 and 4 are perceived as complicated. Cheongsam 3, 5, and 6 are perceived as conservative and understated, Cheongsam 7 and 9 as light, and Cheongsam 8 as sexy, modern, and provocative.

The data obtained from the adjectives 'like-dislike' were analyzed to gain insights into user preferences regarding the incorporation of the Yungang Grottoes Bodhisattva necklaces into cheongsam designs. Table 8 presents the popularity of Cheongsam designs 1 to 9 among respondents. The most favoured cheongsam design among the participants was No. 8, a sleeveless cheongsam with a No. 8 short Yungang Grottoes Bodhisattva necklace and an oblique front piece. The top three sensory psychological words associated with this design were 'sexy', 'modern', and 'provocative'. The following popular words were “complicated”, “flamboyant”, and “mature” for the short-sleeved cheongsam with a No. 8 necklace and a two-side front piece. The third most popular designs were the short-sleeved cheongsam with a two-sided front piece and a No. 10 short necklace, and the sleeveless cheongsam with a No. 8 medium necklace. These findings indicate that young women prefer sleeveless cheongsams with short necklaces, followed by short-sleeved cheongsams with short necklaces and two-sided front pieces. The most popular Yungang Grottoes Bodhisattva necklace choice was the No. 8 short necklace.

Overall, it can be observed that among young women aged 20–35, complicated, sexy, modern, and flamboyant cheongsam designs are the most popular.

Table 7

SENSUAL PSYCHOLOGICAL ADJECTIVES AND SCORES FOR THE NINE CHEONGSAM DESIGNS

Cheongsam number	Sensory psychology words	Score
1	Plain	0.98
	Understated	0.91
	Stable	0.77
2	Classical	0.47
	Formal	0.45
	Complicated	0.43
3	Plain	0.87
	Understated	0.68
	Conservative	0.62
4	Complicated	0.87
	Flamboyant	0.62
	Mature	0.62
5	Conservative	0.51
	Mature	0.43
	Understated	0.43
6	Understated	0.51
	Plain	0.47
	Conservative	0.45
7	Casual	0.98
	Simple	0.81
	Light	0.74
8	Sexy	0.6
	Modern	0.55
	Provocative	0.53
9	Light	0.47
	Modern	0.45
	Stretching	0.36

Table 8

POPULARITY OF NINE CHEONGSAM STYLES

Cheongsam number	Popularity
1	2.43
2	2.98
3	2.72
4	3.21
5	2.94
6	3.09
7	3.09
8	3.26
9	2.91

CONCLUSIONS

This research employed various methodologies such as the literature review, semantic difference method, and data analysis to examine the sensory designs of Yungang Grottoes Bodhisattva necklaces on cheongsam. Based on the findings, the following conclusions can be drawn:

- Significant variations were observed in the suitability of different necklace types for various cheongsam styles. Experiment 1, employing fuzzy terminology and industry experts as subjects, revealed that medium necklaces were most suitable for cheongsam designs with a large round front piece and raglan sleeves, as well as sleeveless cheongsam designs with an oblique front piece. On the other hand, short necklaces were most suitable for short-sleeved cheongsam designs with a two-sided front piece. Conversely, long necklaces were found to be the least suitable for all three cheongsam types.
- The three main types of Cheongsam exhibited the highest compatibility with short Yungang Grottoes Bodhisattva necklaces, specifically No. 8 and No. 10, as well as the simple and elegant double-layered medium necklace, No. 12.
- The choice of the Yungang Grottoes Bodhisattva necklace significantly influenced the overall sensuality of the cheongsam. Different Yungang Grottoes Bodhisattva necklace types and styles contributed to distinct visual effects, while variations in the cheongsam models also impacted the overall sense of style.
- Through mean value analysis of sensual psychology, the top three sensory word scores were compiled for the nine stimulus charts. This approach facilitated a more precise description of the designs and enabled the identification of preferred cheongsam styles and types based on young women's preferred sensory psychology words.
- Among young women aged 20 to 35, cheongsam designs characterized by complexity, sexiness, modernity, and flamboyance were the most popular. Notably, the No. 8 short necklace emerged as the preferred choice among respondents.
- According to the three most popular cheongsam styles among young women, it can be found that young women prefer the modern cheongsam. In the collocation design of the future necklace and cheongsam, the design factors of the light classical style of three layers of necklace and the simple double layer of the necklace will be welcomed by young women. In particular, the design element with a bell pendant on the bottom will be loved by young women.
- In summary, this study sheds light on the sensory evaluation of Yungang Grottoes Bodhisattva necklaces when applied to cheongsam designs. The results underscore the importance of necklace selection in achieving desired aesthetic outcomes for cheongsam, with implications for design choices and preferences among young women.

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Thermal transfer analysis of machines used for the treatment of textile materials

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ABSTRACT – REZUMAT

Thermal transfer analysis of machines used for the treatment of textile materials

The present paper aims to introduce a comprehensive thermal analysis of the sizing-finishing machine (Squeezing Pader Machine) to identify the overheating areas to organise maintenance activities. As there is no universal application for checking the condition of a machine, specific methods must be used depending on the characteristics of the machines being monitored, as machine condition monitoring is very important in terms of productivity, economic benefits and maintenance. The thermal analysis of the equipment in this work paper, has an important role (for planning maintenance activities), because this machine ensures optimal loading with different material treatment solutions, intended for mattresses, according to customer requirements. In the present paper, the authors conducted research on the whole technological flow to plan predictive maintenance activities using online monitoring methods. The mathematical modelling of the data obtained from the thermal analysis of the engines carried out based on the polynomial regression is used to predict the evolution of the temperatures along the analysed lines outside the measurement interval for each engine analysed. In this sense, the authors propose online monitoring of the motors that have the role of stretching and transporting the material, which is not included in the real-time temperature monitoring in the machine software, as the rest of the motors are monitored. Regular monitoring of motors with the help of thermography can help identify potential problems before they become serious, allowing preventive maintenance to improve the equipment's reliability and efficiency.

Keywords: *maintenance, thermal imaging, FLIR SC 640, FLIR RESEARCH IR MAX 4.40 Software*

Analiza transferului termic al maşinilor utilizate pentru tratarea materialelor textile

Scopul lucrări este de a prezenta o analiză termică amplă la maşina de apretare-finisare HAS (Squeezing Pader Machine), pentru a identifica zonele care se încălzesc excesiv în vederea planificării activităților de întreținere. Deoarece nu există o aplicație universală pentru verificarea stării unei mașini, trebuie utilizate metode specifice în funcție de caracteristicile mașinilor monitorizate, având în vedere că monitorizarea stării mașinilor este foarte importantă în ceea ce privește productivitatea, beneficiile economice și întreținerea. Analiza termică a echipamentului din această lucrare, are un rol important (pentru planificarea activităților de întreținere), deoarece această mașină asigură o încărcare optimă cu diferite soluții de tratare a materialelor, destinate saltelelor, în funcție de cerințele clientului. În lucrarea de față, autorii au efectuat o cercetare a întregului flux tehnologic în vederea planificării activităților de mentenanță predictivă prin metode de monitorizare online. Modelarea matematică a datelor obținute în urma analizei termice a motoarelor realizate pe baza regresiei polinomiale este utilizată pentru a prezice evoluția temperaturilor de-a lungul liniilor analizate în afara intervalului de măsurare pentru fiecare motor analizat. În acest sens, autorii propun o monitorizare on-line a motoarelor, care au rolul de a întinde și transporta materialul, care nu sunt incluse în monitorizarea temperaturii în timp real în software-ul mașinii, așa cum sunt monitorizate restul motoarelor. Monitorizarea regulată a motoarelor cu ajutorul termografiei poate ajuta la identificarea potențialelor probleme înainte că acestea să devină grave, permițând întreținerea preventivă în vederea îmbunătățirii fiabilității și eficienței echipamentului.

Cuvinte-cheie: *mentenanță, imagini termice, FLIR SC 640, FLIR RESEARCH IR MAX 4.40 software*

INTRODUCTION

Research on monitoring the condition of industrial machinery is a very important area aimed at avoiding unexpected situations such as malfunctions, breakdowns, failures, shutdowns and not least economic losses [1, 2]. Infrared thermography is a non-contact condition monitoring technique that has been widely used for inspection of equipment, electrical installations, etc. A study concluded that the use of thermography for monitoring electrical motors in the textile industry can be efficient and cost-effective compared to traditional maintenance methods [3]. However, thermography has been used insufficiently for monitoring and fault diagnosis of motors used in textile equipment [4].

Fig. 1. FLIR SC 640 thermal imaging camera components [8]

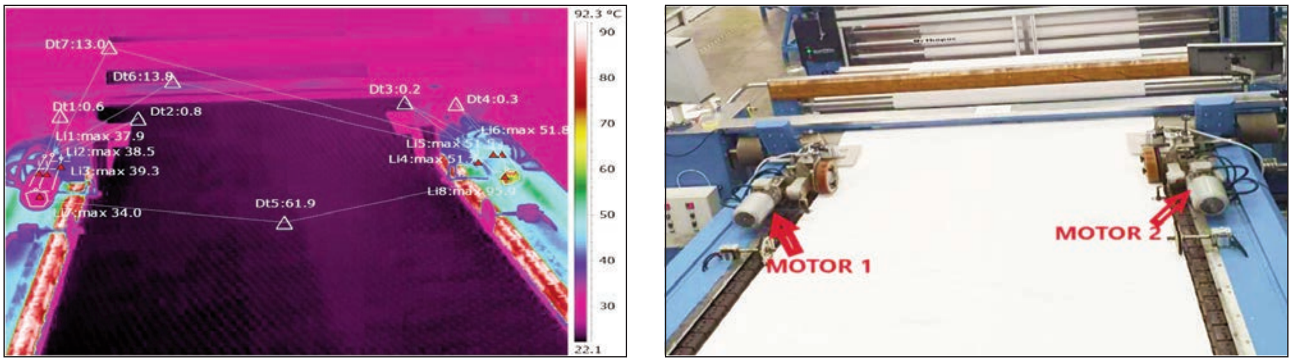
Fig. 2. Equipment for the treatment of textile materials

Regarding the scientific studies based on thermography, a series of papers has been published that analyse various important aspects regarding heat transfer; this research was conducted with the help of the infrared thermal imaging camera [5–7].

Thermography measurements were performed at the Lava Knitting in Oradea. The Flir SC 640 thermal imaging camera was used, which is a portable thermographic scanning equipment, "without cooling", which has the strongest existing IR detector, with a resolution of 640 × 480 pixels and with a thermal sensitivity encountered so far only by cameras with cooling systems (<0.04°C) [8]. As can be seen from figure 1, the thermal imaging camera is equipped with a laser pointer, germanium lens, SD card, USB, and video connector. A great advantage of the Flir SC 640 thermal imaging camera is that it allows scanning objects remotely, with no contact, the testing being non-destructive for the objects to be measured; it ensures predictive maintenance of equipment and the detection of defects in the early stages to reduce costs. Flir Research IR max 4.40 software is used for research and development, allowing real-time analysis of the video sequence [8]. The infrared thermography examination method [9, 10] has recently entered the practice of non-destructive examinations, being a method of measuring the thermal field by recording infrared radiation and visualizing the temperature distribution on the observed surfaces [11, 12]. A condition-based maintenance approach may be used for planning the maintenance activities of textile machines with satisfactory performance [13]. Maintainability has been defined as the feature of a machine to maintain or restore its prescribed functions in the shortest possible time [14]. Therefore, maintainability depends on how failures are identified as well as on how maintenance activities are planned and carried out to prevent or eliminate the deterioration of machines [13]. Preventive and predictive maintenance are the main types of proactive maintenance strategies [15, 16] and their employment in industry has been presented in existing literature [17, 18]. The thermal analysis of the equipment in this work paper has an important role (for planning maintenance activities), of the motors (1 and 2) which have the role of setting the material on the conveyor chain to ensure optimal loading of different material treatment solutions, intended for mattresses, according to customer requirements. Regarding the various thermal analyses performed on textile materials and different equipment (e.g. sewing machines, embroidery machines) the research of this working paper is carried out on the whole technological flow (of treatment of the material intended for mattresses which has a decisive role for ensuring optimal loading with different material treatment solutions, according to customer requirements) to plan maintenance activities, although in this paper we only present a thermal analysis on the motors (simultaneous and synchronous non-functioning of the motors leads to deformation of the material on the drum and its non-conforming treatment) in the Squeezing Pader Machine.

MATERIALS AND METHODS

The state of the textile machines can be evaluated by monitoring different parameters, such as vibration and temperature [19, 20], so their maintenance can be performed a short time before the failure [21–25]. Thermographic measurements were performed on the Squeezing Pader Machine, which is a machine for treating textile materials (mattress covers), as shown in figure 2. As can be seen from figure 3 and table 1, the maximum temperature along line Li1, which is positioned on motor 1, is 37.9°C, and the minimum temperature is 31.5°C. The temperature variation along line Li1 is 6.4°C, and the emissivity is 0.80 along line Li1, positioned on motor 1. The maximum temperature along line Li2, which is positioned on motor 1, is 38.5°C, and the minimum temperature is 31.8°C. The temperature variation along the Li2 line is 6.7°C, and the emissivity is 0.80 along the Li2 line, positioned on motor 1. The maximum temperature along line Li3, which is positioned on motor 1, is 39.3°C and the minimum temperature is 30.6°C. The temperature variation along line Li3 is 8.7°C, and the emissivity is 0.80 along line Li3, positioned on motor 1. The maximum temperature along line Li7, which is positioned on motor 1, is 34.0°C, and the minimum temperature is 29.9°C. The temperature variation along the Li7 line is 4.1°C, and the emissivity is 0.80 along the Li7 line, positioned on motor 1. As can be seen from figure 3 the maximum temperature along



a *b*

Fig. 3. IR and real spectrum image of motor 1, motor 2 and temperatures along the measured lines:
a – infrared image; *b* – real image

line Li4, which is positioned on motor 2, is 51.7°C, and the minimum temperature is 43.2°C. The temperature variation along the Li4 line is 8.5°C, and the emissivity is 0.80 along the Li4 line, positioned on motor 2. The maximum temperature along line Li5, which is positioned on motor 2, is 51.5°C and the minimum temperature is 46.3°C. The temperature variation along line Li5 is 5.2°C, and the emissivity is 0.80 along line Li5, positioned on motor 2. The maximum temperature along line Li6, which is positioned on motor 2, is 51.8°C, and the minimum temperature is 44.0°C. The temperature variation along line Li6 is 7.8°C, and the emissivity is 0.80 along line Li6, positioned on motor 2. The maximum temperature along line Li8, which is positioned on motor 2, is 95.9°C, and the minimum temperature is 52.5°C. The temperature variation along the Li8 line is 43.4°C, and the emissivity is 0.80 along the Li8 line, positioned on motor 2. Figure 4 shows the temperature variation along the lines positioned on motor 1 and motor 2.

Table 1

THERMOGRAPHIC MEASUREMENTS FOR MOTOR 1 AND MOTOR 2

Image camera type	FLIR SC640
Li1 Max. temperature	37.9°C
Li1 Min. temperature	31.5°C
Li1 Max. – Min. temperature	6.4°C
Li1 Emissivity	0.80
Li1 Object distance	2.0 m
Li1 Reflected temperature	35.0°C
Li2 Max. temperature	38.5°C
Li2 Min. temperature	31.8°C
Li2 Max. – Min. temperature	6.7°C
Li2 Emissivity	0.80
Li2 Object distance	2.0 m
Li2 Reflected Temperature	35.0°C
Li3 Max. temperature	39.3°C
Li3 Min. temperature	30.6°C
Li3 Max. i Min. temperature	8.7°C
Li3 Emissivity	0.80
Li3 Object distance	2.0 m
Li3 Reflected temperature	35.0°C

Table 1 (continuation)

Image camera type	FLIR SC640
Li4 Max. temperature	51.7°C
Li4 Min. temperature	43.2°C
Li4 Max. – Min. temperature	8.5°C
Li4 Emissivity	0.80
Li4 Object distance	2.0 m
Li4 Reflected temperature	35.0°C
Li5 Max. temperature	51.5°C
Li5 Min. temperature	46.3°C
Li5 Max. – Min. temperature	5.2°C
Li5 Emissivity	0.80
Li5 Object distance	2.0 m
Li5 Reflected temperature	35.0°C
Li6 Max. temperature	51.8°C
Li6 Min. temperature	44.0°C
Li6 Max. – Min. temperature	7.8°C
Li6 Emissivity	0.80
Li6 Object distance	2.0 m
Li6 Reflected temperature	35.0°C
Li7 Max. temperature	34.0°C
Li7 Min. temperature	29.9°C
Li7 Emissivity	0.80
Li7 Max. – Min. temperature	4.1°C
Li7 Object distance	2.0 m
Li7 Reflected temperature	35.0°C
Li8 Max. temperature	95.9°C
Li8 Min. temperature	52.5°C
Li8 Max. – Min. temperature	43.4°C
Li8 Object distance	2.0 m
Li8 Emissivity	0.80
Li8 Reflected temperature	35.0°C

In the research carried out in this paper on this machine analysed, it can be noticed that the temperature increases in the range of 34°C – 39.3°C for Motor 1 analysed are considered normal operating temperatures, in normal operation, compared to the temperatures analysed for Motor 2 which are in the range 51.5°C – 95.9°C. The temperature differences analysed for the two motors are due to the improper function of the cooling fan of Motor 2. The difference

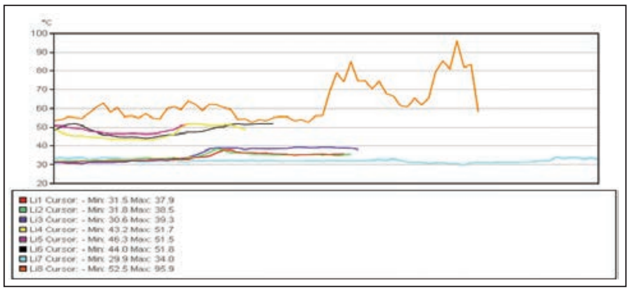


Fig. 4. Temperature variation along the lines positioned on motor 1 and motor 2

in temperature in the fan area between the two motors is 61.9°C as shown in figure 3, a. The differences in temperature along the analysed lines for the two motors are 13°C respectively 13.8°C.

Figure 5, *a* shows the values of minimum and maximum temperatures along the lines Li1, Li2, Li3, and Li7 and the approximation curve of the values for Motor 1 and figure 5, b shows the minimum and maximum temperature values along the lines Li4, Li5, Li6, Li8 and the estimate curve for Motor 2.

In the case of Motor 1, as shown in figure 5, a relation obtained is a polynomial function of degree 5:

$$y = 0.0318x^5 - 0.7757x^4 + 6.7624x^3 - 25.389x^2 + 39.999x + 10.85 \quad (1)$$

The coefficient of determining R^2 established by the regression [26] procedure is:

$$R^2 = 0.9218 \quad (2)$$

In this case, when the polynomial function [8] regression R^2 has a value higher than 0.9 the mathematical model represents the real situation of the heat distribution on the analysed surfaces of Motor 1, temperature values outside this domain.

In the case of Motor 2 as shown in figure 5, *b* the relation obtained is a polynomial function of degree four:

$$y = 0.3312x^4 - 5.2252x^3 + 27.644x^2 - 53.897x + 75.602 \quad (3)$$

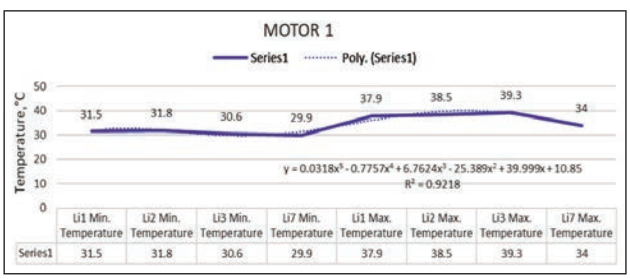
The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.9654 \quad (4)$$

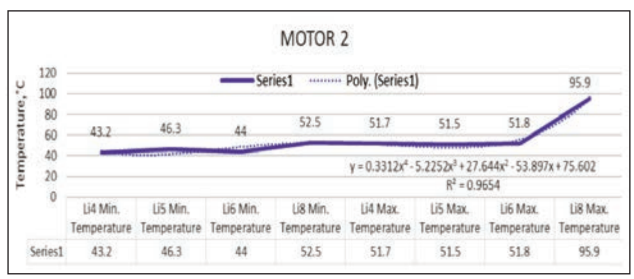
In this case when the polynomial function regression R^2 has a value of less than 0.9 the mathematical model represents less the real situation and the heat distribution on the analysed surfaces of motor 2, temperature values outside this domain.

The purpose of the regressions is to predict the evolution of temperatures along the analysed lines outside the measurement range.

In the case of motors 4 and 5 analysed it can be noticed that the maximum temperature along the analysed lines Li5 and Li6 is 99.1°C respectively 93.1°C (table 2). To ensure acceptable operation, it is recommended that the bearings are properly greased for high-temperature operation. Motors 3, 4 and 5 shown in figure 6 are 4.5–5 kW fan motors, their purpose is to aerate the material to dry it (to maintain a

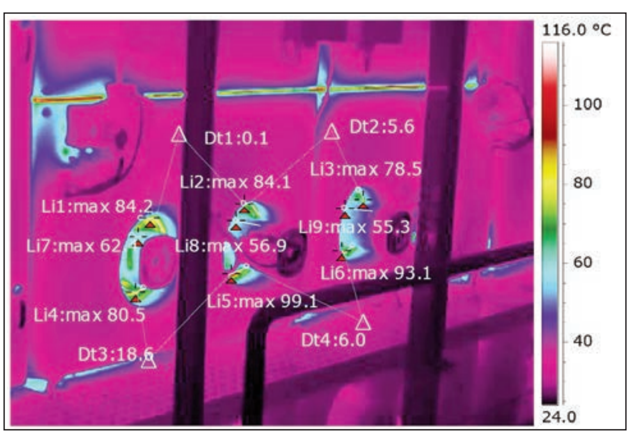


a

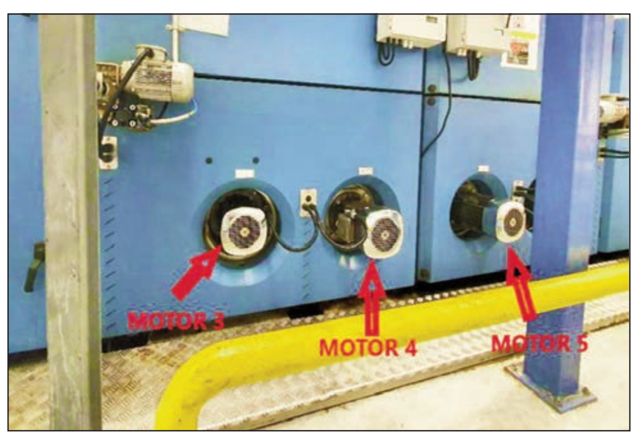


b

Fig. 5. Temperature variation along the minimum and maximum lines and approximation curves for: *a* – motor 1; *b* – motor 2



a



b

Fig. 6. IR and real spectrum image of motor 3, motor 4, motor 5 and temperatures along the measured lines: *a* – infrared image; *b* – real image

Table 2

THERMOGRAPHIC MEASUREMENTS FORMOTOR 3, MOTOR 4 AND MOTOR 5	
Image camera type	**FLIR SC640**
Li1 Max. temperature	84.2°C
Li1 Min. temperature	53.8°C
Li1 Max. – Min. temperature	30.4°C
Li1 Emissivity	0.95
Li1 Object distance	2.0 m
Li1 Reflected temperature	22.5°C
Li2 Max. temperature	84.1°C
Li2 Min. temperature	56.6°C
Li2 Max. – Min. temperature	27.4°C
Li2 Object distance	2.0 m
Li2 Emissivity	0.95
Li2 Reflected temperature	22.5°C
Li3 Max. temperature	78.5°C
Li3 Min. temperature	67.3°C
Li3 Max. – Min. temperature	11.2°C
Li3 Emissivity	0.95
Li3 Object distance	2.0 m
Li3 Reflected temperature	22.5°C
Li4 Max. temperature	80.5°C
Li4 Min. temperature	60.4°C
Li4 Max. – Min. temperature	20.1°C
Li4 Emissivity	0.95
Li4 Object distance	2.0 m
Li4 Reflected temperature	22.5°C
Li5 Max. temperature	99.1°C
Li5 Min. temperature	59.9°C
Li5 Max. – Min. temperature	39.2°C
Li5 Emissivity	0.95
Li5 Object distance	2.0 m
Li5 Reflected temperature	22.5°C
Li6 Max. temperature	93.1°C
Li6 Min. temperature	56.4°C
Li6 Max. – Min. temperature	36.8°C
Li6 Emissivity	0.95
Li6 Object distance	2.0 m
Li6 Reflected temperature	22.5°C
Li7 Max. temperature	62.4°C
Li7 Min. temperature	56.9°C
Li7 Max. – Min. temperature	5.5°C
Li7 Emissivity	0.95
Li7 Object distance	2.0 m
Li7 Reflected temperature	22.5°C
Li8 Max. temperature	56.9°C
Li8 Min. temperature	44.7°C
Li8 Max. – Min. temperature	12.3°C
Li8 Emissivity	0.95
Li8 Object distance	2.0 m
Li8 Reflected temperature	22.5°C
Li9 Max. temperature	55.3°C
Li9 Min. temperature	42.7°C
Li9 Max. – Min. temperature	12.7°C
Li9 Emissivity	0.95
Li9 Object distance	2.0 m
Li9 Reflected temperature	22.5°C

temperature that does not cause damage to the treated material) and their monitoring takes place in real-time in the software, compared to motors 1 and 2 for which the monitoring is not included in the software and therefore requires more attention and is the subject of this research. So, they need separate periodic monitoring and proper operation, considering that these motors (1 and 2) have the role of setting the material on the conveyor chain.

Figure 7 shows the temperature variation along the lines positioned on motor 3, motor 4 and motor 5.

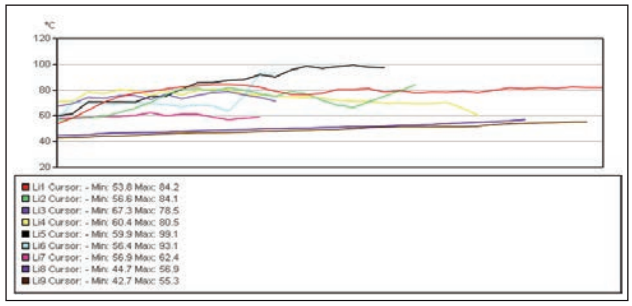


Fig. 7. Temperature variation along the lines positioned on motor 3, motor 4 and motor 5

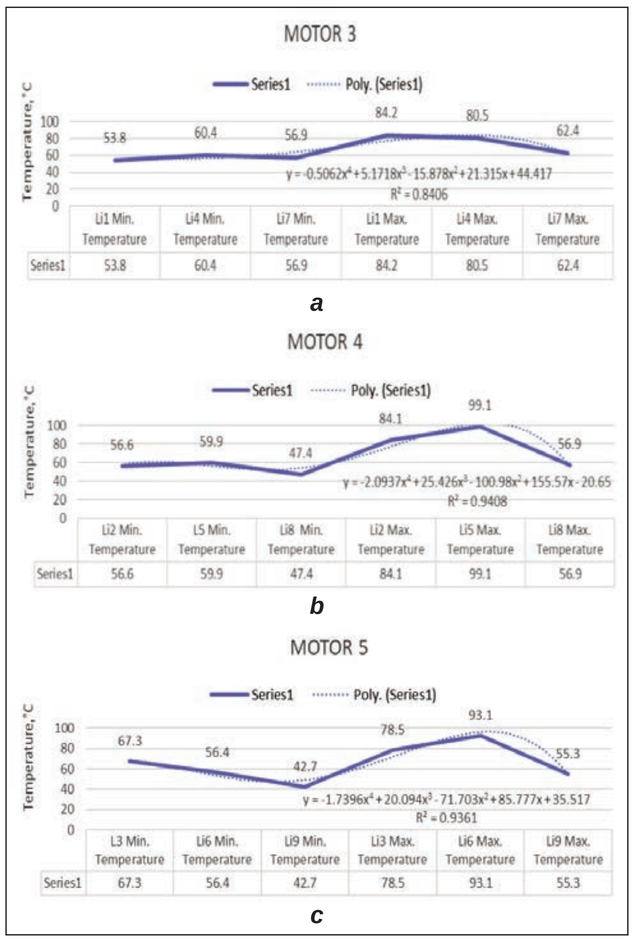


Fig. 8. Temperature variation along the minimum and maximum lines and estimate curves for: *a* – motor 3; *b* – motor 4; *c* – motor 5

In figure 8, the values of minimum and maximum temperatures along the lines Li1, Li4, and Li7 and the approximation curve of the values of Motor 3 are shown, in figure 8, b the values of minimum and maximum temperatures along the lines Li2, Li5, Li8 and the approximation curve of the values of Motor 4 are shown and in figure 8, c are shown the values of minimum and maximum temperatures along the lines Li3, Li6, Li9 and the approximation curve of the values of Motor 5.

In the case of Motor 3, as shown in figure 8, a relation obtained is a polynomial function of degree four:

$$y = -0.5062x^4 + 5.1718x^3 - 15.878x^2 + 21.315x + 44.417 \quad (5)$$

The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.8406 \quad (6)$$

In this case when the polynomial function regression R^2 has a value of less than 0.9 the mathematical model represents less the real situation and the heat distribution on the analysed surfaces of Motor 3, temperature values outside this domain.

In the case of Motor 4 as shown in figure 8, *b* the relation obtained is a polynomial function of degree four:

$$y = -2.0937x^4 + 25.426x^3 - 100.98x^2 + 155.57x - 20.65 \quad (7)$$

The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.9408 \quad (8)$$

In this case, when the polynomial function regression R^2 has a value higher than 0.9 the mathematical model represents the real situation of the heat distribution on the analysed surfaces of Motor 4, temperature values outside this domain.

In the case of Motor 4 as shown in figure 8, c the relation obtained is a polynomial function of degree four:

$$y = -1.7396x^4 + 20.094x^3 - 703x^2 + 85.777x + 35.517 \quad (9)$$

The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.9361 \quad (10)$$

In this case, when the polynomial function regression R^2 has a value higher than 0.9 the mathematical model represents the real situation of the heat distribution on the analysed surfaces of Motor 4, temperature values outside this domain.

DISCUSSIONS

Compared to other papers realized at the international level in which realized thermographic monitoring of motors on different equipment, in the present paper the authors carried out research on the whole technological flow (of mattress material treatment which has a decisive role in ensuring optimal loading with different material treatment solutions according to customer requirements) to plan predictive maintenance activities by different online monitoring methods. If motors 1 and 2 do not work simultaneously and in sync, there is no correct (uniform) wrapping of the treated material on the drum, which can lead to a deformation of the material on it. In addition to the treatments brought to the materials, the machine analysed in this work also has the role of fixing and stabilizing the material through the roller systems and the steam generator. If the two motors (motor 1 and motor 2) do not work properly, during the material treatment process, defects may occur regarding its thermofixing process and a poor load with solutions, due to the difference in the speed of material transport. We can conclude that motors 3, 4 and 5 have the role of ventilation to maintain a constant temperature on the treated material. They have no direct effects on the material because they have real-time temperature monitoring in the software compared to motors 1 and 2 which have the role of stretching and transporting the material, the latter not being monitored in the software. The thermal analysis of the finishing equipment within SC Lava Knitting [27] in Oradea is a very important one (to plan the maintenance activities) because this machine has a huge role in ensuring optimal loading with different material treatment solutions, designed for mattresses, by customer requirements. This paper presents a topic of interest to researchers and practitioners, as it aims to address the issues faced by companies in the field to create a constant technological flow and prevent unexpected engine failures. The authors of the paper recommend regular monitoring of engines with the help of thermography to improve the maintenance and reliability of textile equipment.

CONCLUSIONS

Since there is no universal application for checking the status of a machine, specific methods must be used depending on the characteristics of the monitored machinery. The heating of the analysed motor is due to the operating environment, the authors suggest checking the ventilation holes. The motors analysed in this sizing-finishing machine, are provided with forced air cooling below 15 Hz so therefore it is necessary to cool them forcefully. The operating status of the forced cooling fans must be checked which are mounted separately from the motor housing. The authors propose the installation of thermal insulating pipes that ensure the air intake from the outside of the building where the sizing-finishing machine is and provide a cooler to it. The authors propose solving the problem of motor alignment with the reducer with the means of vibration analysis. At a temperature of over 90°C, there occurs the problem of melting the grease from the bearings, so it is recommended to lubricate the bearings with petroleum jelly appropriate to the thermal operating regime of the motor as well as to periodically remove the lint deposits from the cooling slots of the motor and the suction mouth of the fan for forced air cooling. The mathematical modelling of the results obtained from the thermal analysis of the engines was performed based on the polynomial regression which is used to predict the evolution of the temperatures along the analysed lines outside the measurement range for each engine analysed. In conclusion, thermographic monitoring is an efficient technique for detecting problems that may occur in motors of the textile equipment. In the textile industry, motors are a crucial component in weaving, knitting, finishing, dyeing and printing processes, their performance has a direct impact on the quality and productivity of textile products. Regular monitoring of motors using thermography can help identify potential problems before they become serious, allowing preventive maintenance and improving the reliability and efficiency of textile industry equipment.

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Decoding the shoes of Terracotta Warriors: in terms of restoration technology and functional performance

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ABSTRACT – REZUMAT

Decoding the shoes of Terracotta Warriors: in terms of restoration technology and functional performance

The shoes of the Terracotta Warriors hold significant historical and cultural value as an important legacy of ancient Chinese shoemaking craftsmanship. However, there is a dearth of research on terracotta shoes. Therefore, this study aimed to restore the Terracotta Warrior's shoes from the perspectives of clothing engineering and archaeology, and then to assess the critical function of the restored shoes. Finally, we will explore why the soldiers of the Qin Dynasty (221–206 BC) were so successful in the military. In the restoration process, we utilized Augmented Reality ranging technology to conduct field investigations in museums, obtaining the basic form of the shoe of the kneeling archer figurine No.05438, and based on this, we studied its techniques and materials. Further, a quantitative analysis of the structural functionality of the Qin Dynasty shoes was carried out. Results show that: (1) the shoe soles of the Terracotta Warriors were adorned with neatly arranged circular patterns; the shoe sole was divided into three sections, with a ratio of 8:13:6 among the three sections; (2) the production technique of the shoe sole was consistent with the Thousand-layer sole, and the material used was red ramie; (3) we compared the replica shoes with two similar modern shoes and found that the replica shoes not only exhibited excellent flexibility but also demonstrated better slip resistance in wet conditions. Overall, we successfully reconstructed the shoe and evaluated its functionality using advanced archaeological techniques. Our finding unveiled notable advantages in flexibility and slip resistance in the Terracotta Warrior's shoes, enhancing our understanding of ancient shoes. Additionally, this study also provides valuable practical experience and methodology for archaeology in restoring ancient shoes.

Keywords: *ergonomics, Qin Dynasty shoes, recovery technique, shoe material, shoe's flexibility, slip resistance*

Decodificarea încălţămintei armatei „de teracotă“ în ceea ce privește tehnologia de restaurare și performanța funcțională

Încălţămintea armatei „de teracotă“ are o valoare istorică și culturală semnificativă, ca o moștenire importantă a măiestriei antice chineze în confecţionarea pantofilor. Dar există o lipsă a studiilor în ceea ce priveşte încălţămintea armatei „de teracotă“. Prin urmare, acest studiu și-a propus să restaureze încălţămintea armatei „de teracotă“ din perspectiva ingineriei îmbrăcămintei și a arheologiei și apoi să evalueze funcția critică a pantofilor restaurați. În cele din urmă, a fost explorat motivul pentru care soldații dinastiei Qin (221–206 î.Hr.) au avut atât de mare succes în armată. În procesul de restaurare, a fost utilizată tehnologia pe baza realităţii augmentate pentru a efectua investigații de teren în muzee, obținându-se forma de bază a încălţămintei figurinei de arcaș stând în genunchi nr.05438 și, pe baza acesteia, au fost studiate tehnicile și materialele din care aceasta a fost confecţionată. În plus, a fost efectuată o analiză cantitativă a funcționalității structurale a încălţămintei dinastiei Qin. Rezultatele arată că: (1) tălpile încălţămintei purtate de armata „de teracotă“ erau împodobite cu modele circulare ordonate; talpa a fost împărțită în trei secțiuni, cu un raport de 8:13:6 între cele trei secțiuni; (2) tehnica de producție a tălpii de încălțăminte a fost în concordanță cu cea a tălpii cu o mie de straturi, iar materialul folosit a fost ramia de culoare roşie; (3) au fost comparate copiile cu doi pantofi moderni similari și am constatat că aceştia nu numai că au prezentat o flexibilitate excelentă, ci au demonstrat şi o rezistență superioară la alunecare în condiții de umiditate. În general, a fost reconstuit cu succes pantoful și a fost evaluată funcționalitatea acestuia folosind tehnici arheologice avansate. Descoperirea noastră a dezvăluit avantaje importante în ceea ce priveşte flexibilitatea și rezistență la alunecare a încălţămintei purtate de armata „de teracotă“, îmbunătățind înțelegerea noastră despre încălţămintea din antichitate. În plus, acest studiu oferă, de asemenea, experiență practică și o metodologie valoroasă pentru arheologie în restaurarea pantofilor antici.

Cuvinte-cheie*: ergonomie, încălţăminte aparţinând dinastiei Qin, tehnică de restaurare, materialul pantofilor, flexibilitatea pantofilor, rezistenţa la alunecare*

INTRODUCTION

Historical and cultural heritage serves as a bridge connecting the ancient and modern world, providing a key for contemporary individuals to explore ancient civilizations [1]. This heritage possesses significant historical, scientific, cultural, and artistic value, reflecting the lifestyle, social systems, and economic development of ancient societies [2]. As one of the precious cultural heritages, extensive research has been conducted on the armour techniques and structure of the Terracotta Warriors both domestically and internationally. Since the majority of the warriors are in a standing position, making it difficult to observe their shoe soles, the shoes of the Terracotta Warriors have been rarely considered. However, the shoes hold a significant position in Terracotta Warrior's archaeological research. They serve as important evidence of the shoes worn and equipped by the Qin Dynasty Warriors, as well as crucial samples for studying ancient textiles. Through the study of Terracotta Warrior's shoes, we can not only understand the ancient Chinese shoemaking techniques and material usage, providing a scientific basis for the protection and restoration of the Terracotta Warriors, but also gain insights into the military system, warfare technology, and the soldiers' living conditions during the Qin Dynasty. This research is invaluable in promoting our understanding and appreciation of ancient culture. Therefore, the study of Terracotta Warrior's shoes should not be overlooked.

Currently, research on the shoes of the Terracotta Warriors primarily focuses on analysing their cultural value and discussing their structural functionality. Miao et al. [3], proposed that the shoes of the Terracotta Warriors represented a "pragmatic culture" and possessed practicality and convenience. Yue et al. [4] suggested that the shoes of the Terracotta Warriors, as the oldest and most enduring sewn shoes with Thousand-layer soles (TLS), affirmed the significance and value of restoring the shoes, which helped to further study the origins and development of shoes in China. The "Seal Examination Style" from "Shuihudi Qin bamboo texts" recorded the pattern on the shoe sole of Qin people's shoes as sparse in the middle and dense at both ends, which matched the shoe sole mechanics during wear and the importance of durability. However, the functional performance of these shoes had not been quantitatively studied. Therefore, it is necessary to restore the shoe soles of the Terracotta Warriors based on literature and on-site investigations to conduct functional evaluations.

Scientific archaeology has emerged as a significant field of research in the restoration of shoes. Initially, researchers relied on unearthed relics to make basic inferences about their shoes. For example, Kochkina et al. [5] examined the manufacturing techniques and origins of funeral leather shoes in the Malay Liang Zhan Tomb Site, while Stevens et al. [6] studied the structure, size, and social indicators of wearers, such as their class, gender, and occupation, in 19th-century Boston shoes. With advancements in scientific technology, new techniques have been developed to preserve cultural heritage. More researchers are now utilizing methods like digital reconstruction to achieve shoe restoration. For instance, Abdullin et al. [7] developed a system for restoring fibrous structures, enabling the reconstruction of shoes made from flexible leather and birch bark, which were popular from the 17th to the 19th century. From a modern biomechanical perspective became another protocol to evaluate the structure and functionality of artifacts. Volken et al. [8] analysed the plantar pressure distribution to determine why a 15th-century military shoe could be used for military purposes. Moskvin et al. [9] also utilized computer-aided technologies to analyse the physical, materials science, anatomical, and biomechanical aspects of the shoes and other garments worn by a German warrior from the 2nd to the 4th century AD, based on scientific data to prove their functionality. Huang et al. [10] employed modern techniques such as X-ray testing, multispectral photography,3D scanning, and high-definition photography to successfully restore jade shoes from the Han Dynasty. These cases indicated that the restoration and quantitative analysis of the structure and functionality of ancient shoes are gradually becoming a powerful research tool, providing new insights into traditional archaeological artefacts. However, previous studies have not systematically examined the restoration, structure, and functionality of Terracotta Warriors' shoes.

Therefore, this study aimed to restore the Terracotta Warrior's shoes from the perspectives of clothing engineering and archaeology. The primary objective was to gain a deeper understanding of ancient craftsmanship, structure, and understanding of the functionality of shoes. In addition, our goal is to assess the critical function of the restored shoes and to decode why the soldiers in the Qin Dynasty were so successful in military exploits. According to this study, the producing techniques and technical plans of the Qin Terracotta Warrior's shoes, as well as physical restorations and modern functional evaluations will be studied. Our finding would reveal the exquisite craftsmanship and wisdom of ancient shoemaking, to shed light on the ancient people's understanding of the functional requirements of shoe soles.

METHODS

Restoration objects

The chosen target for restoration research was the kneeling archer figurine, labelled as 05438, which was unearthed from the eastern end of trench T21G18 in Pit2 [11]. Figure 1 exhibited minimal damage. It was depicted wearing a battle robe, draped

Fig. 1. Three-view of kneeling archer figurine in Sichuan Museum

with armour, and wearing square-toed shoes with upturned tips.

Restoration method

Shoe style

Based on the shoe information depicted on the kneeling archer figurine from the Qin Dynasty with the label 05438, we compared it with the shoes unearthed from the nearby Han Dynasty (206 BC–8 AD) at the Mawangdui site and concluded that the square-mouthed shallow shoes worn by the figurine did indeed exist [12]. These analyses and inferences would contribute to further research on the basic form and structure of the shoe.

Basic dimensions

To measure the dimensions of the shoe sole, we utilized an Augmented Reality (AR) rangefinder, which was a non-contact measurement tool based on structured light technology. This application is compatible with Apple iOS12 systems. It uses an invisible laser as a light source to emit encoded light patterns onto the object. By employing specific algorithms, it calculates the distortion of the returned encoded patterns, thereby obtaining the position and depth information of the object and achieving remote distance measurement [13]. The maximum depth range for recognition with this rangefinder was limited to 1.2 meters, therefore, the distance between the phone and the object being measured falls within this range while scanning [14]. The steps are shown below (figure 2):

Step 1. Open the rangefinder application.

Step 2. Keep your phone as parallel as possible to the object being measured and perpendicular to the ground. Slowly move the phone to locate the plane where the object is situated.

Step 3. When a measuring point appears on the plane, move the measuring point to the starting point of the object you want to measure and click the "+" button to begin the measurement.

Step 4. Move the measuring point to the end point of the object and click the "+" button to end the measurement. The length of the object will be displayed. The measurement accuracy of this rangefinder can range from 0.1 mm to 1 mm.

Restoration production

Firstly, based on the analysis of the extracted information from the selected kneeling archer figurine, the restored shoe details were determined based on the original state of the shoe sole. Secondly, through literature research and in-depth interviews [15], the traditional crafting techniques and materials used for making the shoe soles of Terracotta warriors were summarized and compiled. The overall restoration process began with a clothing engineering perspective, utilizing a two-dimensional sole pattern to create a three-dimensional object. The main steps were as follows (figure 3).

The production of the shoe sole included two main stages: paste preparation and sole fabrication, with the latter comprising six major steps:

Step 1: Paste preparation involves mixing wheat or corn flour with warm water at a ratio of 1:2, ensuring that the water temperature remains below 30 °C scale. The mixture is stirred thoroughly until it reaches a consistency resembling that of yoghurt. Next, the paste is rapidly and evenly spread onto a piece of cloth using a spatula before being left to dry in the sun. This serves as a backup for the subsequent steps.

Step 2: Sole fabrication. This step consists of six substeps: cutting the sole, glueing the sole, wrapping the sole, circling the sole, inserting the sole, and pounding the sole.

Cutting the sole: Based on the shoe's last, draw the sole pattern and leave a 2–3 cm margin on the edges for the upper part of the shoe. This will result in the final shoe pattern. Trace the left and right shoe patterns onto the previously prepared and dried linen cloth. Repeat the cutting process until the desired sole height is achieved.

Glueing the sole: According to the desired thickness of the sole, typically 1.5 cm, stack 5–7 layers of sole material together, forming a structure called “xian'er”.

Step 3: Wrapping the sole: Temporarily secure the sole material with sewing thread and then use the bias of the linen cloth to wrap the edges.

Step 4: Circling the sole: Use ramie to make a core and twist it into a rope. Sew a loop of twine along the

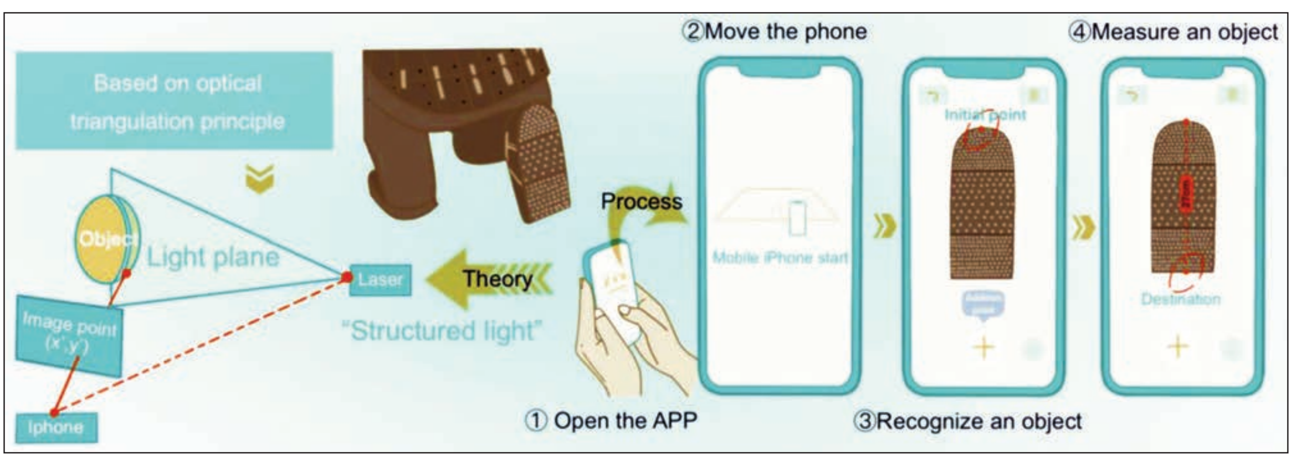

Fig. 2. Non-contact technology – AR distance measurement step diagram and scheme

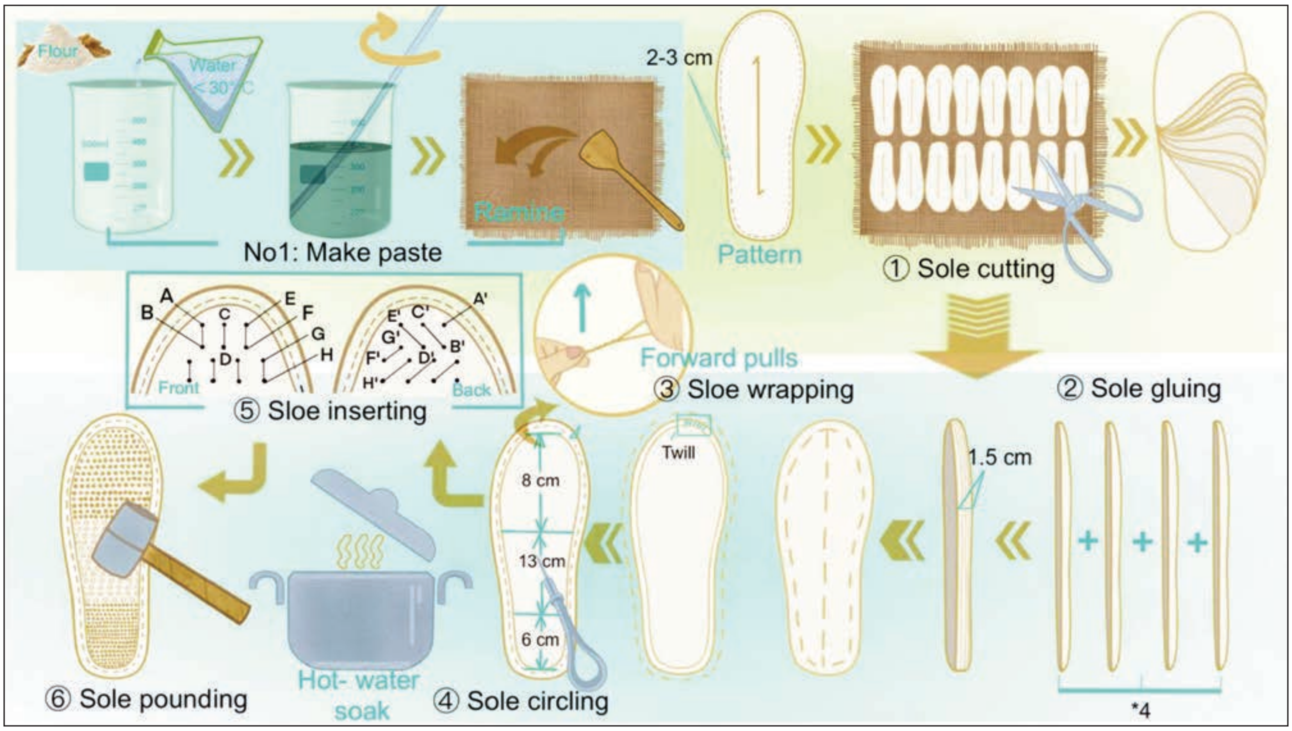

Fig. 3. Shoe sole manufacturing process flow

edge of the sole, spaced about 2 mm apart. Pay attention to ensure tight, neat, and consistent stitching, with stitches aligned horizontally and vertically. The stitches should be tight and evenly distributed. The method of twisting the hemp rope is done manually, as follows [16]:

Divide the ramie fibre into two strands and twist one strand forward on your leg until it becomes a tightly twisted cord. Use one hand to hold the twisted fibre in place.

Twist the other strand using the same method as above and place the two twisted strands together.

Twist forward with your hand and quickly pull it back, repeating this motion.

Step 5: Inserting the sole: Mark the needle holes on the stacked sole material and sew them together using the ramie rope. (Before sewing, the ramie rope can be soaked in wax water and then used. This makes it easier for the rope to pass through the 1.5 cm thick sole, improving efficiency). Use a clamp to secure the stacked sole material. Before each stitch, use an awl to create the needle holes and then pass the needle through.

Step 6: Pounding the sole: After soaking and steaming the stitched sole in hot water, use an iron hammer to flatten it. Finally, place it in a cool and well-ventilated area to air dry naturally, completing the production of the layered sole.

Assessing the key function of restored shoes

The shoes' basic function, slip resistance and flexibility decided the anti-slip ability and the comfort while walking. We contrasted the two properties of the restored TLS shoe (RTLS) and two modern TLS shoes (Zhuangyuan Orchid Cloth Shoes and Qinghong Hundred Years of Cloth Shoes), the similarities and differences among the three samples are summarized in table 1.

The slip resistance of the shoe sole was tested using a computerized slip resistance tester (model GT-7012-BEA). The principle of this system involves placing the sample on the testing interface, applying a specified force, and moving the plane relative to the sample horizontally or at a certain angle. The frictional force is measured and used to calculate the coefficient of friction. The coefficient of friction is used to evaluate the slip resistance of the shoe sole [17]. According to the formula $\mu = f/F$, the coefficient of friction is directly proportional to the frictional force. Therefore, a smaller coefficient of friction indicates poorer slip resistance, while a larger coefficient indicates better slip resistance. Three walking modes were simulated during the testing: forefoot, horizontal, and heel modes, which represented different walking states. Three tests were conducted using the same samples and modes under both dry and wet conditions, as shown in figure 4, *a*. The average values were calculated to represent the slip resistance performance of the samples.

The flexibility performance of the shoe sole was evaluated using a thin film pressure sensor. This device is suitable for measuring pressure, tension, pressure difference, and other physical quantities that can be converted into force [18]. The testing principle involves attaching the sensitive element of the thin film pressure sensor to the middle position of the heel of the shoe sole. The toe part of the shoe was fixed, and the heel of the sample was sequentially lifted to 45°, as shown in figure 4, *b*, to simulate the state of wearing the shoe and effectively evaluate the flexural

Table 1

COMPARATIVE PLOTS OF SIMILARITIES AND DIFFERENCES FOR SAMPLES 1–3					
Name	**Stitch**	**Sewing methods**	**Thickness**	**Material**	**Sole pattern distribution**
RTLS	Vertical seam stitching	Single needle Diamond shape	1.5 cm	Ramie	Dense in the front and back, sparse in the middle
ZOCS	Vertical seam stitching	Single needle Diamond shape	1.5 cm	Ramie	The outsole is evenly distributed
QHYOCS	Circular seam stitching	Circular single needle	1.5 cm	Cotton	The outsole is evenly distributed
No.	**The bottom view**		**The side view**		**The front view**
TWRS (Sample 1)					
ZOCS (Sample 2)					
QHYOCS (Sample 3)					

performance of the shoe sole. During the testing process, the force required to lift the heel of the shoe was recorded. A higher force indicated poorer flexural performance, while a lower force indicated better flexural performance. This process converted the change in weight into a change in pressure. Each sample was tested three times, and the average value was calculated to represent the flexural performance of the samples.

RESULT

Restoration of Terracotta Warrior's shoes

Based on the photographs taken on-site, we have completed the reconstruction of the two-dimensional image of the shoe sole. As shown in figure 5, *a*, the shoe sole was comprised of three areas: Area A, the forefoot region, with a length of 8 cm; Area B, the middle region, with a length of 13 cm; and Area C, the heel region, with a length of 6 cm. The width of the toe box was 11 cm, and the length of the shoe opening was 19.5 cm. The arrangement of stitch holes in different areas was as follows: Area A has the highest number of horizontal and vertical stitch holes, with 22 and 23 respectively. Area B had the lowest number of horizontal and vertical stitch holes, with 10/11 and 14 respectively. The patterns on the forefoot and heel areas are dense, while the patterns in the middle area are sparse. This pattern was the stitching line of

a *b*

Fig. 4. Chart of: *a* – slip resistance test; *b* – flexibility test

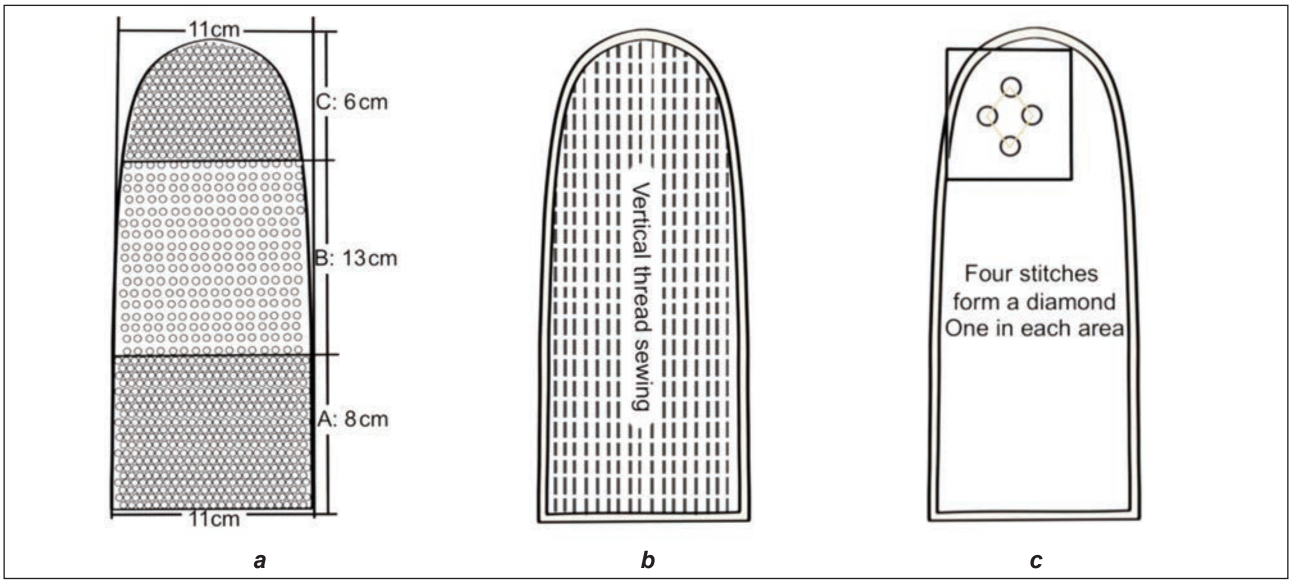

Fig. 5. Chart of: *a* – sole 2D reconstruction; *b* – vertical line stitch; *c* – single needle diamond stitch

sewing, which can be categorized into four types: horizontal lines, vertical lines, diagonal lines, and circular lines. In terms of stitching techniques, there were mainly two types of stitching techniques for the welt seam, namely, the "zaohua diamond" and the "single needle diamond". By comparing the pattern structure of the shoe sole model 05438 with the above techniques, we determined that the stitching method used was vertical line stitching (figure 5, *b*) and the stitching technique was the single needle diamond (figure 5, *c*).

The restoration results of Terracotta Warrior's shoes

Figure 6 shows the reconstructed shoe sole in both their front and back views, detailed images of the front, middle, and backline traces of the sole in both front and back views, as well as an image demo of Terracotta Warrior's recovered shoe sole and wear effect show picturenstrating the wearing effect.

Results of anti-slip performance

Based on the results of the coefficient of friction for the shoe sole in table 2, the following conclusions can be drawn: In a wet environment, sample 1 had the highest static coefficient of friction (SF) in both the horizontal and heel modes. Additionally, sample 3 exhibited the highest values for both the dynamic and static coefficients of friction (DF and SF), indicating better slip resistance. The difference in friction coefficients between sample 1 and sample 2 was not significant for the two media in all three modes. Furthermore, all three samples showed better slip resistance in wet conditions compared to dry conditions.

Results of flexibility performance

The minimum force required to lift sample 1 was 4.9 N, followed by sample 2 which required 7.2 N of force. Sample 3 required the highest force, which was 8.5 N. Based on this, we can conclude that Sample 1 (recovered shoes) was more prone to bending during walking, indicating better flexibility. This superior flexibility was reflected in improved

Fig. 6. Image of: *a* – Terracotta Warrior's shoe sole physical restoration; *b* – craftsmanship detail

Table 2

COMPARATIVE RESULTS OF SLIP RESISTANCE TEST												
No.	Forefoot				Level				Heel			
	Dry		Damp		Dry		Damp		Dry		Damp	
	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF
Sample 1	0.26	0.40	0.22	0.44	0.34	0.46	0.25	0.61	0.29	0.39	0.24	0.49
Sample 2	0.28	0.39	0.27	0.47	0.32	0.40	0.28	0.54	0.27	0.39	0.24	0.48
Sample 3	0.35	0.45	0.35	0.48	0.35	0.48	0.39	0.56	0.33	0.45	0.35	0.46

comfort, enhanced stability, promotion of a natural gait, and increased energy rebound [19]. These advantages provided the wearer with a more comfortable, stable, and efficient walking experience.

DISCUSSION

Sole material

Research shows that the shoe soles of the Terracotta Warriors from the Qin Dynasty were typical examples of multi-layered shoe soles, and they were made from ramie fabric. The earliest evidence of traditional Chinese multi-layered cloth shoes can be traced back to the kneeling statues of warriors from the Zhou Dynasty, which dates back to 1046-771BC [20]. The shoe sole imprints found on these kneeling statues closely resemble those found on the Terracotta Warriors, suggesting that the production technique of multi-layered cloth shoes was already quite mature in ancient times. According to the "Dictionary of Chinese Footwear Culture" there is evidence that during the pre-Qin period (770 – 221 BC), cloth shoes with shoe soles made of hemp, hemp cloth or silk were already being used [21]. In 1979, shoe soles made from woven hemp fabric were discovered at the Maquanwan site, which dates back to the Han Dynasty. These discoveries further confirmed the historical use of hemp fabric in shoe production in ancient China.

Sole structure design

The Terracotta Warriors were burial objects from the Qin Dynasty in ancient China, and their sole design reflected the level of shoe-making technology and craftsmanship during that time. Firstly, the shoe sole of the Terracotta Warriors was divided into different zones – the forefoot, midfoot, and heel – based on the actual needs of the human foot. This design aimed to provide optimum comfort, support and durability, thereby optimising the structure and performance of the shoe sole and improving the overall quality of the shoe. The forefoot and heel areas of shoe soles usually require good cushioning performance and wear resistance to protect the feet from impact and abrasion, hence the more densely arranged patterns in these two areas [22]. The midfoot area, located between the forefoot and heel, played a connecting and balancing role and needed to provide a certain level of support and stability [23]. Secondly, the pattern design of the shoe sole helped increase the friction between the shoe sole and the ground, thereby providing better slip resistance [24]. Lastly, the shoe sole adopted a layered structure known as "qiancengdai", with each layer made of ramie material. This material was lightweight, thin, soft, breathable, and moisture-absorbing, providing sufficient comfort and protection for the feet [25]. Overall, the design of the Terracotta Warrior's shoe sole emphasized comfort and slip resistance, reflecting the meticulous and detail-oriented approach to shoe-making in ancient China. These designs have had a significant influence on the subsequent development of shoe production.

Sole's performance

The main factors influencing the slip resistance of the sole were the contact area, contact surface, sole material, and sole pattern [26]. Slip resistance was primarily evaluated by assessing the magnitude of frictional force, with higher frictional force indicating better slip resistance. In terms of sole material and contact medium, Irvine et al. [27] found that different shoe materials showed different slip resistance performance, with significant differences between dry and wet conditions. Most shoe materials exhibited good slip resistance in dry conditions but performed poorly in wet conditions, such as EVA, TPR, rubber, and PU materials [28]. Chang et al. also indicated that compared to dry conditions, the coefficient of friction of the sole was lower in wet conditions, indicating a poorer slip resistance [29]. However, the results of this study showed that all three samples had higher coefficients of friction under humid conditions, which was contrasted with the results of previous studies. One of the major differences could be observed in the use of sole materials. Previous experiments primarily focused on non-absorbent materials such as rubber, while we used shoe soles made of textile fabric, which was absorbent. Li et al. [30] suggested that water reduced the friction between the sole and the ground, as it hindered their contact and molecular bonding. Hence, the absorbent nature of the textile fabric as a sole material would facilitate better contact between the sole and the ground, resulting in an increased coefficient of friction under wet and slippery conditions. It was important to note that using textile fabric as a sole material may have certain limitations in terms of wear resistance and durability. Therefore, when applying textile fabric in practical production and design, its absorbent properties should be considered alongside other performance indicators, and a comprehensive evaluation should be conducted.

In general, the opposite of stiffness was referred to as “flexibility” [31]. The flexibility of shoes was influenced by factors such as outsole hardness, materials, and structure. Studies showed that the stiffness of the outsole material was significantly greater than that of the upper material, making it the primary influencing factor on shoe flexibility [32]. Typically, shoes with a thinner sole had better flexibility. In this study, all three samples had a sole thickness of 1.5 cm. Therefore, the thickness of the shoe sole was not considered as a factor affecting flexibility and will not be discussed. Through comparing the three samples and considering the flexibility evaluation results of this study, the Terracotta Warrior replica shoe demonstrated superior performance in terms of flexibility, which can be attributed to its structure and craftsmanship. In terms of outsole structure, research has indicated that small and dense sole patterns were lighter and more flexible compared to large sole patterns [33]. However, all three samples had small and dense sole patterns, with differences in their distribution and proportion. The distribution and proportion of the sole pattern in the Terracotta Warrior replica shoe (Sample 1) were better aligned with the natural walking gait of humans. Generally, during normal walking, most bending activities occur in the metatarsophalangeal joint region [34]; while this region accounts for approximately one-third of the entire foot. Interestingly, the dense pattern area in the forefoot of the Terracotta Warrior’s shoes also accounted for one-third of the entire shoe sole, which conforms to ergonomics and facilitates better flexibility of the outsole. Regarding the outsole material, softer materials typically exhibit better flexibility, while rigid materials restrict the bending ability of the outsole. The Terracotta Warrior replica shoe utilized ramie material, which was lighter and thinner compared to cotton fabric, providing better flexibility. In conclusion, the Terracotta Warrior replica shoe demonstrated advantages in terms of flexibility, which was attributed to its outsole structure that aligned with the natural walking gait and the use of flexible ramie material.

CONCLUSIONS

Overall, this study first analysed and reconstructed the shoe sole and structure of the Terracotta Warrior's shoes, and then suitable materials were chosen for fabrication based on a thorough literature review; finally, by employing modern evaluation techniques for shoe structure and functionality, it was established that the shoe of the Terracotta Warrior’s shoes exhibit notable advantages in terms of flexibility and slip resistance. These advantages demonstrated shoes played a vital role in supporting the soldiers of the Qin Dynasty, contributing to their ability to enhance their combat capabilities and unify China 221 BC. These novel findings offer valuable insights into the structure and functionality of ancient shoes.

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Selection of hand features based on Random Forest algorithm and hand shape recognition

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ABSTRACT – REZUMAT

Selection of hand features based on Random Forest algorithm and hand shape recognition

To obtain effective features applicable to hand morphology recognition, the method of obtaining effective feature indicators based on the Random Forest (RF) algorithm to downscale hand morphology parameters is proposed. Firstly, 232 female university students collected three-dimensional hand information, constructed auxiliary point, line, and surface standardised measurement methods, obtained 33 characteristic parts of human dimensions, and used k-means clustering for hand morphology subdivision. Hand morphology can be divided into three categories: short, slender and broad. The RF algorithm is used for feature index importance assessment and hand shape recognition model. The accuracy of the feature metrics determined by the RF algorithm, PCA, and VC method applied to hand shape recognition is compared and analysed to verify the effectiveness of the dimensionality reduction of the RF algorithm. The results showed that the feature indexes used for hand shape recognition were five items: hand length, thickness at the metacarpal, thenar width, the distance between the thumb and index finger, and distance from the root of the little finger to the centre of the wrist. Using the RF algorithm to reduce the dimensionality is more effective; the average recognition accuracy of the four hand shape recognition models is 93.78% on average, compared with PCA and VC reduction methods, the average accuracy of hand shape recognition models is increased by 19.17%, and 14.86% respectively. The study's results can provide methodological references for the objective selection of characteristic indicators and morphological recognition of human body parts.

Keywords: *3D scanning, hand shape classification, Random Forest algorithm, feature selection, hand shape recognition*

Selectarea caracteristicilor mâinii pe baza algoritmului Random Forest și recunoașterea formei mâinii

Pentru a obține caracteristici eficiente aplicabile recunoașterii morfologiei mâinii, este propusă metoda de obținere a indicatorilor eficienți bazați pe algoritmul Random Forest (RF) pentru a reduce scalarea parametrilor morfologiei mâinii. În primul rând, 232 de studente au colectat informații tridimensionale ale mâinii, au construit metode de măsurare standardizate a punctelor auxiliare, liniilor și suprafeței, au obținut 33 de părți caracteristice ale dimensiunilor umane și au folosit gruparea k-means pentru subdiviziunea morfologiei mainii. Morfologia mâinii poate fi împărțită în trei categorii: scurtă, îngustă și lată. Algoritmul RF este utilizat pentru evaluarea importanței indicelui caracteristicilor și modelul de recunoaștere a formei mâinii. Precizia parametrilor caracteristicilor determinate de algoritmul RF, PCA și metoda VC aplicată recunoașterii formei mâinii sunt comparate și analizate pentru a verifica eficacitatea reducerii dimensionalității algoritmului RF. Rezultatele au arătat că indicii de caracteristici utilizați pentru recunoașterea formei mâinii au fost cinci itemi: lungimea mâinii, grosimea la nivelul metacarpianului, lățimea palmei, distanța dintre degetul mare și cel arătător și distanța de la baza degetului mic până la centrul încheieturii mâinii. Utilizarea algoritmului RF pentru a reduce dimensionalitatea este mai eficientă; precizia medie de recunoaștere a modelelor de recunoaștere a formei mâinii este de 93,78% în medie; în comparație cu metodele de reducere PCA și VC, precizia medie a modelelor de recunoaștere a formei mâinii creşte cu 19,17% și, respectiv, 14,86%. Rezultatele studiului pot oferi referințe metodologice pentru selecția obiectivă a indicatorilor caracteristici și recunoașterea morfologică a părților corpului uman.

Cuvinte-cheie*: scanare 3D, clasificarea formei mâinii, algoritm Random Forest, selecție de caracteristici, recunoașterea formei mâinii*

INTRODUCTION

Studying human hand characteristics and classification is essential for size development, hand product design, fit research, and pattern optimization [1]. Hand size acquisition is the basis of hand feature and classification research. There are mainly manual contact measurements, non-contact 3D scanning, and picture measurement methods to acquire hand size.

With the evolution of scientific instruments, non-contact 3D body scanning is more standardized and faster than a traditional tape measure. Since the scanners can measure more parameters, such as the angle, thickness, width, height, volume, and curvature of the human body accurately [2–4], this method is believed to be the most suitable method to obtain anthropometric data in the shortest time and at the cheapest cost [5]. However, 3D body scanning also presents the problem that the complexity of parameter dimensionality while acquiring multi-dimensional parameters makes it difficult to determine the main feature parameters effectively. To improve the interpretability and accuracy of hand morphology recognition, extracting key feature indicators from multidimensional hand parameters is a critical issue in hand morphology research.

Currently, research on hand morphology classification recognition is gradually increasing, mainly in terms of PCA (Principal Component Analysis). Jee et al. used factor analysis to identify three main factors from 21 hand dimensions, hand width, palm length, and finger length, giving descriptive statistics of hand dimensions in Korea [6]. Liu et al. used the PCA method to select five hand characteristics factors from 37 hand measurements for the hand characteristics study [7]. Fan et al. measured 24 hand dimensions and used PCA to dimensionalize the hand measurements and perform K-means cluster analysis to classify the hand morphology of 328 samples into five categories: small, short and fat, standard, long and slender, and wide, to provide a reference for hand product design [1]. All of the above methods in hand morphology classification and identification research idea to use PCA first to reduce the dimensionality of hand measurements and determine feature indicators for classification and identification, in which the cumulative contribution of principal component factors are all below 80%, indicating that at most 80% of hand, features can be explained. Since PCA can eliminate correlations between variables, provided that such correlations are assumed linear, good results are not obtained for nonlinear dependencies [8]. Zhang et al. to reduce the high-dimensional feature index for chest morphology characterization, CV (Coefficient of Variation) was used to eliminate the influence of measurement scale and magnitude, parameters with CV values greater than 10% were selected for chest morphology analysis [9]. Zhang et al. measured 22 characteristic parameters related to neck and shoulder morphology in men and then selected anterior tilt angle, dorsal entry angle, oblique shoulder angle, neck-shoulder width ratio, and transverse sagittal neck diameter ratio as cluster analysis variables based on CV analysis to classify the neck and shoulder morphology and summarize the discriminant rules [10]. The above methods extract variables from multidimensional parameters but require multiple screening and comparison of the extracted feature indicators. Zhou et al. used an RF algorithm to quantify the importance of female breast feature indicators and determine the best breast features for classification and identification. The results showed that dimensionality reduction by RF algorithm is more effective than traditional dimensionality reduction methods such as PCA [5]. CV and PCA methods require multiple screening when extracting feature metrics, and this study expects to determine the metrics of effective hand features directly through dimensionality reduction by RF algorithm.

Therefore, to determine the effective hand features applicable to hand morphology recognition, this paper will start from hand 3D point cloud data, use K-Means for clustering analysis, RF algorithm to quantify the importance of hand feature indexes, and at the same time, build BP (backpropagation), RBF (Radial Basis Function), SVM (Support Vector Machines), RF four supervised machine learning mathematical models, hand model recognition accuracy as a benchmark, compare and analyse the accuracy of hand shape recognition with feature indicators determined by RF algorithm, PCA, VC method, further verify the RF algorithm dimensionality reduction effectiveness, provide reference for hand feature indicator selection and hand shape recognition.

MATERIALS AND METHODS

Participants and measurement

To ensure the representativeness and independence of the sample, the experiment randomly sampled 240 female college students aged 18–25 without physical activities, diseases, and other particular hand morphology as the study subjects. To exclude abnormal data from the analysis, values outside the range of “the mean difference ± 3σ” (σ: SD of differences) were considered weird and excluded from the study [11]. After excluding 3.33% of the samples, the adequate sample size was determined to be 232 people. Refer to GB/T 16252-1996 “Adult Hand Size”, GB/T 5703-2010 “Anthropometric Basic Items for Technical

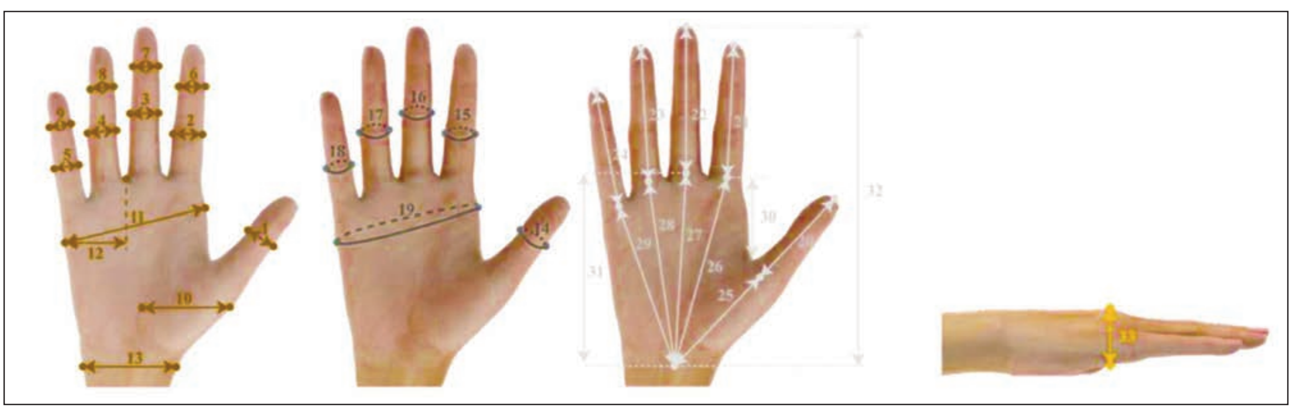


Fig. 1. Schematic diagram of hand measurement items

Design", 33 hand measurement items, including hand length, were determined, as shown in figure 1.

Measuring

The results of manual contact measurements are susceptible to subjective factors of the tester and the muscle tissue undergoes different degrees of extension and contraction movements during the measurement process, resulting in measurement errors [12]. Therefore, this study used the non-contact 3D scanning method to measure the hand dimensions.

According to GB/T 23698-2009 "General Requirements for 3D Scanning Anthropometric Methods", the temperature of the experimental environment was 27±3°C, and the relative humidity was (60±10)%. A multifunctional handheld 3D scanner (EinScan, Xianlin, China, measurement accuracy 0.04 mm) was used to capture the 3D point cloud of the hand. Through point cloud smoothing, rounding, and filling, solve the noise and missing point clouds generated by slight shaking during scanning, and get smooth and complete point cloud data. In this paper, the measurement method of handheld 3D scanning is divided into the following three steps:

Auxiliary point, line and surface definitions: To ensure the stability of repeated measurements, the standardization of auxiliary points, lines, and surfaces before determining the characteristic points, calibration points, lines, and surfaces as shown in figure 2 (finger part to the middle finger as an example).

Hand feature point determination: After determining the required auxiliary points, lines, and surfaces according to the above steps, the hand feature points are determined by combining GB/T 16252-1996 and GB/T 5703-2010. To better analyse the local morphology, such as fingers, the coordinate system needs to be reconstructed for the finger part. Take the middle finger for example. The feature points are calibrated as shown in figure 2. Similarly, other hand width and circumference feature points can be determined.

Hand size measurements: A handheld 3D scanner scans the hand, and 33 hand feature parameters are measured based on the processed hand 3D point cloud data by the step-by-step method described above.

Extraction of hand features

To extract key feature indicators from multidimensional hand parameters for hand morphology recognition and consider the discrete and nonlinear hand feature part size, this paper uses the RF algorithm to determine the indicators of practical hand features. The RF algorithm can quantify the importance of hand features and simplify the calculation process, improving the efficiency and objectivity of the results [5]. RF trains different base classifiers according to each subset and determines the final classification result by the results of the base classifier voting. Gini (Gini index) or OOB (out-of-bag) error rate was used as a metric to evaluate the contribution of each feature in the training process [13]. To determine the hand feature indicators for hand shape recognition, this study uses Gini to evaluate the contribution of feature indicators to the decision tree and the process of scoring the importance of 33 hand feature indicators by RF algorithm including Gini result output calculation, feature indicator importance calculation and feature indicator importance score normalization three stages, the result output expression is as follows

1. Gini results output calculation:

$$GI_q^i = 1 - \sum_{k=1}^{K} P_{qk}^2 \qquad (1)$$

2. The importance of feature indicator X_j at node q of the i decision tree is:

$$VIM_{iq}^{GI(i)} = GI_q^i - GI_l^i - GI_r^i \qquad (2)$$

Suppose there are I decision trees in the RF and the importance of the feature indicators X_j is:

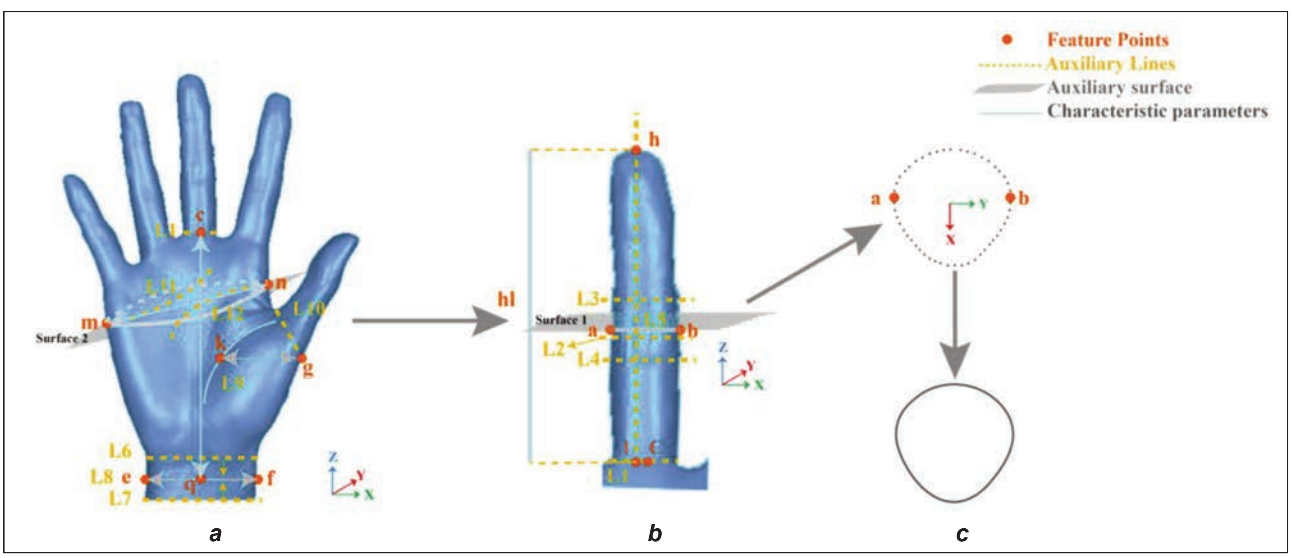


Fig. 2. Determine the hand characteristic parameters: *a* – palm measurement method; *b* – middle finger measurement method, *c* – middle finger perimeter section curve fitting

$$VIM_i^{GI} = \sum_{i=1}^{I} VIM_j^{GI(i)} \quad (3)$$

3. Normalization of importance scores of feature indicators:

$$VIM_j = \frac{VIM_j^{GI}}{\sum_{j=1}^{33} VIM_i^{GI}} \quad (4)$$

Recognition models for hand shapes

Supervised learning finds the mapping relationship between input and output from the already labelled training set. It applies this mapping relationship to the unknown data for classification and prediction [14]. Therefore, this study used the BP neural network, RBF neural network, SVM support vector machine, and RF algorithm to construct four hand morphology recognition models. The model parameters were set as shown in table 1.

RESULT AND DISCUSSIONS

k-Means clustering analysis

To explore the hand morphology classification, the optimal number of clusters needs to be determined. The hypothesis of normal distribution was first tested on the sample, and the data of 33 variables were tested to be approximately normally distributed. Take the length of the hand as an example, a histogram of Gaussian distribution is obtained, as shown in figure 3, *a*.

In this study, a mixed F-statistic was used to determine the number of clusters. The mixed F statistic is abbreviated as, and the larger the value calculated means that all variables are more closely related within classes and more dispersed between classes, so the number of categories corresponding to the largest is the optimal number of categories [15].

By calculating the FMixed value corresponding to each classification number obtained, it can be seen from figure 3, *b* that when the FMixed value is the largest, the corresponding C = 3, so the best classification of 232 female college students' hands is in 3 categories.

Due to the large amount of data obtained from hand measurements, the fast sample clustering (K-Means) method was applied to perform fast clustering analysis on hand data in order to facilitate the exploration of hand morphology classification [16]. The hand morphology and characteristics were analysed based on the clustering index. After ten iterations, the clustering centre converged. Finally, the hand morphology was divided into three categories and named according to the characteristics of each type of hand shape, which were wide and large, slender and short, and fat, as shown in table 2.

To analyse the clustering results more clearly, the clustering centres of the three classes of hand types are described with the corresponding shapes. Among them, the three types of hand morphology contour line pairs are shown in figure 4, *a*. The three types of hand morphology intermediate models and intermediate values are shown in figure 4, *b*.

Table 1

MATHEMATICAL MODEL PARAMETER SETTING					
Models	**Parameter**	**Value**	**Models**	**Parameter**	**Value**
BP	Hidden nodes	11	SVM	Penalty Factor	10
	Input transfer function	Tansig	RBF	Layer	3
	Output transfer function	Purelin		Number of neurons	190
	Layer	3		Kernel functions	newrbe
	Expectation error	0.01	RF	Number of decision trees	500
SVM	Kernel functions	rbf		Minimum number of leaves	5

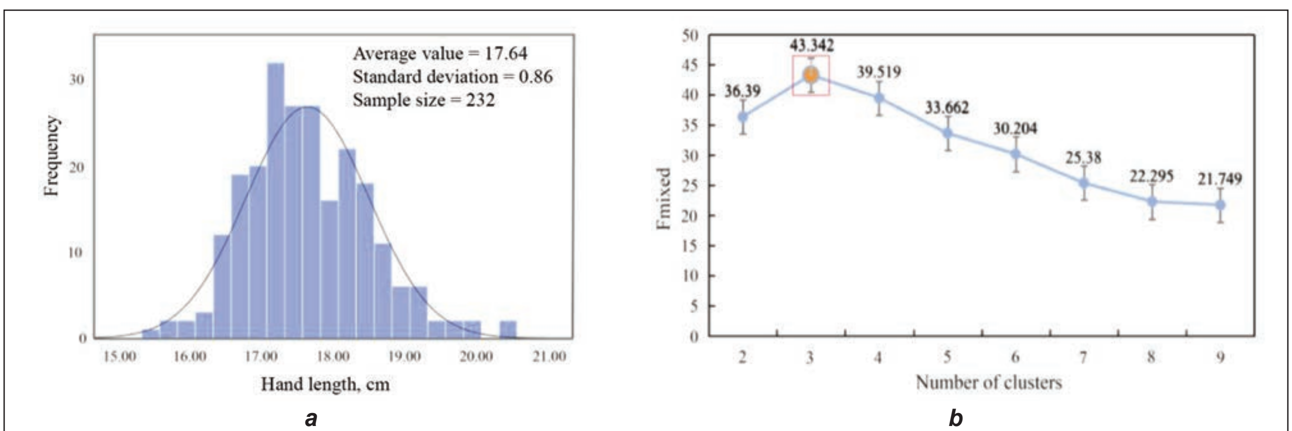


Fig. 3. Graphs of: *a* – histogram of Gaussian distribution; *b* – the mixed F-statistic

Table 2

HAND SHAPE CHARACTERISTICS AND PROPORTION		
Name	**Characteristics**	**Proportion (%)**
Wide large	The palm length is 60% of the hand length, the palm is relatively wide, and the overall size is large.	22.5
Slender type	The hand length, width, and circumference dimensions are smaller, the length dimension is larger, the palm is flatter, and the hand morphology is slender.	40.2
Short fat type	The hand features shorter length dimensions but larger circumference, width, and palm thickness and a short, fat hand morphology.	37.3

Importance assessment of the hand features

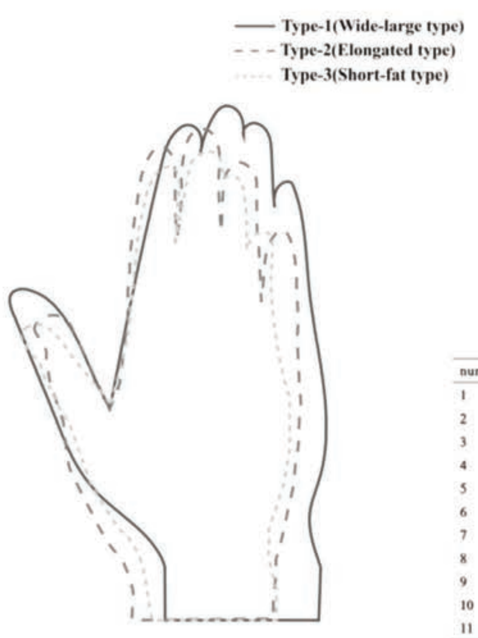
The RF algorithm performs feature metric importance quantification to evaluate the importance of hand feature metrics. It mainly includes three steps of RF algorithm parameter setting, feature index importance ranking, feature index determination, ranking feature index importance, and dividing the samples into a training set and test set in the ratio of 8:2, which are represented as follows:

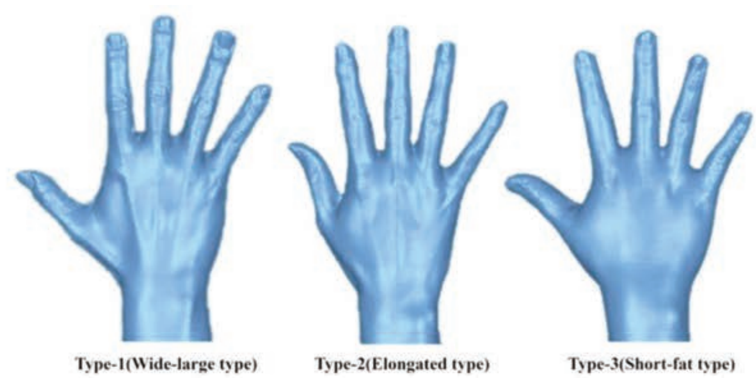
1. Decision tree, number of branches determined

Combined with the RF algorithm decision tree's minimum tree in other machine learning datasets, this study keeps the number of branch variables constant. It determines the decision tree forest size Ntrees = {50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000}. The RF algorithm prediction results were compared with the classification results, and the best decision tree value of 500 was finally determined, and the results are shown in figure 5, *a*. Determine the number of branches using the square root of the characteristic index [17]. Therefore, d = 33 and M = 5 to 6 in this study. The number of branches was determined to be five by changing the size of the number of branches and comparing the predicted results of the RF algorithm with the classification results. The results are shown in figure 5, *b*.

2. Characteristic index determination

The RF algorithm calculated the hand feature index importance score; the results are shown in figure 5, *c*. The importance scores of five indicators, namely, hand length, the distance between the thumb and index finger, thenar width, thickness at metacarpal, and distance between the thumb and index finger, were more significant than 0.4. The five indicators reflected information on hand length characteristics, thumb characteristics, and palm characteristics. There were 15, 7, and 5 hand feature indicators with importance scores in the range of (0.0,0.2], (0.2,0.4], and (0.4,1.4], respectively. The top 15% (top 5), 36% (top 12), and 82% (top 27) sets of hand feature indicators were determined based on the feature indicator importance scores.





number	Type-1	Type-2	Type-3	number	Type-1	Type-2	Type-3	number	Type-1	Type-2	Type-3
1	6.310	5.950	5.660	12	3.850	3.740	3.570	23	7.440	7.120	6.800
2	7.290	6.960	6.630	13	5.339	5.242	4.962	24	5.940	5.670	5.400
3	8.000	7.696	7.312	14	5.890	5.690	5.510	25	7.240	6.940	6.620
4	7.440	7.120	6.800	15	5.604	5.444	5.233	26	10.850	10.250	9.850
5	5.940	5.670	5.400	16	5.640	5.470	5.270	27	10.790	10.120	9.730
6	1.450	1.424	1.350	17	5.270	5.120	4.940	28	10.220	9.690	9.300
7	1.462	1.440	1.359	18	4.710	4.570	4.420	29	9.400	8.860	8.500
8	1.336	1.330	1.255	19	18.690	18.000	17.300	30	4.852	4.143	4.401
9	1.229	1.199	1.142	20	6.310	5.950	5.660	31	10.700	10.140	9.680
10	5.137	4.580	4.828	21	7.290	6.960	6.630	32	17.850	17.040	18.090
11	7.880	7.620	7.400	22	8.000	7.696	7.312	33	2.569	2.395	2.634

a *b*

Fig. 4. Comparison of three types of hand morphology: *a* – shape comparison of three hand types; *b* – three types of subdivided hand shape

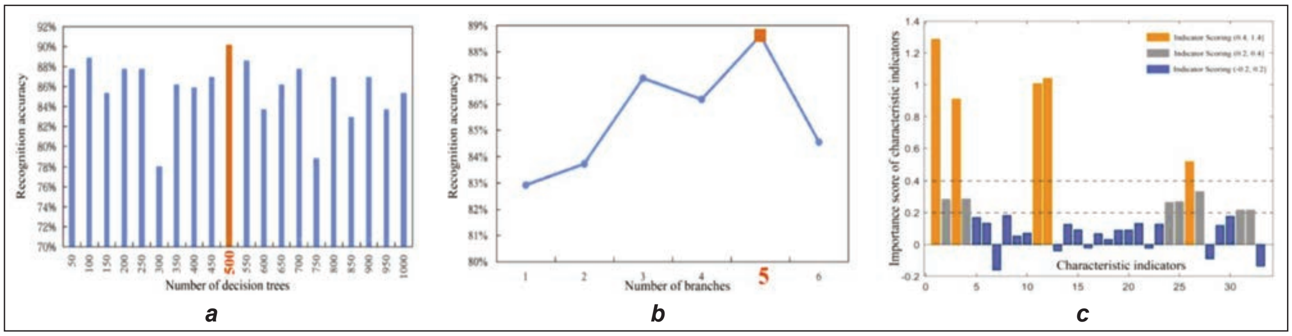


Fig. 5. Importance assessment of the hand features: *a* – recognition accuracy with different numbers of decision trees; *b* – recognition accuracy with different numbers of branches; *c* – index importance score

Validation of the hand feature selection

To verify the best feature index dimension of the RF algorithm for dimensionality reduction, this study used the BP neural network, RBF neural network, RF algorithm, and SVM algorithm to construct four hand shape recognition models, respectively, and the hand shape recognition model accuracy results are shown in table 3 and figure 6.

Combined with t-SNE algorithm 3D visualization to evaluate the dimensionality of feature indicators and RF and other three dimensionality reduction methods (RF, PCA, CV) for hand morphology recognition and analyse the degree of sample dispersion and crossover. t-SNE is a nonlinear dimensionality reduction algorithm that reduces multidimensional data to 2D and 3D visualization more effectively [18]. Analysis of figure 7 shows that when five hand feature indicators are obtained by the RF algorithm for hand shape recognition through dimensionality reduction, the 3 class hand shape boundaries are the most obvious, the distance between the cluster centres is far, and the sample crossover is the smallest, indicating that hand shape recognition is the most effective. Due to the discrete and nonlinear nature of hand size data, the RF algorithm quantifies the contribution value of each feature metric on the decision tree when performing feature metric importance assessment. The importance ranking of the feature indicators is derived by comparing and analysing the

Table 3

HAND SHAPE RECOGNITION ACCURACY OF DIFFERENT FEATURE INDEX DIMENSIONS

Characteristic index dimension	Recognition accuracy (%)				Average recognition accuracy (%)
	BP	SVM	RBF	RF	
5 (RF)	97.43	90	95	92.68	93.78
12 (RF)	87.80	82.50	77.50	92.68	85.12
27 (RF)	82.94	67.50	58.30	78.86	71.90
33	90.23	70	52.50	78	72.68

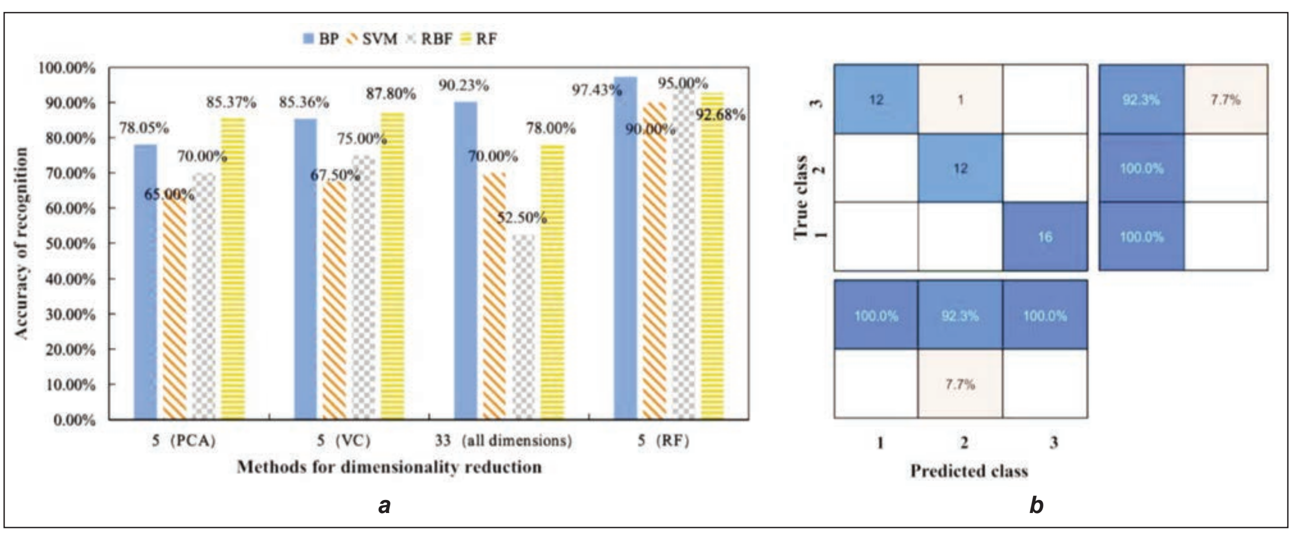


Fig. 6. The accuracy of hand shape recognition by neural networks: *a* – hand shape recognition accuracy with different feature indexes; *b* – confusion matrix of BP hand shape recognition model

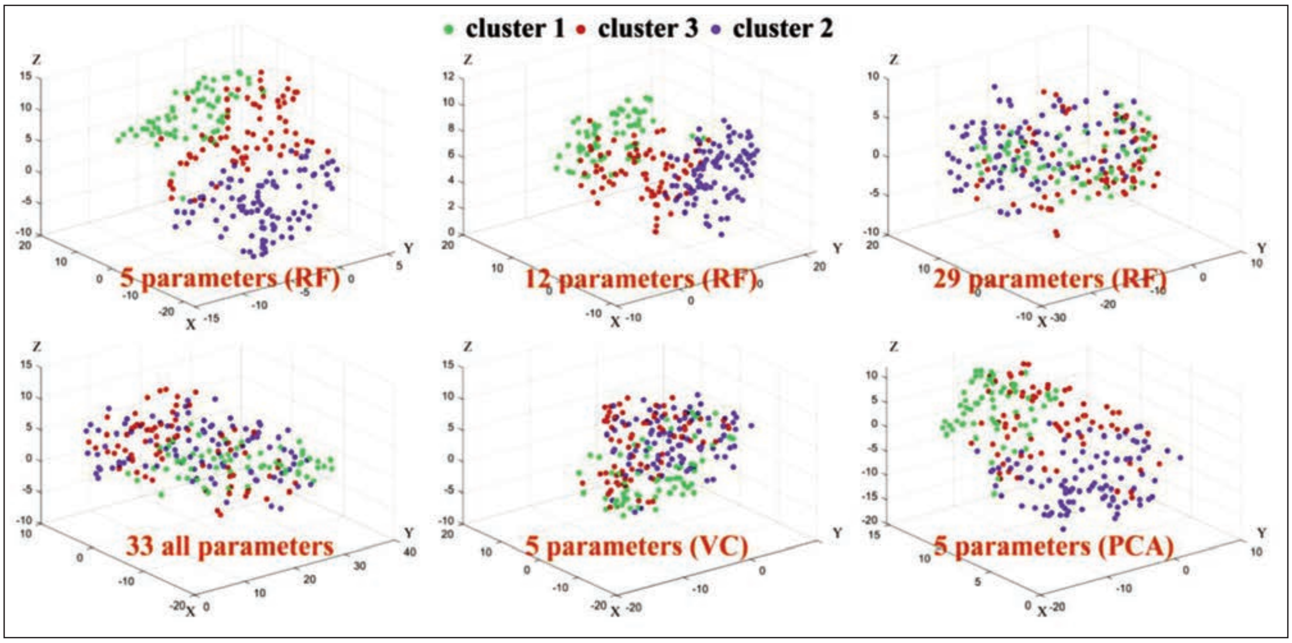


Fig. 7. The accuracy of hand shape recognition by neural networks

magnitude of the contribution value of each feature indicator, so the extracted feature indicators are more objective.

CONCLUSION

To improve the effectiveness of hand feature index selection and hand shape recognition accuracy, this study uses an RF algorithm to evaluate the importance of hand feature indexes. The main conclusions drawn from this study are:

1. The optimal number of clusters was determined to be 3 using the F mixed statistic, and three categories of hand morphology were determined by the K-Means clustering method: short and fat, slender and broad. Among them, the short fat type hand features shorter length dimensions but larger circumference, width, and palm thickness; the slender type hand has smaller width and circumference dimensions and larger length dimensions; the wide large palm is flatter palm is wider and has larger overall dimensions.
2. Dimensionality reduction of the hand feature indicators by RF algorithm to determine the feature indicator dataset as 5, 12, 27; Four hand shape recognition models of BP, RBF, SVM, and RF were constructed, and the best feature index dataset was determined by comparing and analysing the feature index dataset 5 (hand length, distance between the thumb and index finger, thenar width, thickness at metacarpal, and distance between the thumb and index finger). The four models achieved the highest average recognition accuracy of 93.78%.
3. Comparing and analysing the accuracy of RF, PCA, and VC methods to determine feature indicators and 33 total indicators for hand shape recognition, the highest accuracy of hand shape recognition was achieved using the RF algorithm for dimensionality reduction. By comparing and analysing the recognition accuracy of four recognition models, it can be seen that the highest recognition accuracy of the BP neural network hand shape recognition model is 97.43%, which is 2.43%, 7.43%, and 4.75% higher than RBF, SVM, and RF hand shape recognition models, respectively.

The purpose of this paper is to improve the effectiveness of hand characteristic index selection and hand shape recognition accuracy, but due to different regions, different physical movements, and other factors are prone to cause hand morphology differences, further explore the main factors affecting hand morphology differences, expanding the applicability of the method.

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Application of Sodium silicate as a halogen-free flame-retardant and evaluate its effectiveness on the flame-retardancy of Polypropylene fabric

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ABSTRACT – REZUMAT

Application of Sodium silicate as a halogen-free flame-retardant and evaluate its effectiveness on the flame-retardancy of Polypropylene fabric

A halogen-free flame-retardant was synthesized using Silica gel and Sodium hydroxide within the scope of the study. The Polypropylene (PP) fabric was treated with the synthesized Sodium Silicate to investigate its thermal behaviour. The limiting oxygen index (LOI) value of the Polypropylene fabrics dramatically increased after finishing with Sodium silicate and the 50.4% noteworthy LOI value was achieved. The Sodium silicate-treated PP fabrics exhibited a 30.1% LOI value even after washing, compared to the neat PP LOI value which was reported to be 16.4%. The surface modification of the Polypropylene fabric following the plasma treatment was evaluated by elemental mapping, surface topography images, and contact angle measurements and the homogeneity of the Sodium silicate coating was evaluated by Scanning electron microscopy.

Keywords: *flame-retardancy, intumescence, modification, polyolefins, poly(propylene) (PP)*

Aplicarea silicatului de sodiu ca material ignifug fără halogen și evaluarea eficienței acestuia în ceea ce priveşte ignifugarea țesăturilor din polipropilenă

Scopul prezentului studiu a fost sintetizarea unui material ignifug fără halogen folosind silicagel și hidroxid de sodiu. Țesătura din polipropilenă (PP) a fost tratată cu silicat de sodiu sintetizat pentru a investiga comportamentul său termic. Valoarea indicelui limită de oxigen (LOI) al țesăturilor din polipropilenă a crescut dramatic după finisarea cu silicat de sodiu și a fost atinsă valoarea LOI demnă de remarcat de 50,4%. Țesăturile PP tratate cu silicat de sodiu au prezentat o valoare LOI de 30,1% chiar și după spălare, comparativ cu valoarea LOI pură a PP care a fost raportată a fi de 16,4%. Modificarea suprafeței țesăturii de polipropilenă în urma tratamentului cu plasmă a fost evaluată prin cartografiere elementară, imagini topografice de suprafață și măsurători ale unghiului de contact, iar omogenitatea acoperirii cu silicat de sodiu a fost evaluată prin microscopie electronică de scanare.

Cuvinte-cheie*: ignifugare, intumescenţă, modificare, poliolefine, poli(propilenă) (PP)*

INTRODUCTION

The term “flame-retardant textiles” refers to textile materials that maintain their shape and physical characteristics at temperatures above 200°C. A significant percentage (such as 79%) of residential fires result in death or serious injury. Upholstery fabrics and furnishings pose the greatest fire danger in residential. According to reports, suffocation or poisoning accounts for 50% of fire-related fatalities in the United Kingdom. Therefore, materials that will be used to prevent fires should be both flame retardant and low in harmful gas emissions. Human skin is extremely heat-sensitive; at 45°C, it starts to hurt, and at 72°C, it starts to burn. A person should be able to flee a fire in 3 to 10 seconds under typical circumstances.

Typically, textile fibres are easily combustible. For instance, cotton that does not have a flame-retardant finish ignites instantly and needs a temperature of 360–420°C to burn. Flame retardancy is sought after in a variety of products, including clothing for workers, household textiles, children's clothing, upholstery fabrics, textiles for public transportation and vehicles, sleeping bags, upholstery, and furniture used in public spaces due to the growing number of state regulations. To offer flame retardancy in textile materials, numerous compounds have been utilized throughout history. These substances include halogen, phosphorus, metal hydroxide, intumescent (swelling), boron, nitrogen, silicon, carbonizing, and smoke-suppressing agents. According to studies, there is a surge in the use of flame-retardant chemicals in the global market for textile materials and the building and construction, electrical and electronic, and transportation industries. Regulations for fire safety and prevention have increased the usage of materials based on flame-retardants, particularly in these industrial branches. The purpose of applying a flame retardant is intended to expedite the suppression of a fire, especially for the protection of people and property. Flame-retardant textiles could be produced by utilizing naturally flame-resistant textile fibre, acquiring flame-resistant fibre, and treating the fabrics with flame-retardant chemicals. Introducing the application of clay and plaster pigments in colouring to prevent burning, Sabattini provided the first important reference work on the flame retardancy of textiles in 1638. Subsequently, Obadjah Wyld developed a flame retardant that he utilized and patented in England in 1735 by combining borax, ferrous sulfate, and alum. By applying ammonium phosphate, ammonium chloride, and borax components to linen and jute fabrics in France in 1821, Gay-Lussac invented the first systematic study of flame retardant finishing. The historical evolution of flame retardant compounds was outlined by Vahabi et al. [1]. Despite having high flame retardancy characteristics, some compounds also have drawbacks. The fact that the chemicals utilized in the market for flame retardancy are not ecologically friendly, their low washing resistance due to the migration of chemicals in the applied structure, and the decline in the mechanical qualities of the textile product are some major drawbacks. Moreover, halogen combustion produces poisonous and toxic fumes. Saeidi et al. [2] summarized the studies conducted to develop halogen-free compounds as polypropylene flame retardants. They identified the chemicals utilized as being phosphorus, nitrogen, mineral, carbon, and bio-based, as well as their combinations. They illustrated the superiority of the synergistic effect compared to the usage of each component alone [3]. The most popular flame-retardant treatments applied in PP matrices, including flame-retardant chemicals, application methods, and flame suppression mechanisms, were outlined by Zhao et al. [3]. They also concentrated on recent advancements and forecasted the prospects for such applications in the future. The effects of natural fibre reinforcement on the flammability and strength of PP composites were investigated by Bazan et al. [4]. Chen et al. [5] examined the impact of a synergistic flame-retardant system that included strontium carbonate ($SrCO_3$) as a synergistic agent and epoxy resin microcapsule-modified ammonium polyphosphate (MAPP) as a flame-retardant. According to their findings, the LOI was 36.1% when strontium carbonate addition was 1.5 wt%. Dohor-6000A, a brand-new halogen-free intumescent flame retardant, was used by Xu et al. [6] in melt spinning to produce halogen-free flame retardant PP fibre. The reported LOI value was 29.1% and the developed fibres had strong melt drop resistance when Dohor-6000A content approached 25%. He et al. [7] created various bio-based phytic acid-basic amino acid salts (PaArg, PaLys, and PaHis) using three different forms of basic amino acids: arginine, lysine, and histidine. When it comes to imposing flame retardancy on PP, PaArg reported a better efficiency than PaLys and PaHis. They underlined that the LOI value of PP at 22% PaArg by weight was 26.0%. Bourbigot [8], summarized the uses of intumescent in the field of flame protection and flame retardancy. As a more cost-effective approach, Kahraman et al. [9] concentrated on the synergistic effect of mica mineral and intumescent flame-retardant chemical in increasing the flame retardancy of PP. To generate 30% by weight of the total mass of the polymeric compounds, they added various ratios of the mineral mica and the intumescent flame-retardant chemical to PP. Dodecyl sulfate intercalated CaMgAl-hydrotalcite (layered double hydroxides [LDHs]) were successfully prepared by Shen et al. [10] using the co-precipitation method. According to their findings, the LOI value of the material rose to 31.5% when the flame retardant contained 2% by weight of organic anion dodecyl sulfate (O-SDS-LDHs) and 23% by weight of intumescent flame retardant chemicals. Phosphate-loaded chicken feather fibres with layered silicate exterior coatings were performed by Jung et al. [11] as a successful intumescent flame retardant material solution for PP. It has been noted that to maintain the same level of flame retardancy for PP, a tiny silicate component (0.4% by weight) results in a 27% wt reduction in phosphate. Song et al. [12] increased the fire retardancy performance of intumescent flame-retardant PP that contains hydroxymethylated lignin by applying coal dust as a synergist. It was claimed that the dripping issue of PP composites was effectively resolved by adding coal powder. It was found that adding coal dust to the PP composite at a 0.5% loading amount significantly improved the flame retardancy with increased LOI values from 28% to 33%. Wu et al. [13] produced a new and environmentally friendly lignin-based surfactant sodium lignosulfonate (SLS) by co-precipitation method with modified layered double hydroxide (LDH) flame retardant (LDH-LS), subsequently, they were incorporated into the PP matrix by melt mixing method to obtain PP and LDH-LS composites (PP/LDH-LS). According to reports, PP/LDH-LS exhibits an LOI of 29.4%, whereas PP/LDH exhibits an LOI of just 25.2% with a 20% additive ratio [14]. Through the application of nano-SiO_2 particles to the surface and the interlamination of graphite lamellas, Wang et al. (2021) successfully designed and synthesized an eco-friendly nanohybrid expandable graphite (nHEG) in situ using a one-pot technique of the first flame retardant PP. To increase the flame retardancy of PP, Peng and Yang [15] produced cerium nitrate-supported silica as a new kind of catalytic synergist. They underlined that the addition of 1% cerium nitrate-supported silica raised the LOI value of PP composites to 33.5%. To increase the fire safety of nonwoven PP fabric, Qi et al. [16] used surface polarity followed by a conventional finishing procedure. The surface of the nonwoven PP fabric was modified in an ultrasonic medium with a surfactant solution containing cetyltrimethylammonium chloride and then impregnated with an aqueous solution of ammonium polyphosphate and pentaerythritol to increase its hydrophilicity. It has been observed that the contact angle of PP fabric treated with 0.2% cetyltrimethylammonium chloride dropped from 130 of the control sample to 71. Additionally, the LOI value increased from 18.1% to 23.5%. Six novel s-triazine-based bishydrazino and bishydrazido-based polymers were synthesized by Aldalbahi et al. [17] by condensation of bishydrazino s-triazine derivatives with terephthaldehyde or nucleophilic substitution of dichloro-s-triazine derivatives with terephthalic acid hydrazide. They underlined that, depending on their LOI values, these polymers can be categorized as self-extinguishing and flame-retardant materials. Tang et al. [18] prepared phosphorylated MXene/polypropylene (PP) composites by coating phosphorylated MXene on PP fabric, followed by spraying polyethyleneimine (PEI) and heat pressing. Yang et al. [19] prepared more efficient and hydrophobic modified ammonium polyphosphate (M-APP) and charring agent (M-CA) according to the sol-gel method and used them in the preparation of water-resistant and flame-retardant polypropylene (PP) composites. They reported that the contact angles of M-APP and M-CA were 135.11° and 137.89°, respectively. They noted that the flame retardancy of PP loaded with 30% by mass with intumescent flame retardant (M-APP/M-CA = 3:1) significantly increased. The LOI value was found to be 36.8%. A star-shaped coal-forming material (BTETP) with phosphorus and nitrogen was produced and investigated by Qin et al. [20]. Yan et al. [21] used the single pot method and applied phytic acid (PA), melamine (MEL), and layered double hydroxides (LDHs-C) to develop and use an interlayer/surface-modified flame retardant (LDHs@PA-MEL). Thus, they developed a new flame-retardant agent for PP. Yuan et al. [22] used a nucleophilic substitution procedure to create a novel linear polymeric charring agent (PEPAPC), which was then applied to PP to enhance its flame retardancy and anti-drip capabilities. To create an intumescent flame retardant system that would stop the burning of polypropylene (PP), Tian et al. [23] created a triazine-based charcoal-forming agent (PTPA) and combined it with ammonium polyphosphate (APP). They stated a LOI of 29.5%. Zhu et al. [24], prepared decabromodiphenyl ethane/diantimony trioxide (DBDPE/Sb_2O_3) and decabromodiphenyl ethane/hexabromocyclododecane/diantimony trioxide (DBDPE/HBCD/Sb_2O_3) to improve the flame retardancy of polypropylene. They prepared a halogen-free flame retardant PP by using flame retardant systems and single-component intumescent flame retardant PNP1D. The manufacturing of detergents, ceramics and pottery, fireproof paper, and the woodworking sector all employ sodium silicate. In addition to these, it is also utilized in concrete hardening, lumber processing, and clothing dyeing. Cleaning products are one of the common uses for sodium silicate. The rust solvent sodium silicate, which is used in cleaning products, works exceptionally well. To the best of our knowledge, sodium silicate has not been solely applied to PP fabric in the literature to investigate its effect on the flame-retardancy of PP fabric. The objective of this study was to synthesize sodium silicate as a halogen-free flame retardant chemical that would be effective in PP fabric and to retard its combustion behaviour.

MATERIALS AND METHODS

Materials

Silica gel and Sodium Hydroxide chemicals were purchased from Bursa Teknik Kimya (Turkey). 100% PP fabric was supplied by the İpekiş factory and the fabric characteristics are given in table 1.

METHODS

Synthesis of Sodium Silicate

The synthesis of Sodium Silicate involved the stoichiometric ratios of Silica gel (SiO_2) and Sodium Hydroxide (NaOH). Silica gel was added to the bath after sodium hydroxide was completely dissolved in water, and the reaction was then carried out for 2.5 hours in a closed system to prevent the water from evaporating. The balanced chemical equation for the reaction between SiO_2 and NaOH is given in the equation.

$$SiO_2 + 2NaOH \longrightarrow Na_2SiO_3 + H_2O \quad (1)$$

Confirmation of Sodium Silicate Synthesis by Chemical Garden method

The synthesis of sodium silicate was confirmed utilizing the chemical garden method. Cartwright et al. [25] investigated chemical garden formation in different sodium silicate solutions from cations and various metal ion salts. By adding metal salts like copper sulfate or cobalt(II) chloride to an aqueous solution of

Table 1

PP FABRIC PROPERTIES

Fabric composition	Mass per unit area (g/m^2)	Number of threads per unit length (number/cm)		Yarn count (Tex)	
		Weft	Warp	Weft	Warp
100% PP	227	12	15	81.4	73.4

Fig. 1. Formation of chemical garden in Sodium Silicate solution

sodium silicate (also known as water glass), a chemical garden forms. In this experiment, simple or branched plant-like shapes develop over a few minutes to many hours. Copper sulfate was employed to confirm the synthesis of Sodium Silicate, and figure 1 illustrates the formation of the chemical garden.

Surface modification of PP fabric

Surface modification utilizing plasma technology provides numerous advantages over conventional methods when it comes to adding functionality to textile materials [26]. Plasma surface modification was employed to facilitate the treatment of the PP fabric with the synthesized structure. The PP fabric surface structure alterations were measured to determine the efficiency of the plasma treatment: Untreated, 1 and 3 min. plasma-treated (Diener plasma Pico model, 100W power, Oxygen gas flow rate 25 sccm (standard cubic centimetres flowing per minute)) PP fabrics were gone through contact angle measurement. Using an Evident Olympus DSX1000 digital microscope, the surface topography of untreated and plasma-treated fabrics was evaluated.

Treatment of PP fabric with Sodium Silicate

The synthesized halogen-free flame-retardant substance was applied to the PP fabrics during the finishing process. The transfer involved the use of impregnation and coating techniques, which are among the conventional application methods. Utilizing the impregnation method, sodium silicate was applied to plasma-treated PP textiles and allowed to cure for 20 minutes in a 100°C oven. Following the Sodium Silicate synthesis, surplus water was removed by boiling the Sodium Silicate solution at various intervals (3, 5, 7, 15, 30, and 60 minutes), and all fabrics were impregnated for 30 minutes. After oven-drying the Sodium Silicate-impregnated fabrics, the burning test was carried out in the laboratory, and no discernible difference was found between the burning behaviour of the samples, except for the 3 minutes treated sample, but as the time increased, the hand of the fabric was adversely affected, especially for 30 and 60 minutes, which led to the occurrence of hardness in the fabric.
Therefore, the ideal solution boiling time was determined to be 5 minutes.

Morphological observations

The surface morphologies were investigated by a Hitachi TM3030Plus Desktop SEM. At three different magnifications of ×30, ×100, and ×600, SEM micrographs of the samples were taken.

RESULTS AND DISCUSSIONS

Contact angle measurement

Since there are no functional groups in the structure of PP, it is difficult to treat it with the synthesized substance to the desired extent, so the adhesion of the Sodium Silicate to the fabric is ensured by surface modification via plasma treatment. Following plasma treatment, contact angle measurements were carried out to observe the changes in the hydrophilicity of the PP fabric. The advancing and receding angles are established at the left (lower) and right (higher) sides of the droplet, respectively, due to the direction of unit rotation. The results are summarized in table 2.

Table 2

CONTACT ANGLE MEASUREMENT RESULTS OF FABRICS

Treatment type	θ (left)	θ (right)
Prior plasma treatment	123.11	140.05
1 min. plasma treatment	85.13	97.06
3 min. plasma treatment	65.17	45.76

The contact angle is measured between 0–180°. Untreated PP fabric exhibits a higher hydrophobicity, according to table 2. The PP fabric acquired hydrophilic properties after being plasma-treated for 1 and 3 minutes. This effect occurred at a higher rate following plasma treatment for 3 minutes.

Surface topography measurement

Surface topography measurements were performed via Nanosurf Flex Atomic Force Microscope at Bursa Technical University Central Research Laboratory to further reveal the impact of the plasma treatment, and the outcomes are illustrated in figure 2. The average roughness (Sa) and root mean square roughness (Sq) values, known as surface roughness parameters, of the AFM images before and after the plasma treatment are summarized and compared in table 3.

Table 3

SURFACE ROUGHNESS PARAMETERS OF AFM IMAGES

Sample No.	Sample description	Sa	Sq
a	Prior plasma treatment	1614.7 nm	1958.1 nm
b	Post plasma treatment	3002.7 nm	3366.2 nm

When the results were compared, the Sa and Sq values of untreated and plasma-treated PP fabrics increased from 1614.7 and 1958.1 nm to 3002.7 and 3366.2 nm, respectively. An almost double increase in surface roughness parameters is observed. These results demonstrate the effectiveness of plasma treatment on the surface roughness values of PP fabric.

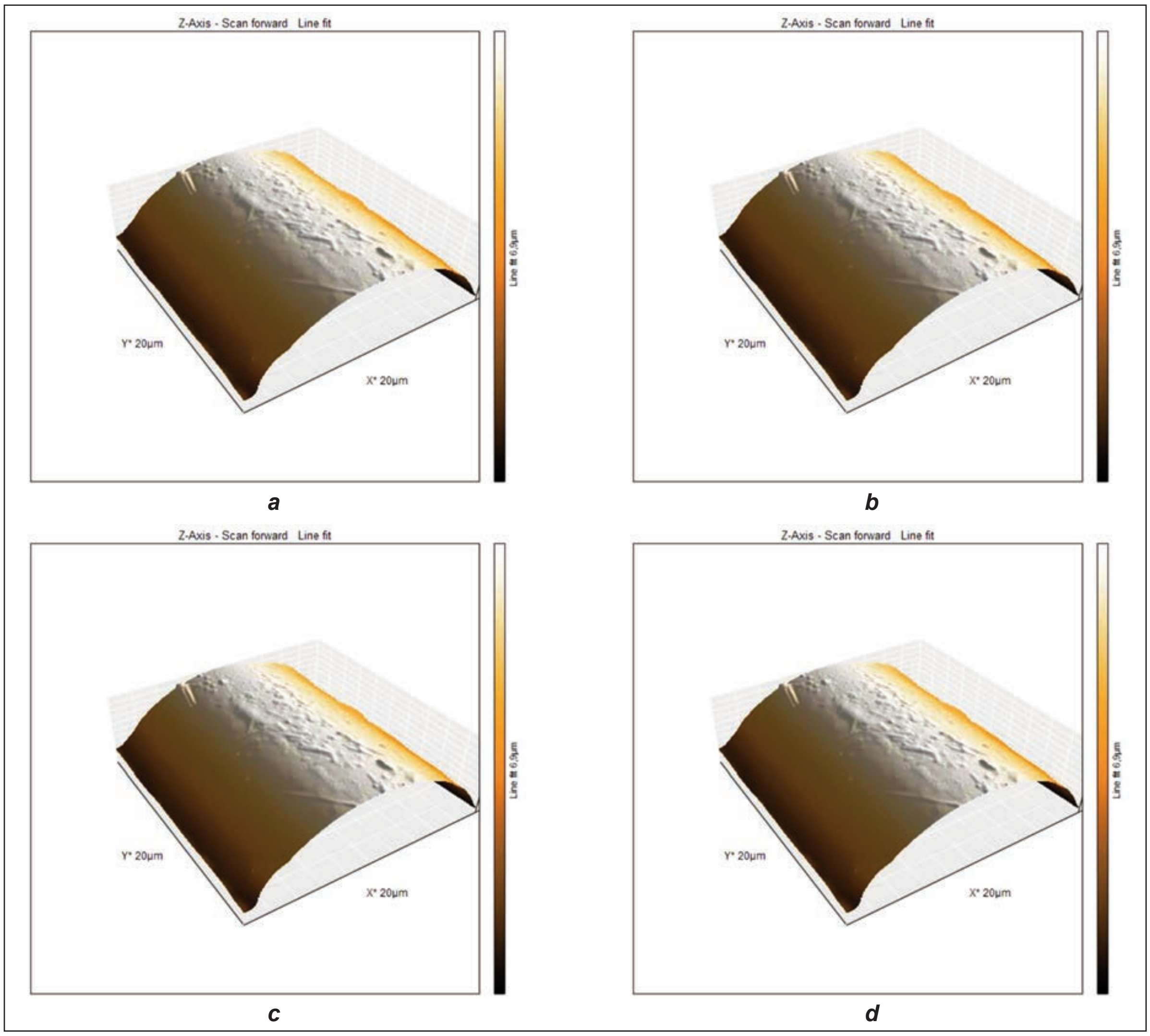


Fig. 2. Surface topographies of fabrics: *a* – prior plasma treatment; *b* – post plasma treatment; *c* – Sodium Silicate treated following plasma application; *d* – Sodium Silicate treated prior plasma application

LOI measurement

According to the TS EN ISO 4589-2 standard, the flame-retardancy of the fabrics was put through the LOI test to ascertain its efficacy. To evaluate the durability of the flame retardancy effect, the fabrics were rinsed with detergent-free water and oven-dried. The LOI test results before and post-detergent-free water rinsing are compared in table 4. It is known that when the LOI value is between 18 and 21%, the material has no flame-retardant effect. According to the results of our study, the fabric does not lose its flame-retardant feature even after a single rinsing with detergent-free water. This demonstrated the efficacy of the applied halogen-free flame-retardant.

Table 4

LOI TEST RESULTS BEFORE AND POST-DETERGENT-FREE WATER RINSING			
Measured value	**Untreated**	**Treated before rinsing**	**Treated post rinsing**
Oxygen Index (%OI)	16.4	50.4	30.1
σ (Expected Std. Deviation)	0.287	0.400	0.315
Sequential Oxygen concentration difference (%d)	0.3	0.3	0.3

Fourier Transform Infrared Spectroscopy (FTIR)

The IR spectrum of Silica gel is illustrated in figure 3. The spectrum exhibited a broad peak at 3439 cm^{-1} caused by the superimposed stretching modes of Si-OH groups and the hydroxyl groups of physically adsorbed water (figure 4). Peaks at 1626 cm^{-1}, and 1480 cm^{-1}, were assigned to the bending vibrations of water and silanol, respectively. Peaks at 1102 cm^{-1} and 969 cm^{-1} reflected the Si–O–Si stretch vibration modes of the silica gel (figure 5).

The existence of characteristic peaks of Silica gel and Sodium Hydroxide in the IR spectra of Sodium Silicate, as illustrated in figure 6, indicates the successful synthesis of Sodium Silicate.

The IR spectrum of untreated PP fabric is illustrated in figure 7. The IR spectrum exhibited peaks at 2950 and 2920 cm^{-1} caused by the asymmetrical stretching of CH_3 and CH_2 groups, respectively. The peak at 2870 cm^{-1} could be attributed to the stretching of the

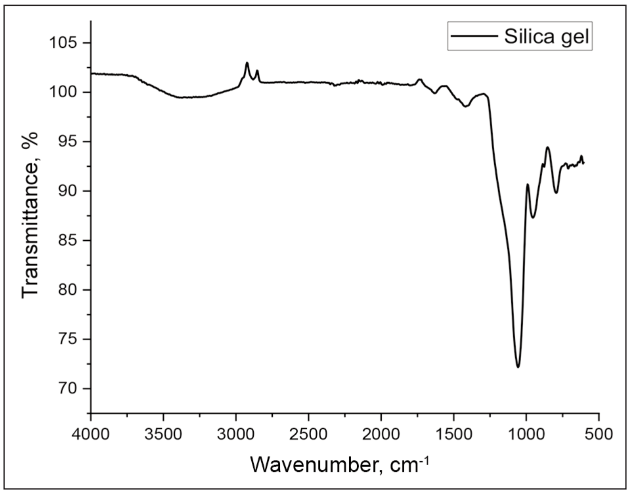


Fig. 3. The IR spectrum of Silica gel

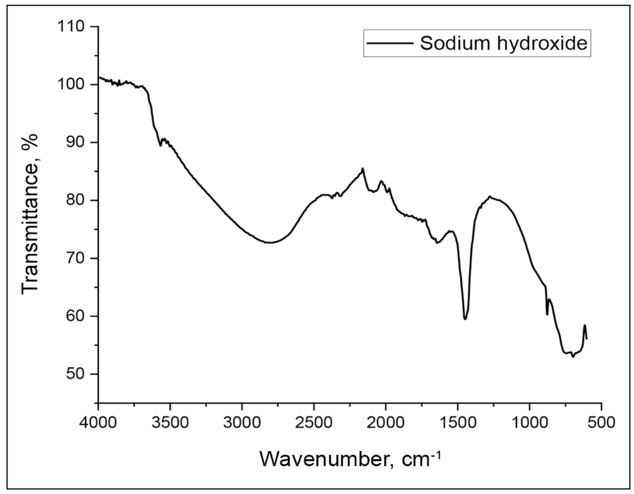


Fig. 4. The IR spectrum of Sodium Hydroxide

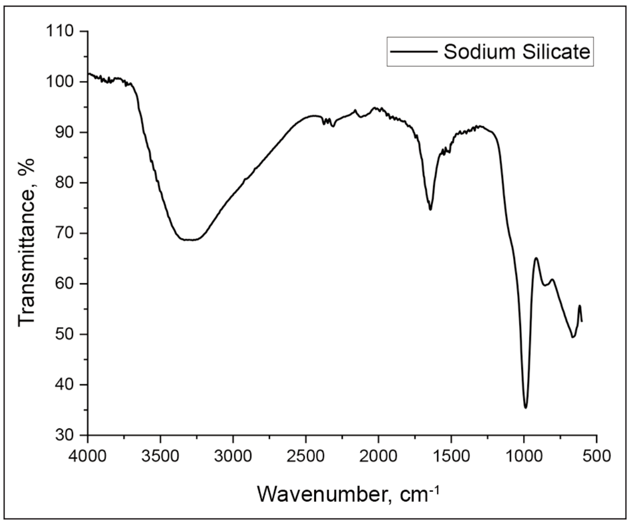


Fig. 5. The IR spectrum of Sodium Silicate

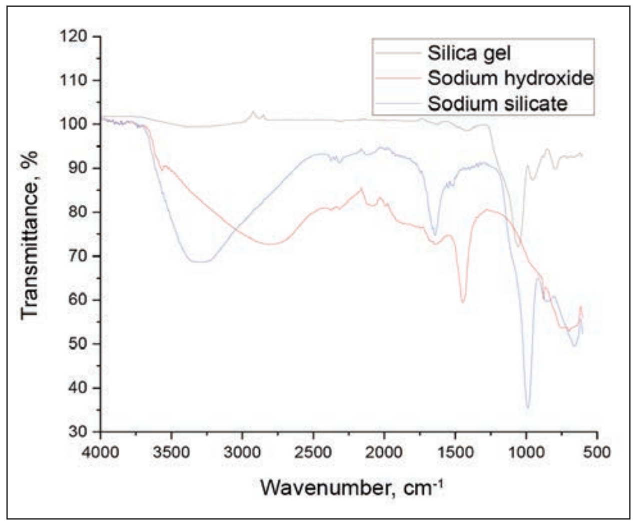


Fig. 6. Joined FTIR spectra of Silica gel, Sodium Hydroxide and Sodium Silicate

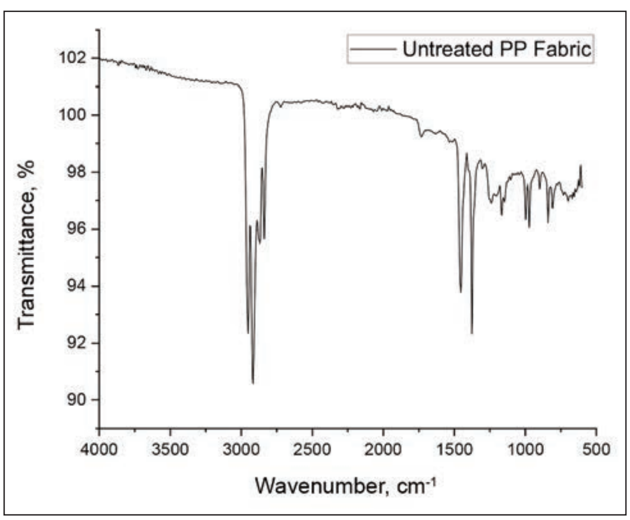


Fig. 7. The IR spectrum of Untreated PP Fabric

CH_3 group. Peaks at 1456 and 1376 cm^{-1}, were assigned to the symmetrical bending of the CH_3 group. Peaks at 1166, 996, and 973 cm^{-1} reflected the CH_3 rocking vibration modes of the PP. The peak at 1166 cm^{-1} could be assigned to the wagging vibration of the C-H group. The peaks at 1166, 973, and 808 cm^{-1} are caused by the stretching vibration of the C-C group. The rocking vibration of the C-H group could be assigned to the peak at 840 cm^{-1}.

Scanning Electron Microscopy (SEM)

The SEM micrographs of the Untreated PP fabric are shown in figure 8, *a–c*. SEM micrographs of plasma-treated PP fabric are given in figure 8, *d–f*. The fibrils migrate toward the surface and roughness increases in the PP fabric following the plasma surface modification, which can be observed in micrographs at magnifications of ×30 (d) and ×100 (e). SEM micrographs of Sodium Silicate-treated PP fabric are given in figure 8, *g–i*. Micrographs demonstrate the uniform dispersion of sodium silicate on the surface of the PP fabric. Figure 8, *j–l* illustrates the SEM micrographs that were taken from the ignition zone following the LOI test. The micrographs reveal that sodium silicate crystallized and created a thermal insulating barrier on the surface of the PP fabric.

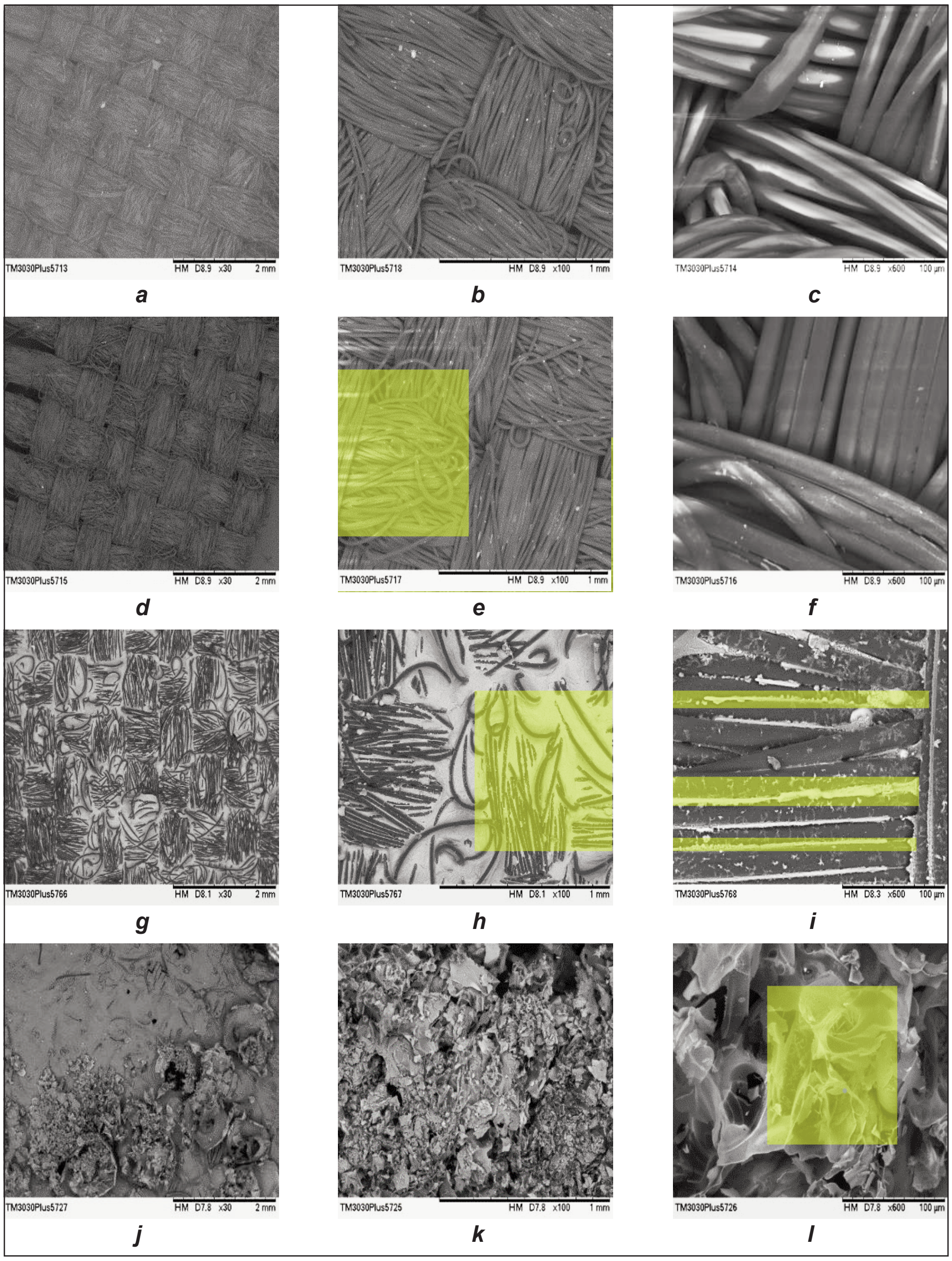


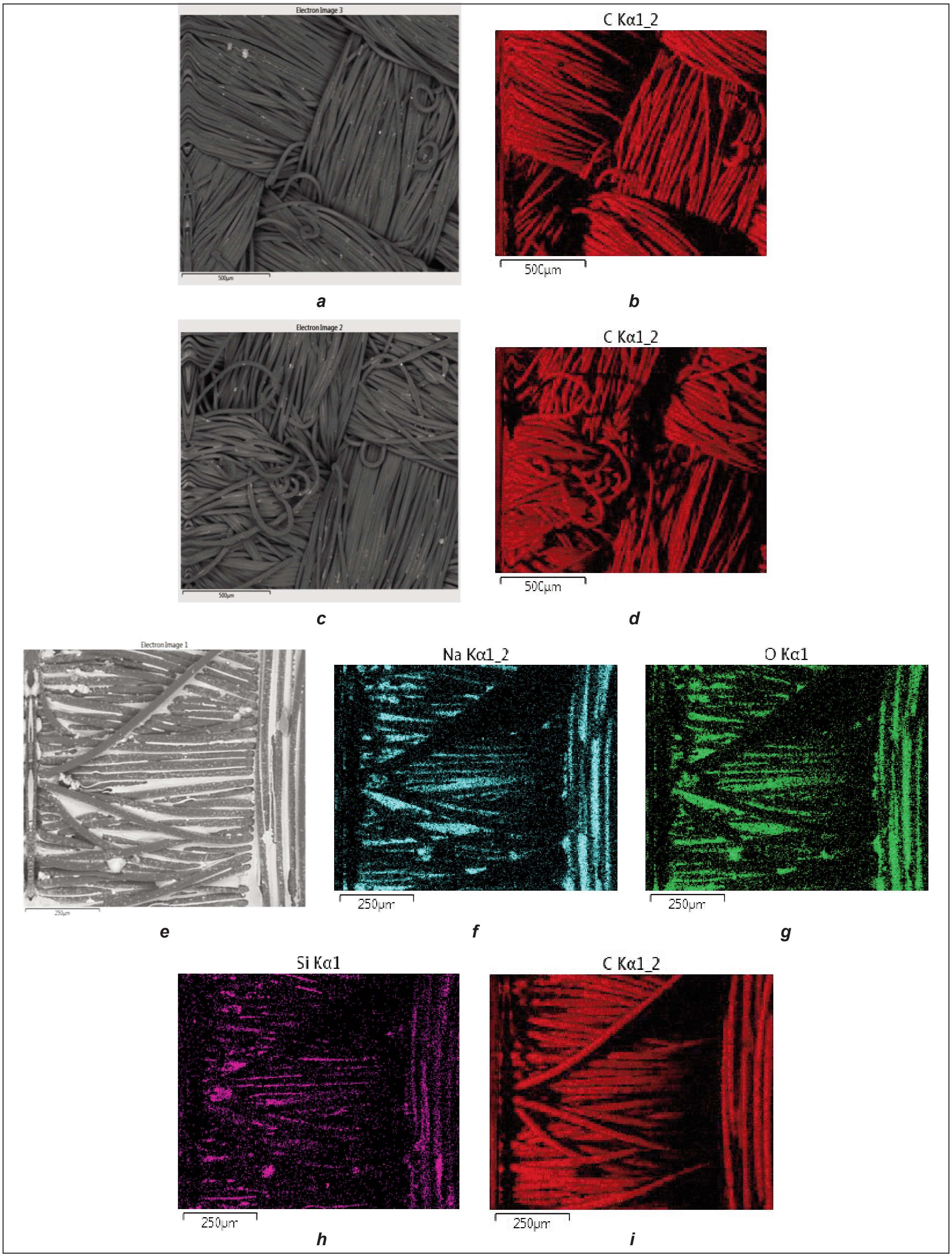
Fig. 8. SEM micrographs: *a* – untreated PP fabric ×30; *b* – untreated PP fabric ×100; *c* – untreated PP fabric ×600; *d* – plasma-treated PP fabric ×30; *e* – plasma-treated PP fabric ×100; *f* – plasma-treated PP fabric ×600; *g* – Sodium Silicate-treated PP fabric ×30; *h* – Sodium Silicate-treated PP fabric ×100; *i* – Sodium Silicate-treated PP fabric ×600; *j* – ignition zone ×30, *k* – ignition zone ×100; *l* – ignition zone ×600

Elemental mapping

The untreated PP fabric, the plasma-treated PP fabric, the Sodium Silicate-treated PP fabric, and the ignition zone post-LOI measurement all underwent elemental mapping. The corresponding images are given in figure 9. Figure 9, *a, c, e, j* shows SEM images, and *b, d, f, g, h, i, k, l, m, n* exhibits the elemental mapping of C, C, Na, O, Si, C, Si, O, Na, C elements, respectively. Since there is no functional group in the structure of PP, only the C atom is observed in its elemental mapping, as illustrated in figure 9, *b*. After the plasma modification, the fibrils open under the influence of plasma power and migrate towards the surface, as seen in figure 9, *d*. Figure 9, *f–k* confirms that the synthesized halogen-free flame retardant chemical is evenly distributed on the PP fabric surface. Considering the elemental mapping of the ignition zone in figure 9, *l–o* the presence of Sodium Silicate forming elements (Na, Si, and O) subsequent LOI measurement exhibits that Sodium Silicate creates a thermal barrier and protects PP fabric from flame.

Energy dispersive X-ray spectroscopy (EDS)

EDS is a technique used for the elemental analysis or chemical characterization of samples. It is a technique based on the interaction of the X-ray excitation source with the sample. Similar to other spectroscopic techniques, the characterisation principle states that distinct peaks in the electromagnetic emission spectrum can be used to identify the atomic structure of each element. EDS analysis results of untreated PP fabric (Sample 1), plasma-treated PP fabric (Sample 2), halogen-free flame-retardant chemical-treated PP fabric (Sample 3) and the ignition zone post-LOI measurement (Sample 4) are given in table 5. It is anticipated that Sample 1 would only show C as a consequence of the EDS analysis because PP does not contain a functional group, although trace amounts of Ti, S, and Al are observed. The structures used in the melt-spinning process are assumed to be the cause of the presence of these elements. The



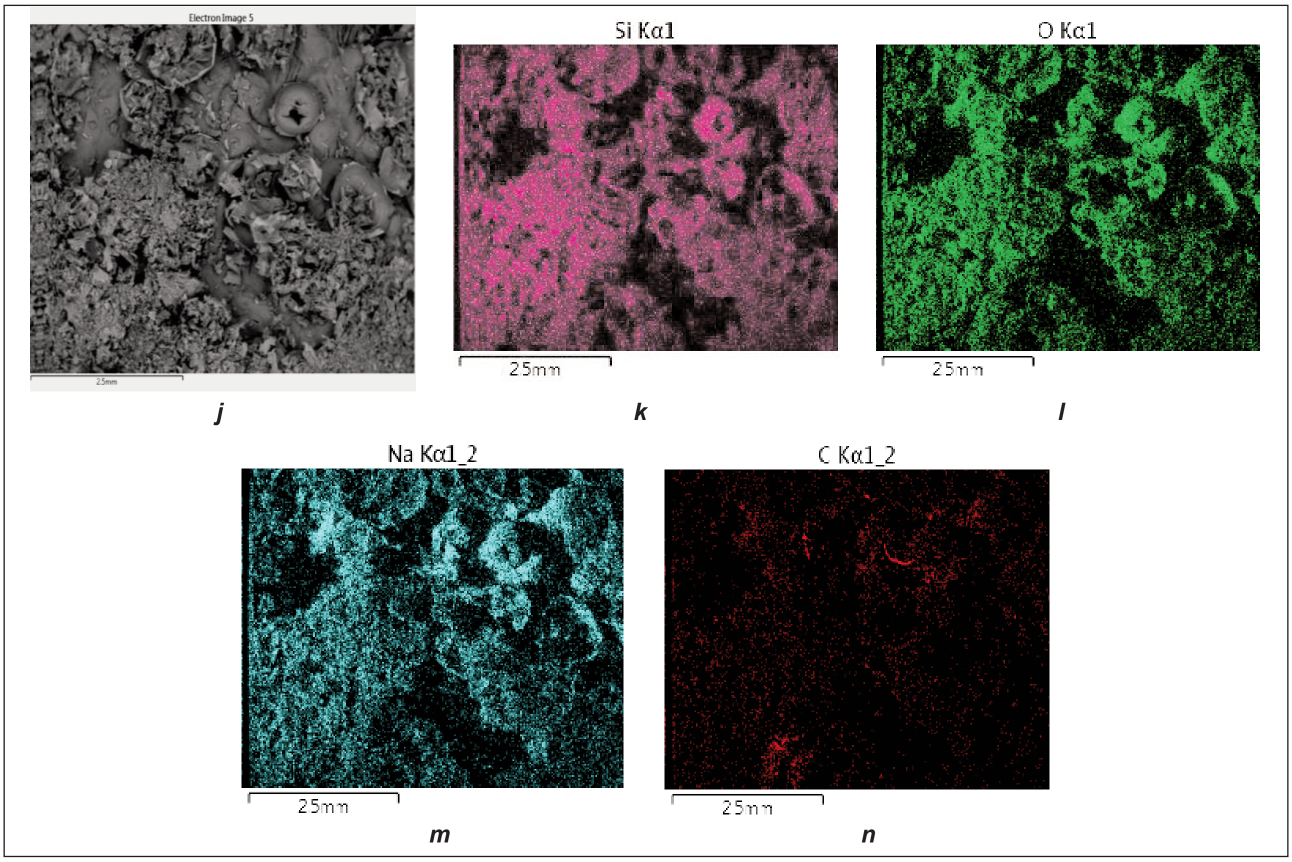


Fig. 9. Elemental mapping: *a, b* – untreated PP fabric; *c, d* – plasma-treated PP fabric; *e–i* – Sodium Silicate-treated PP; *j–n* – ignition zone

Table 5

EDS ANALYSIS RESULTS				
Sample no.	**Element**	**Line type**	**Weight (%)**	**Sigma weight (%)**
1	C	K-series	99.5	0.1
	Ti	K-series	0.3	0.1
	S	K-series	0.1	0.0
	Al	K-series	0.1	0.0
2	C	K-series	95.2	0.1
	O	K-series	4.4	0.1
	Ti	K-series	0.3	0.0
	S	K-series	0.1	0.0
3	O	K-series	47.7	0.1
	Na	K-series	26.6	0.1
	C	K-series	17.2	0.2
	Si	K-series	8.3	0.0
	S	K-series	0.2	0.0
4	O	K-series	50.5	0.3
	Na	K-series	16.7	0.1
	C	K-series	16.8	0.4
	Si	K-series	16.0	0.1

presence of the O element in the EDS analysis of Sample 2 indicates that the plasma surface modification was successful. The presence of Na, Si, and O elements in the EDS results of Sample 3 demonstrates that the PP fabric surface is successfully treated with Sodium Silicate. Due to the low and ignorable weight per cent loss of element C in samples 3 and 4, the EDS results indicate that sodium silicate successfully forms an insulating thermal barrier between the flame and the PP fabric.

CONCLUSIONS

The halogen-free flame retardant, Sodium Silicate, was successfully synthesized using the Silica gel and Sodium hydroxide. According to the results of all elemental analyses, the PP fabric was successfully treated with sodium silicate, raising the LOI value to 50.4%. The Sodium Silicate treatment has been observed to have a self-extinguishing effect on the PP fabric along with avoiding dripping during combustion. It is a significant and noteworthy finding that the LOI value is still 2 times greater than the untreated PP even though the LOI value dropped to 30.1% after the washing process was applied to the PP fabric.

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Unravelling the critical success factors for resilient supply chains – insights from the textile industry of Pakistan

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SHEHERYAR MOHSIN QURESHI

ABSTRACT – REZUMAT

Unravelling the critical success factors for resilient supply chains – insights from the textile industry of Pakistan

This study focuses on developing a theoretical framework for the Resilient Supply Chain for analysing the various types of resilience and the role-play of different managerial levels in developing them effectively. Data is collected from the textile sector of Pakistan with the aid of semi-structured interviews, which were done with employees from different managerial levels. Analytical Hierarchy Process (AHP) was used to define the importance of the multiple Critical Success Factors (CSFs) which were derived from an extensive literature review. The identified CSFs are categorized into Ecological, Engineering, Evolutionary, and Technological resilience. The weight of each criterion and their cause-effect relationships are determined. The findings reveal that the Use of Modern Technology holds the highest weightage at 24.1%, followed by the Development of Effective SCM Strategy (14.6%) and Reliable Supplier Development (9.6%). Additionally, the study establishes connections between the CSFs and different managerial levels (Tactical, Strategic, and Operational), facilitating employee understanding of their roles in mitigating disruptions and fostering resilient supply chains. Overall, this research offers a comprehensive framework for enhancing Textile Supply Chain resilience, providing practical insights for improving operational performance and addressing industry challenges.

Keywords: *supply chain resilience, Critical Success Factors, textile industry, Analytical Hierarchical Process (AHP)*

Evidenţierea factorilor critici de succes pentru lanțurile de aprovizionare reziliente – informații din industria textilă din Pakistan

Acest studiu se concentrează pe dezvoltarea unui cadru teoretic al lanțului de aprovizionare rezilient pentru analiza diferitelor tipuri de reziliență și jocul de rol al diferitelor niveluri manageriale, cu privire la modul de dezvoltare eficientă a acestora. Datele sunt colectate din sectorul textil din Pakistan cu ajutorul interviurilor semi-structurate, care au fost realizate cu angajați de la diferite niveluri manageriale. Procesul de Ierarhie Analitică (AHP) a fost folosit pentru a defini importanța multiplilor Factori Critici de Succes (CSF) care au fost derivați dintr-o analiză extinsă a literaturii. CSF-urile identificate sunt clasificate în Reziliență ecologică, de inginerie, evolutivă și tehnologică. Se determină ponderea fiecărui criteriu și relațiile lor cauză-efect. Concluziile arată că utilizarea tehnologiei moderne deține cea mai mare pondere, cu 24,1%, urmată de dezvoltarea unei strategii eficiente SCM (14,6%) și dezvoltarea de încredere a furnizorilor (9,6%). În plus, studiul stabilește conexiuni între CSF-uri și diferite niveluri manageriale (tactic, strategic și operațional), facilitând înțelegerea angajaților cu privire la rolurile lor în atenuarea perturbărilor și încurajarea lanțurilor de aprovizionare reziliente. În general, acest studiu oferă un cadru cuprinzător pentru îmbunătățirea rezilienței lanțului de aprovizionare textil, oferind perspective practice pentru îmbunătățirea performanței operaționale și abordarea provocărilor din industrie.

Cuvinte-cheie*: reziliența lanțului de aprovizionare, Factori Critici de Succes, industria textilă, Proces Ierarhic Analitic (AHP)*

INTRODUCTION

Supply Chains(SC) of today are facing far more challenges of uncertain situations which hinder their performances at various levels [1]. In recent times, there has been considerable attention given to the efficiency of supply chain management (SCM) and the concept of supply chain resilience (SCR) in both academic research and the manufacturing sector. Wieland [2] stresses the need for more adaptable frameworks in the domain of resilient supply chains is apparent, Singh et al. [3] their study discussed how during the COVID-19, the Public Distribution System (PSD) was disturbed and the supply of essential items was halted thus showing the need for research for a resilient supply chain for disaster management. Remko [4] has pointed out that a strong need for empirical analysis is needed which can aid industries in making their SCs more resilient. The frequency and severity of unexpected unforeseen events have compelled experts and analysts to shift from conventional techniques of risk management to incorporating resilience in SCs to mitigate disruptions caused by human-made disasters [5, 6].

Disruptive risk is the output of natural disasters such as hurricanes, tremors, and flooding, as well as risks caused by human beings examples being any attacks by terrorists and economic job strikes. Disruptive risks usually refer to those which have a minimum likelihood but may cause significant impact in case of occurrence in short or long-term [7]. The purpose of resilience is to bind all the elements in a system but it needs to be ascertained in what ways each element is contributing to the total system. Vegt et al. [8] emphasized the fact that the element that gives the most strength to a system is its resilience which aids the system in unforeseen times.
Looking from the organization's viewpoint, the core function of an organization is Operations Management (OM) whose sole purpose is to keep a balance between demand and the supply of material whereas Corporate Finance makes sure that money outflow is recovered by the supply distribution [9,10]. SCs face various activities that threaten to disrupt the operating activities of SC and jeopardize productive and successful production in today's globally increasingly chaotic environments. The effect of resilience towards the performance of the supply chain is greatly dependent on the ability of the firm to ascertain vulnerabilities that will happen shortly and use its capacity enhancement budget to bridge that gap.

Research gap

The challenges of developing a reliable and consistent SC is becoming all the more difficult in the wake of multiple disruptive events [11]. Organizations are realizing that the need to make their supply chains resilient is not the only way to prosper but they need to develop a network of resilience for the distributors and suppliers, in short, a global resilient SC. This global SC becomes vital in the wake of Low-frequency high-impact (LFHI) risks like extreme weather due to global warming, terrorist attacks, and safety. Hosseini et al. [7] stated that in the present worldwide and progressively powerful and violent situations, SC had stood up to various occasions that took steps to disturb SC operational exercises and endanger proficient and viable execution.
Morales et al. [12] emphasized that the worldwide economy is described by a dynamic intricacy, vulnerability, and unpredictability, which apply serious weights to associations and go up against them, with expanding recurrence, to troublesome and sudden occasions. In such situations, a few associations built up a flexibility profile to expand the ability to envision, adjust, and recuperate balance or even, increase another preferred position after the interruption. Grenoble [15] and Shahzad and Hadj-Hamou [16] argued that changing business scenarios can leave firms inside a store network exposed to higher inward and outer dangers. This introduction is regularly exacerbated by the hindrances which can be either internal or external or both occurring simultaneously on the SCs [17, 18]. A progressively coordinated inventory chain became more significantly interdepend and is a weakness of the company [19]. Interruption to the progression of material or data brought about by such issues can lessen a firm's budgetary and showcase what is more, operational execution [20].

Background to Critical Success Factors

The main purpose of Critical Success Factors (CSFs) for any organization is to identify major three to six areas of work, which will ultimately decide the success of that organization. By exploring, which particular tasks the company needs to do exceedingly well, the success of the company can be determined [21]. Huma et al. [22] emphasise the fact that the success of any organization is heavily dependent on the success of its SC, The activities such as planning, administration and operations must be aligned with the company`s CSFs so favourable results are generated [23].
Business owners lacking the ability to distinguish and oversee CSFs for developing a resilient SC may result in business failure. An empirical framework, which helps organizations transform their SCs resilient in the wake of risks and uncertainty, is needed as apparent in the literature.
Azam et al. [24] gives a list of 11 vital CSFs derived after a thorough review of the literature. Multiple frameworks were studied and the work of established authors was recorded. The CSFs thus identified were an amalgamation of the literature existing from the year 2000 to 2021. The CSFs thus obtained are depicted in figure 1. The percentage of each CSF depicts the weightage of its presence in the selected literature.

Supply Chain Resilience (SCRES)

Corsini et al. [25] emphasized that during the last 10 years, global organizations have been taking lessons from the studies done on the SCs dynamics so they can react effectively against multiple disruptive events. Eltantawy [26] made an important conceptual advance by identifying two types of resilience:

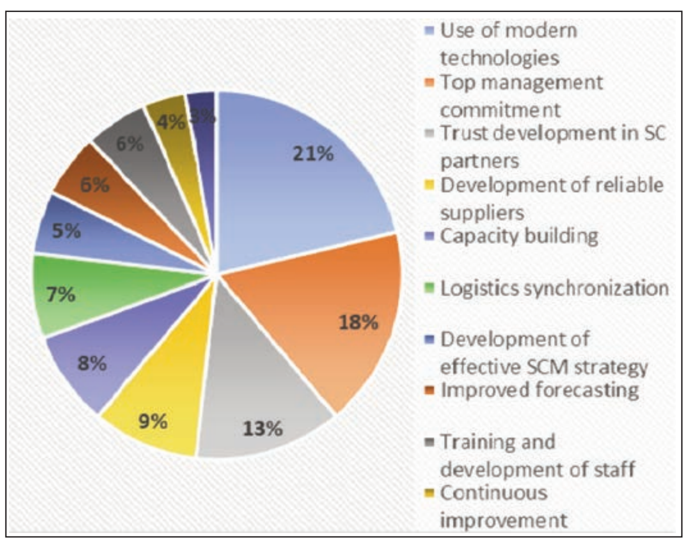

Fig. 1. CSFs identified from the literature

Fig. 2. Framework of Resilient SC [26]

Engineering and Ecological resilience in supply chains. The authors concluded that engineering resilience can be achieved by working towards cultural competency and operational competency whereas Ecological Resilience is an amalgamation of situational awareness and access to the key vulnerabilities of the organization and thus working towards them to mitigate the disruptions. Looking closely engineering resilience focuses on the strengths and weaknesses of the organization whereas the ecological is more about the threats and opportunities present in the VUCA (*volatile, uncertain, complex and ambiguous*) world. The framework given by the authors is depicted in figure 2.

Adobor [27] extended this framework by adding a third form of resilience, evolutionary or socio-ecological resilience. The study discussed how engineering resilience is an efficiency-based approach whereas ecological resilience focuses on the adapting capabilities of the SC. Although both types of resilience are important focusing on these two only will not make the supply chain resilient. Hence another type of resilience is added namely Evolutionary Resilience where the focus is building collaborative capability by developing inter-firm trust, systems thinking visionary leadership etc. The authors conclude that SC managers must concentrate on all three forms of resilience: engineering, ecological, and evolutionary, as the SCs of organizations tend to become more dynamic and evolutionary with each passing day. It is critical to acknowledge that effectiveness; and long-term supply chain performance may require both transformation and adaptability. Because of this realization, businesses must build a variety of skills to manage supply chain risk and lower sensitivity to disruptions (figure 3).

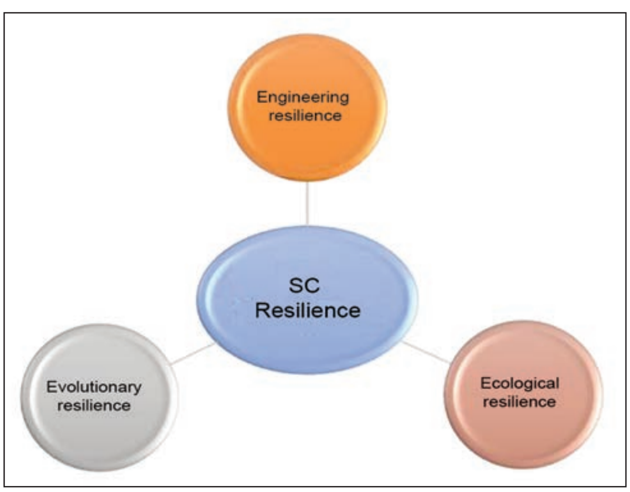

Fig. 3. SC Resilience Framework [27]

METHODOLOGY

Delphi technique

Delphi Technique`s key characteristics, anonymity, use of experts and controlled feedback, are one of the many reasons this technique is in vogue. The method's usefulness in structuring group communication for the discussion of specific issues and as an aid to policymaking are some of its biggest advantages [28]. In Delphi studies, it is done with the utilization of a progressive survey. The respondents have requested data and their viewpoints. It is a technique for putting together individual responses on issues with no or little predefined proof where assessment is critical.

For initial sampling total number of textiles in the selected region is taken into account from state-provided data. Adopting methodological guidelines on participant selection of experts was adopted and the experts were emailed regarding the scope of the study and asked to sign a consent form [29]. Top specialists verified the CSFs identified from the literature and added on any other CSF, which they thought, were important. Data from online meetings and interviews are recorded. Furthermore, structured interviews with key partners to identify all potential CSFs within the local SCs were also done was then utilized in the prioritization of CSFs utilizing MCDM Strategy (figure 4).

The CSFs thus identified are coded as:

- CSF 1 – Top management commitment;
- CSF 2 – Development of an effective SCM strategy;
- CSF 3 – Logistics synchronisation;
- CSF 4 – Use of modern technologies (robust information and communication technology);
- CSF 5 – Information sharing with SC members, collaborative partnership;

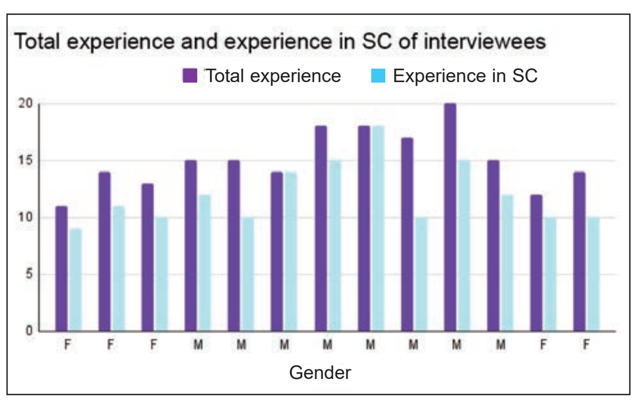

Fig. 4. Demographics of respondents

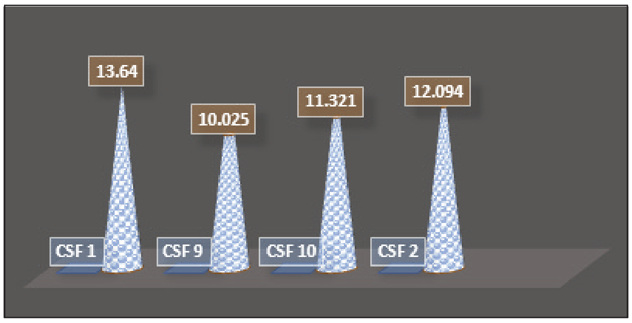

Fig. 5. CSF ranking by experts

- CSF 6 – Improved forecasting;
- CSF 7 – Development of trust in SC partners, collaborative partnership, strategic partnership;
- CSF 8 – Development of reliable suppliers (coordination and collaboration with other organisations)
- CSF 9 – Continuous improvement in the preparedness and response practices (implementing the lesson learned from previous events);
- CSF 10 – Capacity building (mock drill, training, house preparedness, first aid preparedness, etc.);
- CSF 11 – Staff training and development.

The responses received by the experts are summarized in figure 5.

Background of Analytical Hierarchy Process (AHP)

Saaty [30] first introduced the Analytic Hierarchy Process in 1977. For solving problems about elements in a hierarchy, AHP comes in as a useful methodical tool. Hierarchically structured decision-making problems are supported by AHP.
Several MCDM methods applied to logistics research over the past years are presented in table 1.
Table 1 shows that most SCRM research uses MCDM techniques and the most common among them is AHP and Fuzzy AHP. In this research, the AHP technique is used the study explored the 11 CSFs and the relative importance of each CSF. Hence AHP technique is used where each CSF is analysed from the viewpoints given by industrial experts and this weightage for each CSF is calculated.
A review of MCDM techniques is performed and multiple techniques are studied to identify which technique will fulfil the research objectives of the study. AHP is a widely used technique because of its ability to solve complex problems. AHP analysis will give relative weightages to each CSF which would help the stakeholders in decision-making. For this study, the textile sector is chosen. Top decision makers and strategy makers are invited for a virtual interview via Google Meet. The research instrument was developed and its content test and validity tests were performed beforehand. The interviews are lined up. This research tool is drafted in such a way that it runs on two scales of 1–9 and 9–1 and interviewees can choose according to their preference of the CSF.

Table 1

MCDM TECHNIQUES USED BY MULTIPLE AUTHORS IN SCM LITERATURE

Authors	AHP	Fuzzy AHP	Fuzzy TOPSIS
Zaidi and Hasan [31]	X		
Ayyildiz and Taskin Gumus [32]		X	
Gajović et al. [33]	X	X	
Tuammee [34]	X		
Gajović et al. [35]	X	X	
Samvedi et al. [36]		X	X
Gajović et al. [35]	X	X	
Samvedi et al. [36]		X	X

DISCUSSION & ANALYSIS

The CSFs of the resilient supply chain are listed and a hierarchy diagram is developed. The purpose of the study is placed on the top level. The second level combines the factors into commonly understood logical groups. The third level then categorizes the second-level codes into large, remarkably differentiated perspectives as elaborated in figure 6. This is an addition to the body of knowledge in the SCRES which will be counted as one of the first after COVID-19. This framework takes into account the havoc global SCs had to go through during this century`s biggest disruption. The interviewees discussed in detail the problems they faced due to the unavailability of a completely resilient supply chain and showed interest great interest in this study as they termed it the need of the hour.
Step 1: The CSFs verified by the industry experts fit in the textile sector. The sub-criteria are well-defined.
Step 2: Main and sub-criteria are identified, and a hierarchy to show the relationship between the main and sub-criteria is developed for simulation analysis as shown in table 2.
Step 3: To get the ranking and importance. weights of main criteria and their associated sub-criteria, con-

Fig. 6. AHP Hierarchy Diagram

sidered case company experts performed pairwise comparison based on Saaty [30] scale.

Following this, the calculation of the weights of every comparison matrix is then carried out, using the value of the Eigenvector equivalent to the value of the Largest Eigen of the matrix that is evaluated:

$$Aw = \lambda \max w \qquad (1)$$

where "A" signifies a consistent pairwise comparison matrix along with "w" which signifies the priority vector. Further, the calculation is carried out through the addition of the specific weights for weights of each selection in the hierarchy's bottom.

A validity check is conducted after the calculation to make sure the pairwise comparison matrix decisions are made accurately and completely. A pairwise comparison matrix's consistency ratio (CR) is determined by the equation provided:

$$CR = \frac{\lambda \max w - n/RI}{n - 1} \qquad (2)$$

where *RI* is taken from the random inconsistency index. The pairwise comparison matrix's order is shown here by the letter "n". The pairwise comparison matrix falls into a suitable consistency range if *CR* turns out to be less than 0.1; alternatively, the judgements need to be updated. To attain the goal of a perfect order index, AHP is utilized to specify as well as assess the risk elements inside the supply chain. AHP separates and categorizes complicated issues into hierarchical structures based on priorities, characteristics, and options. Using an integer between 1 and 9 or their reciprocals, the decision-maker determines their priority in the paired co-relational matrix. The numbers 3, represent moderate, 5 represent strong, 7 represent very strong and 9 represent extreme judgements, while the numbers 2, 4, 6, and 8 represent an intermediate option between two odd values of above above-stated representations. If a priority needs to be contrasted to itself, it is labelled as "1." The table below provides a basic explanation of the marking or selecting process:

Step 4: Once the pair-wise comparison from experts is done in step 3, Experts Choice® software is used to get the weights of the main criteria and their associated sub-criteria.

It can also be seen in figure 7 that the inconsistency is 0.02 which is < 0.1. Therefore, the judgement is consistent.

Fig. 7. Priority calculation of major nodes

RESULTS

Figure 8 shows the details of the importance of weights and ranking of sub-criteria. The most effective CSF is Logistics Synchronization which has a score of 18.9% followed by collaborative partnership

Table 2

MAIN AND SUB-CRITERIA			
Criteria	**References**	**Sub-Criteria**	**References**
Evolutionary Resilience	[27]	Top management commitment	[37–39,46–52]
		Development of reliable suppliers (Coordination and collaboration with other organizations	[39,53-60]
		Trust development in SC partners, collaborative partnerships, strategic partnership	[38,41,45–47,49,51,58,61–63]
Ecological Resilience	[26, 27]	Training and development of staff	[38,41,45–47,50,51,64]
		Capacity building (mock drill, training, house preparedness, first aid preparedness, etc.)	[45,58,59,65,66]
Engineering Resilience	[26, 27]	Logistics synchronization	[41,45,47,52,65-67]
		Continuous improvement in the preparedness and response practices (implementing the lessons learnt from previous calamities)	[65,67–69]
		Development of an effective SCM strategy	[39,45,59,60,66,67]
Technological Resilience	Proposed	Use of modern technologies (Robust information and communication technology)	[38–41,43,45–49,51,57,58,61,63,65,67–70]
		Information sharing with SC members, collaborative partnership	[38,40,57]
		Improved forecasting	[45,59–61,65,67]

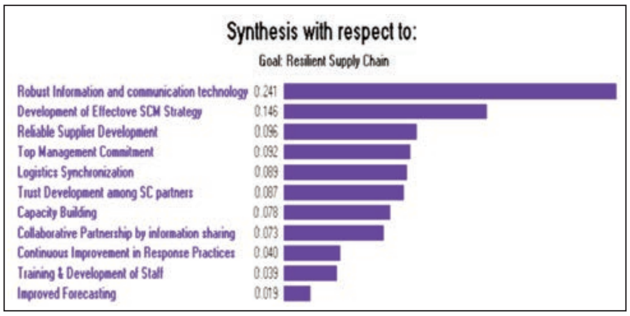

Fig. 8. Priority calculation of each Sub Node by using Expert Choice

by information sharing scoring 17.4% and Top Management Commitment scoring 15.4%. The first two CSF fall under the Technological Resilience domain while the third highest-scoring CSF is from the evolutionary resilience domain.

The below framework depicted in figure 9 is the novel outcome of this study. The top management which is the Tactical level of management will be focusing on four major areas. Their first CSF is a commitment towards the success of the organization. The second area of focus for organizations is their planning for the continuous improvement of the response system. The third area of focus is capacity building which relates to their second focus. Identifying capacity gaps and continuously working on them thus building value of the organization for themselves and all stakeholders involved. The fourth major CSF under their domain is the training and development of staff. Cardoso et al. [71] states that the most important asset a company owns is its people and their training should be taken seriously.

The strategic level focus is on four major CSFs that is development of effective SCM Strategy, logistics synchronization development of reliable suppliers and building trust amongst the SC partners. These four CSFs reinforce the trust among SC partners and help to build co-dependent supply chain teams.

The operational level focuses on three major CSFs and all three are related to the technology. With the advent of the Industrial Internet of Things (IIoT), there have been revolutionary changes in the way business is done. Khan et al. [72] focuses on Blockchain technology and how it revolutionizing sustainable production.

CONCLUSION

The conclusion of this study has several important implications for academia, industries, and policymakers. The adaptable theoretical framework presented in figure 9 offers a valuable reference for researchers exploring SC Resilience across various sectors.

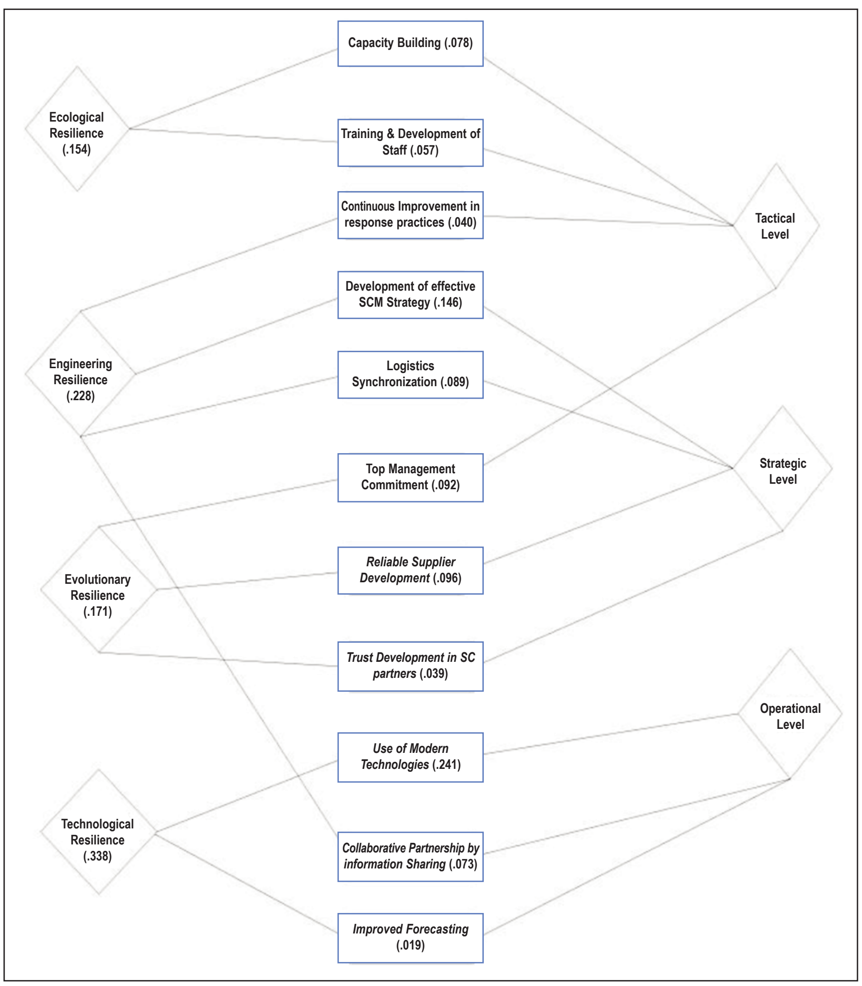

Fig. 9. The theoretical framework of a Resilient Supply Chain

By tailoring Critical Success Factors (CSFs) to specific industry contexts, researchers can gain deeper insights into resilience dynamics in diverse supply chain settings. For industries, the identified CSFs and resilience domains provide practical insights to strengthen their supply chains. Prioritizing investments in areas like Technological and Engineering resilience, such as robust information systems and structural adaptations, can enhance businesses' ability to withstand disruptions and uncertainties.

Implementing effective Supply Chain Management (SCM) Strategies and fostering reliable supplier development are also essential to building resilient supply chains. From a policy perspective, this study underscores the importance of investing in technological advancements and sustainable practices to improve supply chain resilience at national or regional levels. Policymakers can use the findings to design targeted interventions and incentive programs that promote the adoption of modern technologies and sustainable practices within industries, fostering resilience and contributing to economic stability.

FUTURE RESEARCH

The study's conclusion opens up exciting avenues for future research in the field of supply chain resilience. Researchers could delve into the dynamic aspects of resilience, exploring how disruptive events like pandemics or natural disasters impact the identified CSFs and their interrelationships. Additionally, investigating the role of organizational culture, collaboration among stakeholders, and proactive risk management strategies could provide deeper insights into the factors influencing supply chain resilience. Moreover, the framework's adaptability invites further exploration of its implementation and effectiveness in different industrial sectors. Comparative studies across diverse industries could uncover sector-specific challenges and opportunities for resilience enhancement. Furthermore, longitudinal research tracking the evolution of supply chain resilience over time could shed light on how organizations adapt and respond to changing circumstances. This will ultimately benefit industries and policymakers in building robust and sustainable supply chains.

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Does social compliance affect the remaining safety culture in supply chains? Framework in the textile industry

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ABSTRACT – REZUMAT

Does social compliance affect the remaining safety culture in supply chains? Framework in the textile industry

Social Compliance audits aim to ensure a safe and healthy working environment, focusing on child labour, occupational health, safety, and discrimination. Safety culture, encompassing attitudes and behaviours promoting workplace safety from top management to employees, is of paramount importance. This study examines the impact of social compliance audits on safety culture in three textile factories located in different provinces of Türkiye, selected based on audit effectiveness. Questionnaires were administered to 280 participants, and path analysis using SPSS v28 and SPSS Amos v26 programs was conducted. The analysis reveals that social compliance significantly influences safety culture through factors such as safety climate, performance, risk awareness, and fatalism. Audited factories demonstrate a strong alignment with safety culture compared to non-audited ones, with safety performance being the most influential aspect. Positive relationships between safety climate and performance are observed across all three factories.

In conclusion, this study highlights the responsibility of factory management for employee health, safety, social rights, and quality of life. It emphasizes the positive impact of proactively fulfilling compliance measures on both employees and the company. The authors suggest that making social compliance audits mandatory across various sectors, not just textiles, could enhance product quality and employee satisfaction. Further research is needed to explore the significance of these audits on management and employee performance.

Key-words: *safety culture, social compliance, safety management, path analysis, textile*

Conformitatea socială are efect asupra culturii de siguranță în lanțurile de aprovizionare? Studiu de caz în industria textilă

Auditurile de conformitate socială urmăresc să asigure un mediu de lucru sigur și sănătos, concentrându-se pe subiecte precum munca minorilor, sănătatea în muncă, siguranța și discriminarea. Cultura siguranţei, care cuprinde atitudini și comportamente care promovează siguranța la locul de muncă, de la conducerea de top până la angajați, este de o importanță capitală. Acest studiu examinează impactul auditurilor de conformitate socială asupra culturii siguranței în trei fabrici textile situate în diferite provincii ale Turciei, selectate pe baza eficacității auditului. Chestionarele au fost administrate la 280 de participanți și s-a efectuat analiza traseului utilizând programele SPSS v28 și SPSS Amos v26. Conformitatea socială influențează semnificativ cultura siguranței prin factori precum climatul de siguranță, performanța, conștientizarea riscurilor și fatalitatea. Fabricile auditate demonstrează o aliniere puternică la cultura siguranței în comparație cu cele neauditate, performanța în materie de siguranță fiind cel mai influent aspect. Relații pozitive între climatul de siguranță și performanță sunt observate în toate cele trei fabrici.

În concluzie, acest studiu evidențiază responsabilitatea conducerii fabricii pentru sănătatea angajaților, siguranța, drepturile sociale și calitatea vieții. Subliniază impactul pozitiv al îndeplinirii în mod proactiv a măsurilor de conformitate atât asupra angajaților, cât și asupra companiei. Autorii sugerează că obligativitatea auditurilor de conformitate socială în diferite sectoare, nu doar în textile, ar putea îmbunătăți calitatea produselor și satisfacția angajaților. Sunt necesare cercetări suplimentare pentru a explora importanța acestor audituri asupra managementului și performanței angajaților.

Cuvinte-cheie: *cultura siguranţei, conformitate socială, managementul siguranței, analiza traseului, textil*

INTRODUCTION

Social compliance audit is a continuous progress in the workplace. In 2013, after the Rana Plaza disaster in Bangladesh, the importance of social compliance audits was realized, albeit in a bad way [1]. For social compliance audits, brands aim to prioritize employee health and safety in their supply chains both with their audit standards (INDITEX etc.) and with audits such as BSCI (Business Social Compliance Initiative), SEDEX (Supplier Ethical Data Exchange), SA (Social Accountability) 8000. Social compliance is a very comprehensive audit that investigates several topics such as child labour, forced labour, health and safety, freedom of association, discrimination, national legal working hours, management systems and compensation. Each of the topics is aimed at making workplace conditions better than before. Safety culture is a management system in which a safe working environment is created by proactively preventing hazards or risks that may occur in the workplace by involving everyone from the highest level to the lowest level in a workplace [2]. It can be understood that there is a good safety culture in the workplace from how much the management is involved in safety measures, how good the communication between the employees or the management with the employees is, and the importance given to the ideas and opinions of the employees regarding the risks and hazards that may occur in the working environment [3].

This study aims to reveal the state of safety culture in textile supply chains where social compliance audits aiming to ensure that employees receive their social rights are carried out and whether social compliance audits have an impact on the formation of safety culture or not. The study was carried out by face-to-face survey method at different times in 3 different textile production factories located in 3 different provinces of Tekirdağ, Kastamonu and Kahramanmaraş within the borders of Turkey. While preparing the social compliance questionnaire, the amfori BSCI manual audit booklet [4] available on the internet database as open access was used.

GENERAL INFORMATION

Social compliance

Social compliance refers to an organization's adherence to certain social standards, including those related to child and forced labour, human trafficking, workers' health and safety, salary and overtime and freedom of speech and association. Social compliance has become an important issue for multinational companies that source products from suppliers in developing nations [5]. Social compliance audits can have two objectives which are management stuff and accounting stuff. Management staff is for assessing the risks, managing stakeholders, seeking out opportunities and efficiencies and maintaining legitimacy. Contrary to management, accounting stuff is for maintaining democracy, and sustainability purposes [6].

A social compliance audit is one type of social accounting which means an extension of disclosure into providing information about employees, products, community services and the prevention and reduction of pollution [7]. There are rules of social accounting to be conformance such as deals with measurement, recording and communication. These rules are also applied to social compliance. But, in social compliance, these rules affect not only the organization's policies or practices but also the supply and distribution chains [5]. Besides the widely comprehensive effectiveness, social compliance is a continuous progress.

During the 1990s, several advocacy campaigns and media investigations uncovered widespread labour violations within global supply chains of the light industry. These violations encompassed a range of issues such as the use of child labour, sexual harassment, mandated overtime work, minimum and overtime wage violations, and union-busting tactics [8]. Initially, buyers in the apparel global value chains denied responsibility for the actions of their suppliers [9].

Buyers based in developed nations have faced criticism for relocating their operations to developing or non-developed countries, in pursuit of exploiting low-cost labour and relaxed social and environmental regulations [1, 10]. In the past, several incidents of supplier non-compliance have led to buyers being criticized for failing to manage their suppliers' social obligations [11]. These can be examples of the incidents in the Rana Plaza building complex in Bangladesh collapsed on 4th April 2013 [12] and a fire in an apparel factory in Pakistan (i.e., the Baldia factory) that killed 260 people in 2012 [1].

There are several audits for social compliance such as Business Social Compliance Initiative (BSCI), Supplier Ethical Data Exchange (SEDEX) Social Accountability (SA) 8000, Initiative for Compliance and Sustainability (ICS), Worldwide Responsible Accredited Production (WRAP), Customs Trade Partnership Against Terrorism (C-TPAT), Responsible Jewellery Council (RJC) and International Labor Organizations (ILO) Ethical Trading Initiative. The list of what each of audits focus on is shown in table 1.

Social compliance audits have become more important for both suppliers and buyers after the accidents in the textile industry. However, the implementation of social compliance audits plays an important role not only in the textile sector, but also in the pharmaceutical sector, marine systems, and even in the United States, where the C-TPAT audit originated, in providing security against terrorist incidents at customs.

Looking at the audit topics of social compliance audits in general (table 1), it is seen that they are mainly based on unionization, fair wages, ethical business behaviour, occupational health and safety, child labour, discrimination, working hours and environment.

Globally, around 160 million children, including 63 million girls and 97 million boys, are currently in child labour, which is nearly 10% of the total child population worldwide. Shockingly, almost 50% of these children, equivalent to 79 million in absolute terms, are involved in hazardous work that directly puts their health, safety, and moral development at risk [13].

A study conducted in the United States shows that the occurrence of discrimination in the workplace was highest among black women with a rate of 25%, while white men reported the lowest rate of 11%. According to the reports, blacks reported a 60% higher rate of discrimination as compared to whites, and women reported a 53% higher prevalence of discrimination compared to men [14].

International Labour Organization estimates that there are around 340 million occupational accidents and 160 million victims of work-related illnesses worldwide annually [15].

Safety culture

Culture is defined in the Cambridge Dictionary [16] as "the way of life, especially the general customs and beliefs, of a particular group of people at a particular time". It is also defined in the Dictionary [17] as "the behaviours and beliefs characteristic of a particular

Table 1

LIST OF THE SOCIAL COMPLIANCE AUDITS					
No.	**Amfori BSCI**	**SA 8000**	**ICS**	**SEDEX**	**WRAP**
1	Social Management System & Cascade Effect	Child Labour	Management System, Transparency and Traceability	Child and Young Labour Law	Compliance with Laws and Workplace Regulations
2	Workers Involvement and Protection	Forced Labour	Minimum age, Child Labour and Young Workers	Labour Law	Prohibition of Forced Labour
3	The Right of Freedom of Association and Collective Bargaining	Health and Safety	Forced Labour	Health and Safety	Prohibition of Child Labour
4	No Discrimination, Violence or Harassment	Freedom of Association	Discrimination	Freedom of Association	Prohibition of Harassment or Abuse
5	Fair Remuneration	Discrimination	Disciplinary Practices, Harassment or Ill Treatments	Discrimination	Compensation and Benefits
6	Decent Working Hours	Disciplinary Practices	Freedom of Association and Grievance Mechanism	Disciplinary Practices	Hours of Work
7	Occupational Health and Safety	Working Hours	Working Hours	Working Hours	Freedom of Association and Collective Bargaining
8	No Child Labour	Remuneration	Wages and Benefits	Wages & Compensation	Health and Safety
9	Special Protection for Young Workers	Management System	Health and Safety	Environment	Prohibition of discrimination
10	No Precarious Employment				Environment
11	No Bonded, Forced Labour or Human Trafficking				Customs Compliance
12	Protection of the Environment				Security
13	Ethical Business Behaviour				

group of people, as a social, ethnic, professional, or age group". The root of culture comes from the word "cultivate" [17]. The word "cultivate" has many definitions such as "to prepare and work on (land) to raise crops; till", "to promote or improve the growth of (a plant, crop, etc.) by labour and attention". And it is also defined as "to develop or improve by education or training; train; refine" [17]. It is stated that It is crucial to establish a work environment that encourages top-level performance and enables swift and efficient reactions to unforeseen situations [18].
It is not to be wrong if it is said that safety culture is a kind of product that can be "cultivated" in an organization like planting seeds to earth.
However, there is no exact definition of safety culture as stated by some researchers [2, 19, 20], according to the International Nuclear Safety Advisory Group (INSAG), a committee established by the International Atomic Energy Agency (IAEA) in the aftermath of the 1986 Chernobyl accident, the development and maintenance of a "safety culture" was identified as crucial in addition to formal procedures that have been properly reviewed and approved [21, 22]. The term safety culture was in a report of the Three Mile Island accident in 1979 by the U.S. Nuclear Regulatory Commission (NRC) however it is not labelled as "safety culture". It is said that "the only theme that runs from our conclusions is that the main shortcomings in commercial reactor safety today are management issues, not hardware problems" [23].
Safety culture is assessed by Beus et al. [24] likely to be harder to change some things in the organization's contrary to safety climate. According to Guldenmund's proposed model [2], safety culture can be conceptualized as having three layers. The core layer pertains to fundamental assumptions about safety, while the middle layer involves espoused values and attitudes. Finally, the outermost layer comprises behavioural manifestations and physical symbols, such as safety posters and signage. The concept of safety culture is frequently associated with the notion of "deep" meaning [25]. Additionally, safety culture is influenced by individual attitudes, behaviours, habits, and the organizational culture and style" [26].
Some of the definitions of safety culture are given in table 2.
Even though safety culture does not have a certain definition, it can be summarized as the fact that safety culture is emphasized by the beliefs, behaviours, attitudes, and habits of an organization and it can remain involving the organization individually and collectively [26, 33].
Safety climate is considered as a subcomponent of safety culture's structure [34, 35]. Safety climate is defined by Zohar [36] for the first time as "a unified set of cognitions [held by workers] regarding the

Table 2

DEFINITIONS OF SAFETY CULTURE		
Definition	**Author**	**Measurement**
The values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organization's health and safety management	Health and Safety Executive [27]	Qualitative
The set of shared assumptions, values, beliefs, and behaviours that shape the safety-related decisions and actions of an organization's members, and that affect the safety performance	Choudhry et al. [28]	Quantitative/ Qualitative
Values, beliefs, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organization's health and safety management	Cooper et al. [29]	Quantitative/ Qualitative
The integration of core principles such as the preventability of accidents, line management's responsibility for safety, safety as a condition of employment, and management's accountability for employee safety.	Cox and Cox [30]	Qualitative
organization's psychological, behavioural, and contextual capabilities to anticipate, monitor, respond, and learn to manage safety risks and create an ultrasafe organization.	Feng et al. [31]	Qualitative
The concept of safety culture has its roots in extensive research on organizational culture and climate, where culture encompasses the values, beliefs, and underlying assumptions of an organization.	Flin et al. [32]	Quantitative/ Qualitative

safety aspects of their organization". Neal and Griffin [34] is defined as the measurement of the concept of safety culture as combining safety communication (i.e. if there is an open exchange of information regarding safety), management values (i.e. if management gives places for high priority for safety), safety training (i.e. if the training is accessible, relevant, and comprehensive) and safety systems (i.e. if safety procedures are perceived to be effective in preventing accidents) [37].

The key differentiating factor between the two types of safety performance behaviour lies in the fact that compliance pertains to task-oriented behaviour, while safety participation encompasses voluntary extra-role behaviour initiated by employees [38].

Aim of the study

This study aims to determine the effect of the effective role of social compliance audits in ensuring occupational health and safety, which is an important parameter of social compliance audits carried out to control problems such as gender inequality, discrimination, lack of occupational health and safety, and low wages, on the safety culture in workplaces.

METHODS

Study design

This study is conducted in three different locations and textile factories. The factories are selected according to their harmony with social compliance audits. One factory is still in the system and there is no preparation for social compliance. The other factories were selected as workplaces that have been undergoing social compliance audits for many years and have an acceptable level of approval.

Of the research literature review in Türkiye and the World, many reports about social compliance audits such as BSCI, SEDEX, SA 8000, ICS, and Inditex Audits, many articles about safety culture, social compliance, the relationship of safety culture and social compliance have been searched and interviewed with the three of social compliance auditors to be making a simple research model. To reveal how importance the of safety in textile workplaces, national and world statistics such as European Stats, International Labour Organization (ILO) statistics and Türkiye Social Security Institution, are investigated. According to the research conducted and interviews, the parameters of social compliance audits can be categorized under six headings which are management, occupational health and safety, child and young labour, freedom of unionization, human rights, and payments. Those are also the main values that provide a safety culture in the workplace. 'Safety culture' is part of the term 'management and organizational', although it is generally referred to as an element of organizational culture [39]. The unions play an important role in maintaining and enhancing occupational safety and health conflict with employers in general [40]. In a study conducted on female workers by Shin et al. [41], it shows that a monthly well-paid salary has a positive effect on safety participation and compliance.

The research model of the study is demonstrated in figure 1. Briefly, those which are the main parameters of social compliance generate social compliance. Social compliance directly affects safety culture. Safety culture is affected by two unobserved which are safety climate and safety performance and one observed sub-dimension which is risk awareness.

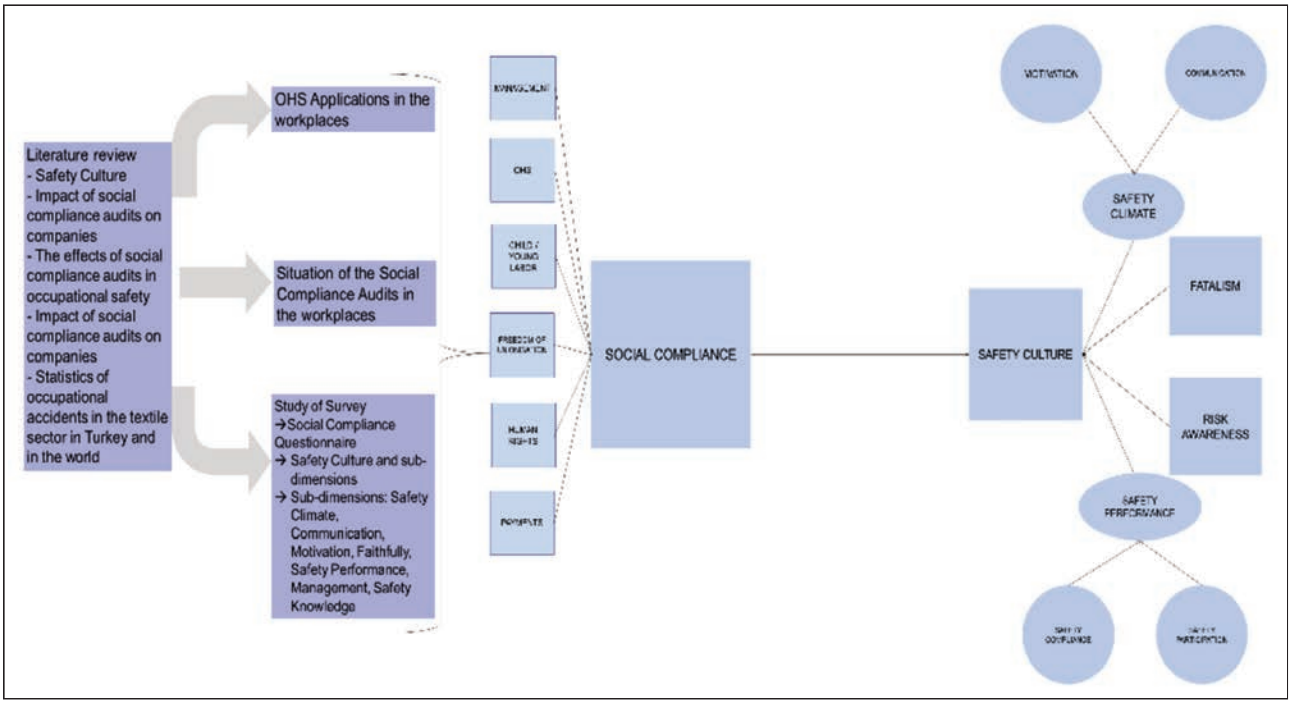

Fig. 1. Researching model

Selected questionnaire and scale

The Social Compliance questionnaire consists of a total of 17 questions. The survey questions are based on the headings specified in the Amfori BSCI audit manual [4], which is available online, and "critical" questions are prioritized.

Questionnaire questions were prioritized, with the lowest 1: Strongly Disagree and the highest 5: Strongly Agree, with the lowest 1: Strongly Disagree and the highest 5: Strongly Agree.

Safety climate and safety performance scales were developed by Griffin and Neal [34], a Turkish adaptation study conducted by Sakallı et al. [42] and used as the determinant of safety culture in this study. In the research, it has been stated that safety culture is a whole of behaviours, attitudes and perceptions of a working environment, whereas safety climate is a superficial and observable phenomenon. [27, 36].

The fatalism scale developed by Alev [43] was used to examine how effective they think beliefs are in the event of accidents and the effect of this on safety culture.

Risk awareness is shaped by knowledge, intuition, control, experiences, and personality-based attitudes [44]. To show the way that effects of risk awareness on safety culture, the risk awareness scale developed by Alev [43] was used.

The safety climate scale is composed of management and communication sub-dimensions. Safety performance is composed of safety attendance and safety compliance.

Samples

This study has been analysed by using a face-to-face survey method in three different textile companies in three different locations in Tekirdağ, Kastamonu and Kahramanmaraş provinces within the borders of Turkey. A total of 309 employees participated. A total of 91 employees from the company located in Tekirdağ, 101 people from the textile factory in Kastamonu and 88 people from the textile factory in Kahramanmaraş participated in the survey study.

While selecting the factories, since the effect of social compliance audits on the safety culture was wanted to be investigated, the factories were preferred by considering the status of the selected factories in terms of social compliance. The factory located within the borders of Tekirdağ province has not yet entered any social compliance audit. The factories located in Kastamonu and Kahramanmaraş have been undergoing social compliance audits for many years and last passed the audits in December 2022.

Data analysis tools

Path analysis

Path analysis is an analysis that examines the relationship networks between observed (measured) variables [45]. The purpose of path analysis is to make inferences by estimating the importance and magnitude of the relationship assumed to be between variables. Path analysis was formed as an extension of multiple regression models. In path analysis, not only the causality between variables but also the method called causal modelling, the relationships between variables can be investigated and predicted [46].

Path analysis is more suitable for analysing more complex models than other types of analysis because both direct and indirect effects can be studied and multiple relationships between factors can be analysed simultaneously to generate models [47]. Although path analysis is similar to regression analysis, it differs from regression analysis with some features. One of these features is that the number of dependent variables is always one in regression analysis. On the other hand, in path analysis, more than one dependent variable can be defined simultaneously.

In this study, IBM SPSS AMOS Version 26.0 was used to determine and evaluate the suitability of the model and to perform path analysis.

Compliance criteria tests

Chi-square (x2) analysis is one of the most basic measurement methods that test the fit of the applied model. The chi-square is conceptually a function of the difference between this fit-measured covariance matrix the model covariance matrix and the sample size. Chi-square statistics vary according to the size of the sample. This analysis gives significant results in measurements with large sample ($N \geq 200$) values. For this reason, it is stated that the chi-square degree of freedom ratio X^2/DF provides an evaluation of the fit of the model [48].

Many fit indexes determine the fit of the model. The fit indices included in this study are the goodness of fit index (*GFI*), one of the fit indexes based on residues, which is the index of the amount of variance and covariance explained by the model. The *GFI* value is related to the number of samples. The higher the sample size, the higher the *GFI* value. The *GFI* value ranges from 0 to 1. It is "accepted" to have *GFI* values between $0.90 \leq GFI < 0.95$; It is defined as a "good fit" indicator when it is between $0.95 \leq GFI \leq 1.00$. This means that covariance is calculated among observed variables [48, 49].

GFI equation 1 is the following:

$$GFI = 1 - \frac{X_m^2}{X_b^2} \quad (1)$$

of the tested model, *b*; the GFI fit index is calculated as above to show the independent model.

Comparative fit index (*CFI*) is the most used index value among fit indices based on independent models. If the *CFI* value is greater than 1, it is evaluated as 1. *CFI* takes values ranging from 0 to 1. Values between $0.95 \leq CFI < 0.97$ are acceptable fit; $0.97 \leq CFI \leq 1$ indicates good fit [48].

CFI equation 2 is the following:

$$CFI = 1 - \frac{X_m^2 - sd_m}{X_b^2 - sd_b} \quad (2)$$

of the tested model, *b*; independent model, *sd*; the *CFI* fit index is calculated as above to show the degrees of freedom.

The standardized root mean square residual (*SRMR*) is the square root of the sum of the squares of the residues in the correlation measurement [48]. In other words, it is the standardized difference between the observed covariance and the estimated covariance. The fact that the value obtained as a result of the measurement is close to zero indicates the perfect fit. Values below 0.05 also indicate a good fit, while $0.05 \leq SRMR \leq 0.10$ indicates an acceptable fit [48].

SRMR equation 3 is the following:

$$SRMR = \sqrt{\frac{2}{p(p+1)} \Sigma_{i \leq j} \{[s_{ij} - \sigma_{ij}(\theta)]\}^2 / s_{ii} s_{jj}} \quad (3)$$

Table 3

GOODNESS OF FIT INDEX CRITERIA	
Goodness of Fit Index	**Recommend level** [48, 50–52]
GFI	>0.90
CFI	>0.90
CMIN/DF	<2.0
SRMR	<0.05
RMSEA	<0.05
AGFI	>0.90

Table 3 explains the recommended level of goodness of fit index criteria.

Ethic

This research is related to the PhD thesis, and it was approved by the Ethics Committee of Applied Sciences Institute of Marmara University with the decision number 21.10.2022-388101/2000000485.

RESULTS

Demographic results

The result of the reliability analysis of the questionnaire study is shown in table 4. It is calculated as 0.89. It was stated that Cronbach's Alpha Coefficient is not reliable if $0 < R2 < 0.40$; $0.40 < R2 < 0.60$ indicates low reliability; $0.60 < R2 < 0.80$ indicates highly reliable; $0.80 < R2 < 1.00$ indicates high reliability [53]. Based on this, it can be inferred that the answers given to the survey questions of this study are highly reliable.

Table 4

RELIABILITY ANALYSIS		
Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**No. of items**
0.893	0.906	45

In table 5, the total number of the research and the related numbers of the factories are shown. A total of 280 persons have attended this research. 142 persons (50.7%) of them are women and 138 persons (49.3%) of them are men. Between 25 and 34 persons have the highest percentage of participating in this research with 31.8%. Over 55 persons have the lowest percentage with 3.9%. According to table 5, most of the participants are from the factory in Kastamonu with 101 persons.

Table 5

TOTAL DESCRIPTIVE STATISTICS									
Various (n=280)		**Tekirdağ**		**Kastamonu**		**Kahramanmaraş**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Sex	Woman	10	11	75	74.3	57	64.8	142	50.7%
	Man	81	89	26	25.7	31	35.2	138	49.3%
Age	18–24	14	15.4	16	15.8	11	12.5	41	14.6%
	25–34	35	38.5	28	27.7	26	29.5	89	31.8%
	35–44	20	22	39	38.6	29	33	88	31.4%
	45–54	19	20.9	16	15.8	16	18.2	51	18.2%
	55+	3	3.3	2	2	6	6.8	11	3.9%
Total		91	100	101	100	88	100	280	100%

Table 6

FIT CRITERIA AND INDEXES OF PATH ANALYSIS OF THE FACTORIES			
	Factory		
Models	**Tekirdağ**	**Kastamonu**	**Kahramanmaraş**
CMIN	0.000	0.000	0.000
DF	14	15	15
P	***	***	***
CMIN/DF	16.747	17.968	18.181
GFI	1.000	1.000	1.000
CFI	1.000	1.000	1.000
SRMR	0.000	0.000	0.000
RMSEA	0.418	0.412	0.444
AGFI	0.36	0.499	0.355

Note: *** Expresses that the p-value is less than 0.01.

In table 6, the criteria and indexes of the factories are shown. In a study conducted by Bayram [48] and Bentler [51], it is the perfect fit if *GFI*, *CFI* and *AGFI* values are more than >0.90 equal to 1.000 and *CMIN*, *SRMR* and *RMSEA* values are lower than 0.05. Bayram [48] explains this situation as the fact that the reason why it is given more than one (at least 5 different) fit index values in SEM applications. If more of the fit index values are above the acceptable limits, the other values which are not acceptable do not cause a problem for the model.

As indicated in table 6 in the section of Method, *CMIN, GFI, AGFI, SRMR*, and *CFI* values are saturated and show a good fit for each of the factories [48, 51, 52].

In table 7, regression analysis of the factory in Tekirdağ shows that there is no relationship between risk awareness and safety culture. On the other hand, it shows that social compliance has a positive and significant relationship with safety culture. Therefore, all parameters which are risk awareness, Safety Climate, Safety Performance and Fatalism have significant relationships with Safety Culture.

When looking at table 8, shows the covariance between the parameters and social compliance.

Table 7

REGRESSION ANALYSIS OF THE FACTORY IN TEKIRDAĞ				
Relationship			**Estimate**	**P**
Safety culture	←	Risk awareness	–0.009	0.784
Safety culture	←	Safety climate	0.541	***
Safety culture	←	Safety performance	0.693	***
Safety culture	←	Fatalism	0.139	***
Safety culture	←	Social compliance	0.178	***

Note: *** Expresses that the p-value is less than 0.01.

Table 8

COVARIANCE TABLE OF THE FACTORY IN TEKIRDAĞ				
Relationship			**Estimate**	**P**
Safety performance	↔	Risk awareness	0.471	***
Safety performance	↔	Fatalism	0.209	0.014
Risk awareness	↔	Fatalism	0.592	***
Safety climate	↔	Social compliance	0.207	***
Safety performance	↔	Social compliance	0.148	0.010

Note: *** Expresses that the p-value is less than 0.01.

There is a significant relationship between social compliance and the safety culture parameters which are safety performance and safety climate. And there is also a relationship between safety performance and risk awareness. It can be seen from the table that fatalism has covariance with safety performance and risk awareness. It explains that social compliance has a more effective safety culture indirectly via safety climate and safety performance.

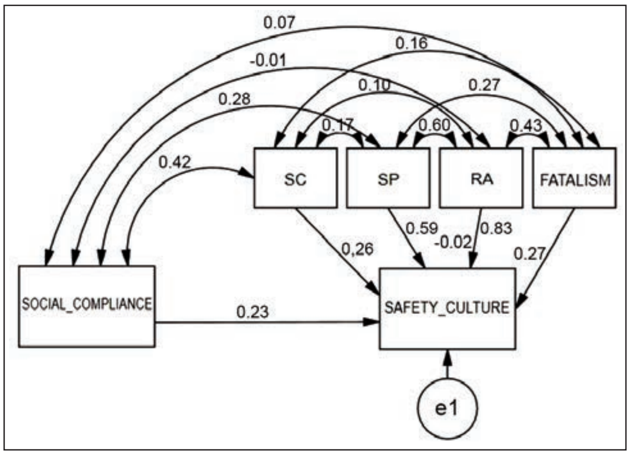

Fig. 2. Path analysis of effecting the safety culture in Tekirdağ factory (SC – Safety Climate, SP – Safety Performance; RA – Risk Awareness)

In figure 2, explains the relationships between social compliance and safety culture. Social compliance has direct effects on safety culture with 0.23. Safety culture is positively affected by all the parameters and social compliance with 0.83 which is a very high score. Risk awareness negatively affects safety culture with –0.02. Risk awareness and safety performance have strong correlations and safety performance directly affects safety culture with 0.59. There is a relationship between safety climate and fatalism with 0.16. The analysis shows that fatalism affects safety culture with 0.27. There is a relationship between risk awareness and fatalism at 0.43. Safety Climate directly affects safety culture with 0.26. Social compliance has a positive relationship with safety climate and safety performance with respectively 0.42 and 0.28. There is an almost neutral relationship between social compliance and fatalism.

This model, explains that social compliance directly quiet affects safety culture. On the other hand, it is explicitly seen that it is more effective indirectly on safety culture via safety climate and safety performance.

Regression analysis values that belong to the factory in Kastamonu are shown in table 9. The score of the value shows it's significant statistically if the score is $0.01 < p < 0.05$ and it is highly significant statistically if the score is $p < 0.01$ [54]. It shows that all parameters which are Awareness of Risk, Safety Climate, Safety Performance and Fatalism have relationships significantly with Safety Culture. Social Compliance has a significant relationship with Safety Culture significantly.

Covariances between the parameters for the factory in Kastamonu are given in table 10. It shows that there is a linear relationship between social compliance and risk awareness, safety climate, and safety performance. And it shows that there is also a linear relationship between risk awareness and safety performance.

Table 9

REGRESSION ANALYSIS OF THE FACTORY IN KASTAMONU

Relationship			Estimate	P
Safety culture	←	Risk awareness	–0.080	***
Safety culture	←	Safety climate	0.234	***
Safety culture	←	Safety performance	0.693	***
Safety culture	←	Fatalism	0.163	***
Safety culture	←	Social compliance	0.069	0.037

Note: *** Expresses that the p-value is less than 0.01.

Table 10

COVARIANCE TABLE OF THE FACTORY IN KASTAMONU

Relationship			Estimate	P
Safety climate	↔	Risk awareness	–0.112	0.026
Safety performance	↔	Risk awareness	0.246	***
Safety performance	↔	Social compliance	0.075	0.010
Risk awareness	↔	Social compliance	-0.131	0.034
Safety climate	↔	Social compliance	0.079	0.008

Note: *** Expresses that the p-value is less than 0.01.

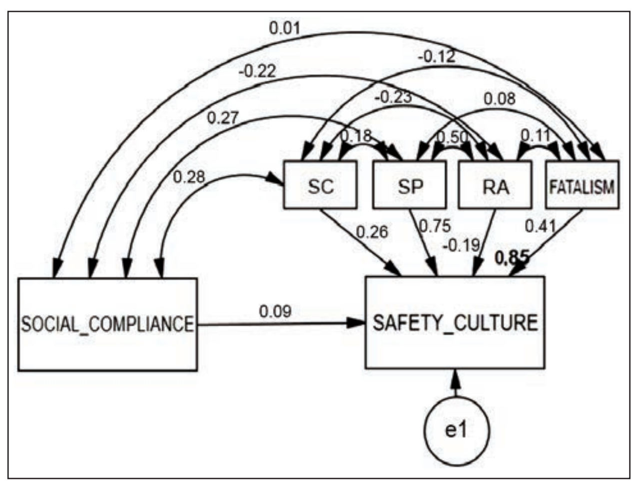

Fig. 3. Path analysis of effecting the safety culture in the Kastamonu factory (SC – Safety Climate, SP – Safety Performance; RA – Risk Awareness)

Figure 3 explains the relationships between social compliance and safety culture. Social compliance has direct effects on safety culture with 0.09. Safety culture is positively affected with 0.85 which is a very high score. Risk Awareness affects negatively with –0.19. But risk awareness and safety performance have strong correlations and safety performance directly affects safety culture with 0.75. There is a negative relationship between safety climate and fatalism with –0.12 which explains that the one who has a low score for fatalism is the one who has a high score for safety climate. The analysis shows that fatalism affects safety culture with 0.41. There is no strong relationship between risk awareness and fatalism. Safety Climate directly affects safety culture with 0.26. Social compliance has a positive relationship with safety climate and safety performance with respectively 0.28 and 0.27. There is an almost neutral relationship between social compliance and fatalism.

It can be said for the factory in Kastamonu that social compliance, directly and indirectly, affects safety culture. Safety performance is the most effective parameter of safety culture. Risk awareness is more effective in a safety culture via safety performance.

The value of p for regression analysis should be less than 0.05 for strong evidence. But if it is above 0.05, then the hypothesis is not rejected. If value lies between $0.05 \leq p < 0.10$, it means there is some evidence although not strong [55, 56]. In table 11 the regression analysis of the factory in Kahramanmaraş shows that social compliance has a positive relationship and there is some evidence of their positive relationship with safety culture. Therefore, all parameters which are Risk Awareness, Safety Climate, Safety Performance and Fatalism have significant relationships with Safety Culture.

Table 11

REGRESSION ANALYSIS OF THE FACTORY IN KAHRAMANMARAŞ

Relationship			Estimate	P
Safety culture	←	Risk awareness	–0.153	0.008
Safety culture	←	Safety climate	0.196	***
Safety culture	←	Safety performance	0.714	***
Safety culture	←	Fatalism	0.39	***
Safety culture	←	Social compliance	0.085	0.062

Note: *** Expresses that the p-value is less than 0.01.

Covariances between the parameters for the factory in Kahramanmaraş are given in table 12. It shows that safety climate has a linear relationship with social compliance and safety performance, and fatalism has a linear relationship between safety performance and risk awareness. Safety Performance also has a linear relationship with risk awareness.

Figure 4 explains the relationships between social compliance and safety culture. Social compliance has direct effects on safety culture with 0.09. Safety culture is positively affected by the parameters with 0.86. Risk Awareness was affected negatively with –0.15. But risk awareness and safety performance

Table 12

COVARIANCE TABLE OF THE FACTORY IN KAHRAMANMARAŞ

Relationship			Estimate	P
Risk awareness	↔	Fatalism	0.560	***
Safety performance	↔	Fatalism	0.236	***
Safety performance	↔	Risk awareness	0.335	***
Safety performance	↔	Safety climate	0.045	0.038
Social compliance	↔	Safety climate	0.080	***

Note: *** Expresses that the p-value is less than 0.01.

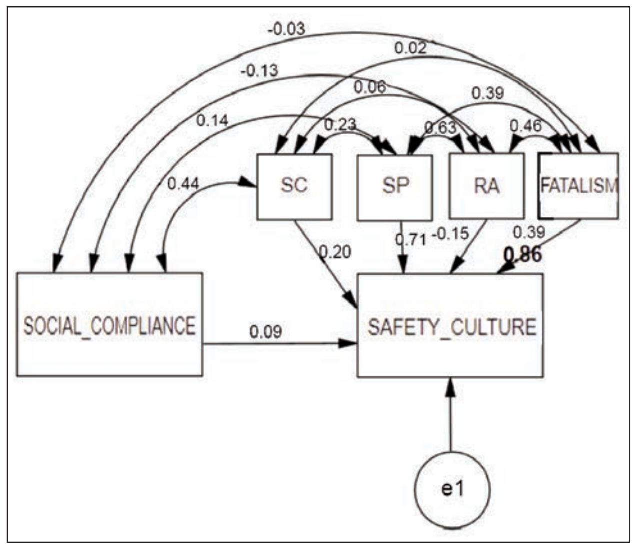

Fig. 4. Path analysis of effecting the safety culture in the Kahramanmaraş factory (SC – Safety Climate, SP – Safety Performance; RA – Risk Awareness)

have strong covariance and safety performance directly affects safety culture with 0.71. There is a weak relationship between safety climate and fatalism with 0.02. The analysis shows that fatalism affects safety culture with 0.39. There is quite a strong relationship between risk awareness and fatalism. Safety Climate directly affects safety culture with 0.20. Social compliance has a positive relationship with safety climate and safety performance with respectively 0.44 and 0.14. There is a negative relationship between social compliance and fatalism.

DISCUSSION AND CONCLUSIONS

In conclusion, social compliance affects safety culture not only directly but also indirectly via safety climate and safety performance in three different textile factories. But for the factory in Tekirdağ where there is no social compliance audition, it shows in table 7 that risk awareness does not effectively on safety culture. Safety culture is mostly related to risk awareness in many industries [57–59]. This could have several meanings. One of them is that workers are aware that management does not take action to reduce the risks even if the workers report the risks in the workplace. Another may mean that employees exhibit unsafe behaviour due to insufficient risk awareness. In another perspective, as a result of a study conducted by Li et al. [60], it was revealed that agricultural workers with high-risk perceptions exhibited unsafe behaviour. Based on this, it may mean that employees do not comply with the safety culture because they know the job very well. On the other hand, the results of the factory in Kastamonu show that all the parameters positively affect safety culture. The managements for both factories play the role of social compliance auditions.

Safety performance and safety climate influence safety culture more than others when social compliance affects them.

In research conducted by Toksöz et al. [61], it states that legal requirements and occupational health and safety are the criteria with the highest importance levels with 30% importance in the distribution of social compliance score. In another research conducted by Azim et al. [62], the study has suggested that adherence to compliance standards can lead to greater employee satisfaction and engagement within an organization. The research indicates that creating a positive work environment and fostering employee commitment and engagement are crucial components for the success of businesses [63]. Another study shows that there is a strong link between the cooperation and communication between management and employees, their commitment to awareness, training and OHS practices [64].

It can be understood that management attitudes play an important role in effecting commitment and occupational health and safety practices.

As a result, when this study and literature studies are examined, the management of the factories is responsible for the health, safety, social rights and quality of life of the employees. This study shows that due to this responsibility, fulfilling their compliance to ensure employee health and safety without waiting for the social compliance audits carried out by the companies will have a positive impact on both the employee and the company.

However, it is thought that making social compliance audits mandatory not only for the textile sector but also for many different sectors with certain conformities by governments will increase product quality as well as employee satisfaction.

In future studies, researchers will be useful in revealing the importance of these audits by examining the impact of social compliance audits on management and the impact on employee performance.

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The influence mechanism of digital technology empowering green innovation of textile firms: a knowledge search perspective

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ABSTRACT – REZUMAT

The influence mechanism of digital technology empowering green innovation of textile firms: a knowledge search perspective

Digital technology is a vital engine for the green innovation of textile firms. In recent years, knowledge search through digital platforms has allowed for obtaining richer knowledge information. Using a data engine for data mining can improve the efficiency of firm knowledge retrieval. Considering these factors, this paper collects data from 226 textile firms and uses multiple regression analysis methods to analyse the impact mechanism and path of digital technology empowering textile firms' green innovation. The study found that digital technology has a positive impact on the green innovation of textile firms through the mediating role of knowledge search. Environmental dynamism positively moderates the relationship between digital technology and green innovation of textile firms. Based on this, the management enlightenment of textile firms using digital technology to realize knowledge search and promote green innovation is put forward.

***Keywords**: digital technology, textile firms, green innovation, knowledge search*

Mecanismul de influență al tehnologiei digitale ce susţine inovația ecologică a firmelor textile: o perspectivă de căutare a informaţiilor

Tehnologia digitală este un motor vital pentru inovația ecologică a firmelor textile. În ultimii ani, căutarea informaţiilor prin intermediul platformelor digitale a permis obținerea de informații mai vaste. Utilizarea unui motor de căutare pentru extragerea datelor poate îmbunătăți eficiența colectării informaţiilor companiei. Luând în considerare factorii menţionaţi, acest studiu colectează date de la 226 de firme textile și utilizează metode de analiză de regresie multiplă pentru a investiga mecanismul de impact și traseul tehnologiei digitale, care sporesc inovația ecologică a firmelor textile. Studiul a constatat că tehnologia digitală are un impact pozitiv asupra inovației ecologice a firmelor textile prin rolul de mediere al căutării informaţiilor. Dinamismul mediului moderează pozitiv relația dintre tehnologia digitală și inovația ecologică a firmelor textile. Pe baza acestui fapt, se propune informarea managerială a firmelor textile utilizând tehnologia digitală, pentru a realiza căutarea de informaţii și a promova inovația ecologică.

***Cuvinte-cheie**: tehnologie digitală, firme textile, inovație ecologică, căutarea informaţiilor*

INTRODUCTION

“Green textile” is a prominent theme in the development of the textile industry. Digital technology enables the high-end, intelligent, and green development of textile firms. Printing and dyeing equipment, for example, uses digital technology to drive new energy-saving and environmental protection technologies and promote textile firms to develop in a green direction supported by digital platforms [1, 2]. Digital technology improves the manner of information dissemination and processing with its characteristics of embeddedness and integration. These traits promote resource-sharing and integration and profoundly affect the information interaction mode and cooperation relationship among firms. Digital technology helps firms search for diversified and novel knowledge and helps firms obtain complementary resources needed for green innovation [3].

“Knowledge search” includes knowledge identification, search acquisition, integration, and utilization. Firms use digital technology to collect, organize and analyse data, thereby promoting product research, green production and marketing [4].

Textile firms are facing environmental dynamics in the process of green innovation. Market demand, technological development, and the information environment are encountering dynamic development, which leads to behavioural changes or modified needs of stakeholders, such as competitors, customers, partners, and governments. Albert et al. [5] analysed 112 firms from the Spanish auto parts manufacturing industry based on the structural equation of variance, pointing out that green innovation strategies such as environmental management and green practice can help firms gain competitive advantages. According to dynamic capability theory, a positive relationship can be seen between institutional pressure and eco-innovation [6]. When the market trend frequently changes, the ability of textile firms to collect relevant information directly affects their understanding of raw material fluctuations and changes in consumer demand, which in turn affects their green innovation. Digital technology helps firms conduct data collection, knowledge acquisition, and information-sharing ahead of dynamic market changes.

In summary, this paper focuses on clarifying the following three research questions. First, we try to verify whether digital technology can become a powerful starting point for textile firms to achieve green innovation. Second, we explore the intermediate transmission mechanism of digital technology affecting the green innovation of textile firms, that is, explore whether textile firms can use digital technology to complete knowledge searches and achieve green innovation. Thirdly, in the context of environmental dynamics, this paper discusses the situational mechanism of digital technology affecting the green innovation of textile firms. To solve the above problems, based on the new development model of digital intelligence governance, we clarify the influence mechanisms and action paths of textile firms to use digital technology to obtain knowledge and improve the level of green innovation. Moreover, we reveal the moderating effect of environmental dynamics in the process of how digital technology affects knowledge search and green innovation in textile firms.

LITERATURE REVIEW

With the deepening of research on firm innovation, green innovation can be divided into two categories: incremental and radical green innovation.

"Incremental" green innovation is the improvement of existing products and technologies, or the transformation of technology platforms and products to improve the design of existing products [5–6]. This innovation expands current knowledge and skills, grows and enriches existing product lines, and improves the efficiency of existing distribution channels to meet the needs of consumers or markets [7]. In contrast, "radical" green innovation explains the connotation and extension of Schumpeter's "radical innovation," fundamentally realizing a breakthrough in existing technology [8]. Relying on a new technology platform, firms develop new products or services to subvert the competitive environment to tap into potential consumers or markets [7]. Radical green innovation seeks new possibilities, emphasizes the acquisition and creation of new knowledge, and engages in more innovation. For example, the textile printing and dyeing sector is a typically pollution-intensive industry. Textile firms form efficient and energy-saving equipment, and green and environmentally friendly textile technologies, to reduce the pollution of production and save costs. These measures prevent and control pollution from the source, improving the competitiveness of green development of textile firms.

With the development of digital technology, data has become a basic strategic resource. Digital technology has brought about changes in the information mechanism. Digital technology is the starting point to support and promote digital transformation, which has a vital impact on the green innovation of textile firms [9]. Digital technology achieves incremental and radical green innovation by allowing textile firms to achieve core technology breakthroughs, reduce management costs, and save on energy consumption.

The application of digital technology can promote green innovation in multiple areas such as product development, and knowledge systems, thereby promoting the automation and upgrading of textile equipment [10]. These developments facilitate the "integration of informatization and industrialization" of firms and solve the key problems of radical green innovation [11]. Digital technology reduces the management and information retrieval cost for firms, triggering energy "conservation-oriented" technological progress. Digital technology enables R&D departments to improve communication and operational efficiency, achieve vertical and horizontal expansion of organizations, and accelerate green patent research, development, and innovation [12].

Knowledge search is a dynamic process of finding, analysing, and applying resources [13]. The process of knowledge search can be divided into knowledge mining, absorption, integration, and utilization [14]. According to the purpose of knowledge search, firms can form a proactive and a reactive search mode [15]. The "proactive" search mode is mainly reflected in the complex network that firms can use to develop new products and equipment and build network platforms in the context of digital intelligence. These actions expand the scope of resources available to firms and promote real-time connections between firms, companies, and virtual systems. In this manner, a complex network can be formed to break through existing knowledge limitations [16].

In comparison, a "reactive" search mode is mainly reflected in the further strengthening and improvement of the original firm to meet the needs of digital transformation [17]. The application of digital technology is conducive to the knowledge search of textile firms. With a deepening knowledge search, it will be more difficult for firms to absorb and apply new knowledge and technologies [18]. In the process of proactive knowledge search, firms lock in the scope of knowledge search according to emergency needs. Knowledge search through digital platforms can obtain richer knowledge information [19].

A rapid influx of new knowledge will lead to the problem of information overload and reduce the efficiency of information processing. Firms can use the new generation of information technology to establish a closed loop of data collection, transmission, storage, processing, and feedback, thereby breaking through the data barriers between various levels and different industries. This development improves the efficiency of knowledge retrieval [20]. The data-enabled connection ability can improve communication between individuals in the firm, strengthening the close relationship between individuals and information, and promoting proactive knowledge search [21].

With the help of new technology, firms can quickly perceive the information needed by firms, reducing the time, manpower, and material resources for firms to find, absorb, and sort out new external knowledge. In this way, firms can identify diversified markets and technologies and reduce the cost of knowledge management [22].

In the process of reactive knowledge search, data processing capability plays a supporting role in the acquisition, integration, and utilization of resources and information by firms [23]. Therefore, digital technology can shorten the knowledge distance. With the help of digital technology, it is easier for textile firms in particular to obtain external information and innovative resources, thus increasing the possibility of integration and deep transformation of knowledge and improving the ability for reactive knowledge search.

Textile firms realize both radical and incremental green innovation in the process of knowledge search. On the one hand, knowledge search can provide firms with more novel and cutting-edge green technology data and allow firms to achieve radical green innovation [24]. Proactive search can strengthen the ability of firms to collect all types of green information in the external environment and obtain ideas for designing green products, new product sales channels, and potential markets [25].

On the other hand, textile firms can obtain the latest market information on upstream and downstream firms through knowledge search, thereby improving the competitiveness in green development. A reactive knowledge search enables firms to make full use of external knowledge sources, allowing the integration and application of various green and low-carbon technologies, and closely integrating green technologies with firms to form a driving force for incremental green innovation. The knowledge resources acquired in reactive search are integrated and applied to the process of incremental green innovation [26]. Reactive search enables firms to collect preliminary ideas about innovative modes from other firms in the market and improve their ability to transform products and improve services [27].

"Environmental dynamics" is a dynamic change in the environment caused by the complexity and instability of the external environment of the firm [28]. The concept covers customer needs, market changes, industry policies, the socioeconomic environment, and the technological development level of the external environment [28, 29]. The change of competitive advantage created by organizational capability depends on the dynamic change in the environment.

Consequently, the moderating effect of environmental dynamics in the green innovation process of textile firms is worth examining.

With the continuous increase of environmental dynamics, the impact of digital technology on green innovation of textile firms is enhanced. Environmental changes affect the overall operation of firms. Therefore, in a dynamic environment, the stronger the firm's digital technology and data management capabilities, the more accurate the understanding of macro-environmental changes such as industrial trends and environmental policies [29]. Textile firms rely on the accumulation of data resources, obtain demand information in real-time based on digital technology, analyse customer preferences, and develop environmentally friendly textile products in the market. In addition, these firms make predictive judgments on environmental protection needs and promote green innovation.

Based on the above analysis, this paper proposes the following hypotheses: first, digital technology has a positive impact on the green innovation (radical and incremental green innovation) of textile firms. Second, digital technology promotes green innovation by supporting knowledge search (proactive and reactive) in textile firms. Moreover, environmental dynamism positively moderates the impact of digital technology on the green innovation of textile firms (figure 1).

RESEARCH METHODOLOGY

Sample and data

Textile firms have gradually realized transformation and upgrading, adopting medium and high-end knitted fabrics as key areas of green development. Furthermore, green innovation has been encouraged as well as the development of textile firms under the guidance of digital technology. Data collection in this

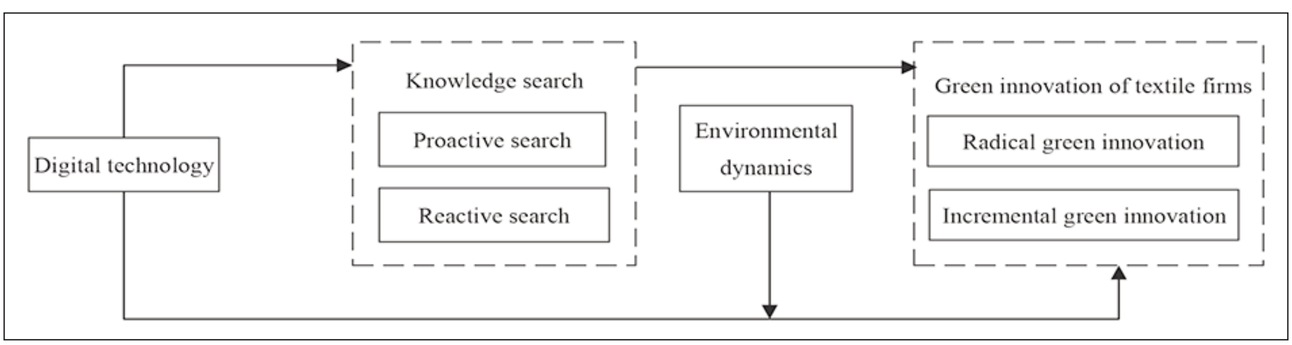

Fig. 1. Influence mechanism of digital technology empowering textile firms' green innovation

Table 1

SAMPLE DESCRIPTIVE STATISTICS							
Sample characteristics		**Frequency**	**Relative frequency**	**Sample characteristics**		**Frequency**	**Relative frequency**
Years of firm	Less than 10 years	59	26.1%	Firm scale	Small and micro firms	84	37.2%
	10–20 years	93	41.2%		Medium-sized firms	77	34.1%
	More than 20 years	74	32.7%		Large firms	65	28.8%
Form of ownership	State-owned firms	12	5.3%	Manager gender	Male	185	81.9%
	Private firms	214	94.7%		Female	41	18.1%

work has mainly adopted field research and the acquisition of questionnaires. The respondents chose textile firms with a high level of green innovation and complete production and processing by digital technology or digital platforms. In this study, the respondents are middle and senior managers of the firms. To add scientific rigour, 60 questionnaires were distributed for pre-survey before the formal collection of data. The questionnaire was improved based on the results of the pre-survey.

The study employed a longitudinal research method, and 300 questionnaires were distributed in two stages. The questionnaire was issued for the first time with questions relating to firm age, the scale of the firm, the form of ownership, and information related to digital technology. Overall, 259 questionnaires were recovered. The second questionnaire was issued a month later, including information on knowledge search, environmental dynamics, and green innovation of textile firms, with 226 questionnaires recovered. The effective recovery rate of the questionnaire was 75.33%. After completion of the survey, a total of 226 valid questionnaires were obtained. The sample characteristics are shown in table 1.

In the valid questionnaires, state-owned firms accounted for 5.3%, and private firms accounted for 94.7%. Males comprised 81.9%, and females accounted for 18.1% of respondents. In addition, the results show no serious homologous deviation.

Variables' measurement

Digital technology (DT)

Reviewing and analysing the measurement methods of existing literature [30], text mining methods were used to obtain the frequency of keywords related to the application of digital technology in the firm's annual report. The final sum of word frequency plus the logarithm of 1 is used to describe the degree of the firm's digital technology application.

Knowledge search

Referring to the scale of knowledge search studied by Luisa et al. [15] and Ricci et al. [21], and making some adjustments in line with the knowledge search situation of textile firms, eight items were finally determined to measure proactive search (*PS*) and reactive search (*RS*).

Green innovation

The measurement of green innovation (GI) is mainly based on the research of Urbinati et al. [8] and Mikalef et al. [10]. Six items were determined and measured from the two dimensions of radical green innovation (RI) and incremental green innovation (II).

Environmental dynamics

The measurement of environmental dynamics (ED) refers to the research of Wilden and Gudergan [31] and others, making appropriate adjustments according to the environmental externalities faced by textile firms. Four items are used to measure the environmental dynamics of textile firms.

In addition, referring to previous studies [3, 19, 28], the scale of firms and their financial characteristics may affect the green innovation of textile firms. Corporate assets can affect the basis for firms to invest social capital in firm innovation. The profitability and growth of firms play a key role in the green innovation of firms. In particular, a higher profitability and operating income growth rate are conducive to the realization of green innovation. Therefore, this paper chooses firm size (ES), asset size (ASSET), profitability (PROFIT), and firm growth (GROWTH) as control variables.

The classification standard of firm scale comes from the *Statistical Method for the Classification of Large, Medium, Small, and Micro Firms* (2017) issued by the Chinese National Bureau of Statistics. According to the firm, the number of employees, and the operation situation, the firm is divided into four types: large, medium, small, and micro, which are recorded as 1, 0.75, 0.25, and 0, respectively. The asset size (ASSET) is characterized by the natural logarithm of the total assets of the firm at the beginning of the period; profitability (PROFIT) is characterized by net profit/average asset; firm growth (GROWTH) is characterized by the growth rate of business income. The remaining variables were measured by a Likert 5 scale.

Reliability and validity test

The scales selected in this paper adopt the mature scales of domestic and foreign scholars and combine the textile firms to use digital technology to realize knowledge search and promote the specific situation of green innovation research to make appropriate adjustments. In terms of questionnaire design, in addition to the basic information of the firm and the individual, each item adopts a Likert five-level scale (1 = Completely inconsistent, 5 = Fully consistent).

The Cronbach's α values of each variable in table 2 are all greater than 0.7, and the reliability is good. The factor load of each item exceeded 0.7. The average variance extraction (AVE) value of each variable was higher than 0.7, which met the requirement of a critical value of 0.5. The combined reliability value (CR) was greater than 0.7, and the validity of the scale was good. Among them, the minimum AVE value is 0.799, and its square root value is 0.894, which is higher than the correlation coefficient between factors, so the data pass the discriminant validity test. The model has a good fitting effect.

Correlation analysis

The correlation coefficient between variables (table 3) is within a reasonable range, which further verifies the relevant hypothesis proposed above.

The results of the multicollinearity test between variables show that the maximum variance inflation factor (VIF) of the regression coefficient is 3.524, which is far less than the critical value of 10. Therefore, there is no multicollinearity between variables.

Table 2

RELIABILITY AND VALIDITY TESTS

Dimensions	Items	Factor loading	AVE	CR	Cronbach's α
Proactive search [21]	Your firm actively explores new textile knowledge and market opportunities.	0.783	0.846	0.844	0.881
	Your firm strives to break the limitations of existing textile knowledge and production capacity.	0.824			
	Your firm takes the initiative to enter the field of emerging textile technology and explore new channels.	0.851			
	Your firm dares to bear the risk of knowledge search and application.	0.772			
Reactive search [29]	Your firm should improve the existing knowledge level and reserve according to the current needs.	0.859	0.826	0.917	0.821
	Your firm completes the improvement of reserve knowledge through knowledge search.	0.893			
	Your firm improves the existing textile technology through knowledge search.	0.912			
	Your firm improves the production process or process of printing and dyeing through knowledge search.	0.794			
Environmental dynamics [31]	Your firm is facing consumer demand and market preferences change quickly.	0.757	0.794	0.856	0.897
	The green technology transformation and upgrading of your firm is fast.	0.926			
	The emergence and promotion of new knowledge and technology in your industry is fast.	0.886			
	The relevant policies and institutional adjustments faced by your firms are frequently issued.	0.741			
Radical green innovation [17]	Your firm is trying new environmentally friendly textile products in the market.	0.799	0.816	0.799	0.834
	Your firm actively develops new environmentally friendly textile products.	0.805			
	Your firm agrees that textile products should meet the advanced environmental protection needs.	0.827			
Incremental green innovation [10, 30]	Your firm provides improved environmentally friendly textile products in the existing market.	0.859	0.892	0.903	0.782
	Your firm strives to improve the quality of supply of environmentally friendly textile products.	0.836			
	Your firm stage access to environmental management information supplies better textile products.	0.796			

Table 3

VARIABLES' DESCRIPTIVE STATISTICS AND CORRELATION COEFFICIENT TABLE (N=226)										
Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Firm Scale	——									
2. Asset Size	0.267^{**}	——								
3. Profitability	0.124^{*}	0.105	——							
4. Firm Growth	0.132^{*}	0.124	0.087	——						
5. Digital Technology	0.098^{**}	0.158^{***}	0.106	0.129	——					
6. Proactive Search	0.101	0.251	0.124	0.112	0.385^{**}	——				
7. Reactive Search	0.097	0.103	0.211	0.083	0.299^{*}	0.413^{*}	——			
8. Environmental Dynamics	0.135^{*}	0.058	0.059	0.034	0.246^{*}	0.428^{*}	0.256^{**}	——		
9. Radical Green Innovation	0.162^{**}	0.206^{**}	0.247^{*}	0.167	0.345^{*}	0.314	0.483	0.256	——	
10. Incremental Green Innovation	0.179^{*}	0.159^{*}	0.281^{*}	0.151	0.284^{**}	0.497	0.211	0.354^{*}	0.285	——
Mean Value	0.564	2.598	0.219	0.063	1.156	3.894	3.165	3.669	3.852	3.217
Standard Deviation	0.291	1.687	0.183	0.074	0.579	1.173	0.816	1.247	1.535	1.266

Note: N = 262, * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$.

Regression model

To analyse the path of textile enterprises using digital technology to influence the green innovation of textile firms, we have established a multiple linear regression model. The quantitative expression can be constructed in the following form:

$$\begin{gathered} GI_{it} = \alpha_0 + \beta_1 DT_{it} + \gamma_1 \sum CONT_{it} + \varepsilon_{it} \\ OB_{it} = \alpha_1 + \beta_2 DT_{it} + \gamma_2 \sum CONT_{it} + \varepsilon_{it} \\ GI_{it} = \alpha_2 + \lambda_1 DT_{it} \times ED_{it} + \gamma_3 \sum CONT_{it} + \varepsilon_{it} \\ GT_{it} = \alpha_3 + \beta_3 DT_{it} + \tau_1 OB_{it} + \gamma_4 \sum CONT_{it} + \varepsilon_{it} \end{gathered} \tag{1}$$

Based on the effective sample data of textile firms, concerning other management statistical research methods, SPSS 22.0 and AMOS 24.0 statistical tools are used to analyse the characteristics of the sample data obtained. To ensure the reliability of the scale and the obtained data, descriptive statistical analysis, correlation analysis, and multiple hierarchical regression analysis were carried out to verify the direct effect of digital technology on green innovation of textile firms and the mediating role of knowledge search.

RESULTS AND DISCUSSION

The benchmark regression results are shown in table 4.

Table 4

BENCHMARK REGRESSION RESULTS						
Variables	**Radical Green Innovation(*RI*)**			**Incremental green innovation(*II*)**		
ES	0.152^{*} (1.73)	0.102^{*} (1.75)	0.096^{*} (1.68)	0.213^{**} (2.31)	0.165^{*} (1.84)	0.171^{*} (1.77)
ASSET	0.098^{*} (1.82)	0.056^{*} (1.66)	0.071^{*} (1.69)	0.102^{***} (4.85)	0.086^{***} (4.99)	0.093^{***} (5.51)
PROFIT	–0.076 (–1.21)	0.023 (0.89)	–0.051 (–1.35)	0.086 (0.57)	0.101^{**} (2.13)	0.095^{**} (2.28)
GROWTH	0.134^{**} (2.36)	0.064^{*} (1.98)	0.078^{*} (2.04)	0.104 (0.62)	0.077 (0.64)	0.063 (0.84)
DT	—	0.264^{**} (3.16)	0.251^{**} (3.35)	—	0.367^{***} (4.28)	0.258^{***} (4.65)
DT*ED	—	—	0.103 (1.57)	—	—	0.124^{***} (2.96)
R^2	0.089	0.213	0.249	0.301	0.423	0.468
Adj. R^2	0.086	0.211	0.245	0.296	0.416	0.464
F	2.248	18.846	21.318	29.842	46.545	49.843
Max *V1F*	2.197	1.767	1.728	1.529	1.354	2.106
D-W	2.159	1.995	2.140	1.963	2.240	1.958

Note: * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$, the same below.

The regression results show that digital technology has a significant positive impact on both incremental green innovation and radical green innovation. At the same time, environmental dynamism plays a positive moderating role in the process of digital technology affecting the radical green innovation of textile firms but does not play a moderating role in incremental green innovation. The reason is that, in a more turbulent environment, firms actively explore the power of new products and needs, thereby achieving the overall green innovation ability and technical level through knowledge search.

Hierarchical regression is used to verify the mediating role of knowledge search in the process of digital technology affecting green innovation. Table 5 shows the results of the moderated mediation effect test.

The application of digital technology can drive textile firms to carry out both proactive and reactive searches. Textile firms can complete knowledge searches with the support of digital technology and broaden the channels of knowledge learning and technology introduction. Therefore, the R&D activities of production technology such as green printing and dyeing in textile firms can be supported by new knowledge and technology.

A significant positive correlation is found between proactive search and incremental and radical green innovation. In particular, proactive search partially mediates the relationship between digital technology and both incremental and radical green innovation of textile firms.

In comparison, reactive search plays a partial intermediary role in the process of digital technology and incremental green innovation of textile firms. At the same time, reactive search does not play an intermediary role in the process of digital technology and radical green innovation of textile firms. The reason is that reactive search focuses on the improvement and perfection of existing technology and knowledge and may have less of an effect on the improvement of firm innovation.

The conclusion of the study once again verifies the findings of Mikalef et al. [10], Ghobakhloo [11] and Urbinati et al. [17] and other scholars on the mechanism of digital technology promoting green innovation. The results of this work point out that the improvement of digital technology plays an important role in the green innovation of textile firms. At the same time, this paper verifies the path of digital technology promoting green innovation through knowledge search, extending the results of Marques et al. [16], Foss [18] and other scholars on knowledge search. The findings of this study place digital technology, knowledge search, and green innovation in the same framework, offering a new path toward green innovation for textile firms.

The interaction between digital technology and environmental dynamics has a crucial relationship with the radical green innovation of textile firms. That is, the positive moderating effect of environmental dynamics on digital technology and radical green innovation is significant. However, environmental dynamism does not moderate the relationship between digital technology and incremental green innovation because the incremental green innovation of textile firms is mostly achieved through the efforts of firms to build strategic alliances and improve the existing technical level. The impact of environmental dynamics on firms' use of digital technology to achieve incremental green innovation is relatively small, and the impact of external uncertainty on the risk of green innovation is weak. Therefore, it is necessary to

Table 5

RESULTS OF THE MODERATED MEDIATION EFFECT TEST

Variables	*PS*	*RS*	*RI*		*II*	
ES	0.167* (1.68)	0.201** (2.28)	0.073* (1.86)	0.084** (2.97)	0.134* (1.83)	0.128* (1.85)
ASSET	0.098** (2.29)	0.146** (2.16)	0.065* (1.75)	0.071* (1.77)	0.053*** (4.69)	0.059*** (4.28)
PROFIT	0.131** (2.38)	0.098*** (5.57)	0.036 (1.43)	0.021* (1.69)	0.062* (1.89)	0.041* (1.92)
GROWTH	0.081* (1.84)	0.059** (2.36)	0.081* (1.92)	0.104 (1.57)	0.078 (0.76)	0.083 (0.99)
DT	0.315** (2.36)	0.263*** (6.21)	0.232** (2.15)	0.241*** (3.94)	0.174*** (5.35)	0.169*** (4.86)
DT*ED	—	—	—	0.105 (1.65)	—	0.105** (4.58)
PS	—	—	0.099*** (6.94)	0.075*** (5.73)	0.104** (2.42)	0.105*** (4.58)
RS	—	—	0.102 (1.60)	0.095 (0.73)	0.095*** (3.24)	0.092 (1.32)
F	32.845	39.946	27.523	35.362	54.673	50.253
R^2	0.354	0.384	0.267	0.336	0.483	0.452

strengthen the response speed of textile firms to the dynamic changes of the market environment, improve the ability of forward-looking search and responsive search, and promote the gradual green innovation and disruptive green innovation of textile firms.

Compared with the research results of Guo et al. [13, 14], this study further proposes to strengthen knowledge management and search activities from internal and external to promote green innovation of textile enterprises. Through the use of emerging digital and information technology to expand external cross-border search channels, textile firms can accelerate the development of intelligence and platform, and promote the application of digital and networked emerging technologies. This study expands the research results of Luisa [15]. Textile firms should use the industrial Internet to connect customers, suppliers, universities, research institutes, and other entities, break the boundaries of time, space, and organization, facilitate knowledge search and form knowledge associations among various entities, promote the improvement of products and services, and accelerate green innovation. Through digital technology and knowledge search, innovative green textile products are cultivated, the application of digital intelligent technology is promoted, and a new development model of green innovation in textile firms is effectively formed.

CONCLUSIONS

This paper mainly examines how digital technology facilitates knowledge search and promotes green innovation in textile firms. The use of digital technology by textile firms can encourage knowledge search that promotes green innovation. Moreover, digital technology has a significant effect on both the incremental and radical green innovation of textile firms. When distinguishing various types of knowledge search and green innovation, the influence mechanism of knowledge search on the green innovation of textile firms differs. Among the differences, proactive search is conducive to radical and incremental green innovation, with a stronger effect on radical green innovation. In comparison, reactive search is conducive to incremental green innovation.

Digital technology provides advanced tools and means for firms' proactive search. Therefore, digital technology is an important way for textile firms to realize the absorption, introduction, imitation, and application of new technologies. These developments provide a vital driving force for firms to realize both incremental and radical green innovation. Digital technology can also allow textile firms to complete reactive searches, further enlarging the original technological achievements and reserve knowledge resources of firms. Thus, digital technology plays an important guiding role in the sustainable green innovation of textile firms.

Knowledge search is not only positively affected by digital technology but also significantly promotes the green innovation of textile firms, which proves the relationship between digital technology, knowledge search, and green innovation. In addition, environmental dynamism positively moderates the impact of digital technology on radical green innovation. Environmental dynamics stimulate textile firms to actively try to develop new environmentally friendly textile products in the market and improve the level of proactive and reactive search of textile firms. The use of digital technology as a crucial means and tool promotes low-carbon green innovation in textile firms. Knowledge search plays a mediating role in the relationship between digital technology and green innovation in textile firms. Moreover, knowledge search is affected by the difference in the effect of digital technology, and the mediating effect of different knowledge search types varies.

As some statistics are not available, this paper conducted a questionnaire survey on managers of textile firms, obtaining data from 226 questionnaires. However, the industry selected by the sample does not include all textile firms, so the research results may have certain limitations. Due to the dynamic and lagging nature of knowledge search and the green innovation process, it can further collect longer-term continuous data in future research. In this manner, it can longitudinally analyse the statistical data of samples to dynamically examine the mechanism of digital technology promoting green innovation by empowering textile firms' knowledge search. Although this study considers the endogeneity of the data, the research concerning pathways to enhance competitiveness is insufficient.

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Examining the nexus between cotton and kapas of MCX market on stock prices of textile industry in India using ARDL model

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ABSTRACT – REZUMAT

Examining the nexus between cotton and kapas of MCX market on stock prices of textile industry in India using ARDL model

This research study makes efforts to find the correlation between the prices of commodities in MCX and the prices of stocks by considering the textile companies and allied commodities in the commodities market. The study examined whether the price of cotton and kapas in the commodities market i.e., Multi Commodity Exchange (MCX), might have an effect on the stock prices of textile companies in India using the ARDL Model. The secondary data related to cotton and kapas prices are downloaded from the MCX website. Similarly, the data related to the closing prices of stocks of India's top five textile companies based on market capitalization, are downloaded from the website of Kotak Securities. All the ARDL models for the short run are considered as too weak as the coefficient of determination and adjusted R-squared are too low.

Keywords: *Autoregressive Distributed Lags (ARDL), MCX, textile industry, cotton, kapas*

Examinarea legăturii dintre bumbac și kapas pe piața MCX în ceea ce priveşte prețurile acţiunilor din industria textilă din India folosind modelul ARDL

Acest studiu de cercetare face eforturi pentru a găsi corelația dintre prețurile mărfurilor pe piața Multi Commodity Exchange (MCX) și prețurile acțiunilor, luând în considerare companiile textile și mărfurile conexe pe piața mărfurilor. Studiul a examinat dacă prețul bumbacului și kapas-ului pe piața mărfurilor, adică Multi Commodity Exchange (MCX), ar putea avea un efect asupra prețurilor acțiunilor companiilor textile din India care utilizează modelul ARDL. Datele secundare legate de prețurile bumbacului și kapas-ului sunt descărcate de pe site-ul MCX. În mod similar, datele referitoare la prețurile de închidere ale acțiunilor din primele cinci companii textile din India pe baza capitalizării bursiere sunt descărcate de pe site-ul web al Kotak Securities. Toate modelele ARDL pe termen scurt sunt considerate prea slabe, deoarece coeficientul de determinare și R-pătrat ajustat sunt prea reduse.

Cuvinte-cheie*: Model Autoregresiv cu Lag-uri Distribuite (ARDL), MCX, industria textilă, bumbac, kapas*

INTRODUCTION

The textile industry is extremely important to the overall structure of the Indian economy. Known for its centuries-old tradition of textile production [1, 2], India has established itself as a global powerhouse in the field. The industry encompasses a diverse range of activities [3], from the cultivation of raw materials like cotton, silk, and jute to the manufacturing of various textiles and garments [4]. It is a major source of employment, providing livelihoods to millions of workers, particularly in rural areas. Textile exports are a substantial source of revenue for the economy due to their high value on the global market [5]. The industry's strength lies in its ability to offer a wide array of fabrics, including traditional handloom and handcrafted textiles, as well as modern and technologically advanced products. Furthermore, efforts are being made to promote sustainable and eco-friendly practices in the sector, ensuring its long-term viability and global competitiveness [6–8].

The textile industry of India is mainly dependent on primary raw materials i.e., Cotton and kapas (raw cotton) [4]. As one of the largest producers of cotton globally [9, 10], India's favourable climatic conditions and vast agricultural lands make it an ideal hub for cotton cultivation [11]. The country boasts a rich variety of cotton, with different regions specializing in different types. The cultivation of kapas provides a steady supply of raw cotton for the industry [12], which is then processed into various textiles and garments. The availability of these raw materials has enabled India to establish a robust textile sector [13, 14], fuelling its growth and contributing significantly to both domestic consumption and international exports. Now it will be interesting to examine whether the prices of cotton and kapas in the commodities market affect the stock prices of textile companies [15, 16] in India. Moreover, examining such kinds of effects would also highlight the presence of a correlation between stock and commodity markets in India [17–19].

The correlation between the stock and commodity is complex and interconnected [20]. Commodities such as oil, gold, agricultural products, and metals are traded in the commodities market, while stocks represent ownership in companies and are traded in the stock market [21]. These markets are influenced by several factors, incorporating geopolitical happenings, supply and demand dynamics, global economic situations, and investor sentiment [22]. Variations in commodity values can have a profound influence on the stock market, particularly for companies involved in commodity production, transportation, or consumption. Moreover, fluctuations in stock prices can also influence commodity prices, as investor perceptions of future economic growth or recession impact demand for commodities [23]. Overall, the commodities market and stock market are closely linked [24], reflecting the intricate relationship between global trade, economic activity, and investor behaviour.

Similarly, while considering the textile industry in India, the price of cotton and kapas in the commodities market, particularly on the Multi Commodity Exchange (MCX), has a direct influence on the stock values of textile firms in India [25,26]. Cotton and kapas are the main raw materials for the textile industry, and any fluctuations in their prices can significantly influence the profitability and financial performance of textile companies. When the prices of cotton and kapas rise in the commodities market, it leads to increased input costs for textile manufacturers. This, in turn, can result in lower profit margins and reduced earnings for the companies. As a result, investors react to such developments by selling off their shares, leading to a decline in the stock values of textile firms. Conversely, if the prices of cotton and kapas fall, it benefits the textile companies as their input costs decrease. This can lead to improved profit margins and increased earnings, subsequently driving up the stock prices. Therefore, the commodities market, especially the price movements of cotton and kapas, directly influences the investment sentiment and stock performance of textile companies in India. It is also noted that the current price of both the commodities i.e., cotton and kapas might not affect the current stock price of textiles companies in India, rather it may affect the future stock price of textiles companies. In other words, the current stock price of textile companies might be affected by lagged values or prices of the commodities. Hence, the Autoregressive Distributed Lags (ARDL) model will be most suitable in examining the nexus between cotton and kapas of MCX and stock prices of textile companies of India as the ARDL model considers the lag values to capture the dynamic correlation among variables over time [27].

REVIEW OF LITERATURE

There are good numbers of literature in which discussions on the linkage between multi-commodity exchanges on stock prices have appeared [28]. Cointegration can be determined by examining the longstanding connection between the variables and the temporary stimuli using the ARDL bounds. Cointegration is observed between corn and soybean futures contracts, long-term influences on corn prices in Brazil come from exchange rates and corn traded in the United States, while oil prices have a shorter-term impact [29]. Level and non-level time series were used to conduct both the ADF test [30] and Zivot-Andrews tests [31], covering the years leading up to the 2005 liberalisation of the financial markets. Once the financial market of China opened up, the RMB's exchange rate versus the US dollar and the Hong Kong dollar began to move in tandem with the price of Chinese stocks [32]. Employing ARDL bounds testing examines linkages among the growth of the stock market, inflation, money availability and economic growth. Time series data of the Indian economy (1994–2012) were used for this purpose. Market capitalization and turnover ratio, stock market expansion and growth, price rise and turnover ratio, price rise and money supply, and market capitalization and inflation were all determined to be one-way relationships [33].

The ARDL limits test confirms the long-term cointegration of macroeconomic indicators in India. According to long-term ARDL estimations, sector-specific GDP and stock market indices are positively and strongly connected [34]. ARDL bounds testing calculations for the current and expected price of oil utilising data from 1st January 2007 to 30th April 2015 confirmed longstanding equilibrium links between the two [35]. Cointegration evidence from ARDL bound testing Bangladesh's economy grew steadily over time, with a GDP expansion of roughly 6.5%, thanks in large part to government measures for prospective stock issuance that increased the country's access to long-term finance [36]. An ARDL was used to explore the correlation of the US stock market, the worldwide commodity market and developing Islamic stock markets. The sample data comprises stock prices from 1995 to 2019, as well as commodity prices. The US stock market has no long-term relationship with Islamic Developing stock markets or global commodity markets [37].

Trading probability and stock market index are all intertwined over time, according to Bhattacharya et al. [38] analysis of the correlation among stock market activities and its endogenous liquidity factors using the ARDL Bounds Testing Approach. The long-run coefficients suggest that the explanatory factors have a long-term effect on the stock market. Market capitalization has a progressive and considerable influence on economic development over the medium and long term, estimations of ARDL.

Nepal experiences long-term economic development, stock market expansion, and regulating variables all have a solid relationship with one another [39]. The stock market, real estate sector of Vietnam and economic expansion may all be studied together using the ARDL. In Vietnam, the expansion of the real estate sector, the economy and the stock market all work together [40]. Khan et al. [41] time series data for the period of 1st January 2000 to 31st December 2018 to analyse the asymmetric influence of oil prices on stock yields on the Shanghai Stock Exchange. The estimated value of the Akaike Information Criterion is the smallest associated with other lag selection criteria; hence it is utilised for lag selection. When oil prices rise, it lowers stock yields, as shown by the asymmetric long- and short-term results we looked at, while when oil prices fall, they have an affirmative effect on stock yields [42].

Mroua and Trabelsi [43] examine the correlation between exchange rate fluctuations and BRICS stock market index volatility from 1 January 2008 to February 2018. The PMG/ARDL model found that stock market indexes' previous performances only significantly affect their present returns over the long run. All BRICS countries' short-term and long-term market index yields are heavily affected by exchange rate movements. Manogna and Mishra [44] use daily data to test the association, the ARDL bound test shows no long-term relation between the BSE FMCG index and agricultural commodities. Indian agricultural commodities markets lack data to predict stock prices. There appear to be better long-term investing prospects in the Islamic stock markets of Gulf Cooperation Council countries because they are less efficient in the short term [45, 46].

The World Bank's logistic performance index (LPI) is based on the weighted averages of six important factors, including the speed of the customs clearance process, the infrastructure's suitability for trade and transportation, the ease of shipping goods at competitive prices etc. The results show the significance of foreign direct investments and their positive correlation with the LPI over the medium and long term, which is a good sign for an economy's expansion [47]. Alshubiri [48] analyses the impact of volatile commodity prices, uncertain economic policy, and sustainable stock market sustainability on alternative investments such as gold, oil, and bitcoin, discovering favourable long-term effects on stable returns.

Garg et al. [49] examined the effects of macroeconomic factors on the commodity indices iCOMDEX composite, bullion, metal, and energy traded on MCX between January 2016 and March 2020 using the ARDL model. According to the short-run model, the wholesale price index and the index of industrial production have a positive and large impact on the iCOMDEX composite, while no macroeconomic variable has a significant short-term impact on bullion. Kumar et al. [50], Kumar et al. [51] and Meher et al. [52] examined the stock market's relationship with international gold costs, crude oil costs, and India's exchange rate. The nonlinear autoregressive distributed lag model shows that the exchange rate has a negative relationship with international gold prices in the short and long run, crude oil positively affects the stock market, and international gold prices positively affect crude oil.

Research gap

Despite the extensive research on commodity markets and stock prices, there remains a notable research gap in exploring the specific nexus between cotton and kapas (raw cotton) prices on the stock prices of textile industries in India. While many studies have examined the influence of commodity prices on stock markets, few have concentrated on the dynamic correlation between cotton and kapas prices and their effects on the Indian textile sector using the ARDL model. Investigating this relationship can provide valuable intuitions for stakeholders, investors and policymakers in the textile industry to make informed decisions and develop effective risk management strategies.

Objectives of the study

- To explore the effects of prices of cotton and kapas in the commodities market, on stock prices of textile companies in India.
- To develop a model to predict or derive stock prices of textile companies in India with the prices of cotton and kapas in MCX using the ARDL model.

RESEARCH METHODOLOGY

The analysis is analytical. The analysis is based on secondary data. For examining the nexus between Cotton and Kapas of MCX on Stock Prices of Textile Industries in India, the Autoregressive Distributed Lags model (ARDL) has been used. The secondary data related to the prices of cotton and kapas are downloaded from the MCX website. Similarly, the data related to the closing prices of stocks of India's top five textile companies based on market capitalization, are downloaded from the website of Kotak Securities. The top five companies are Page Industries with 466.23 billion Market Capitalization, KPR Mill with 198.01 billion Market Capitalization, Trident Group India – 172.66 billion Market Capitalization, Welspun India – 91.02 billion and Alok Industries – 64.3 billion. The data ranges from 1st April 2021 to 31st March 2023. For making all the data stationary, log returns have been calculated and the stationarities of all the data are examined using the Augmented Dickey-Fuller test. For examining the different formulated ARDL models which show the impact of the prices of cotton and kapas in MCX on the Stock Prices of Textile Industries in India, the values of (Akaike Information Criterion) AIC, Bayesian Information Criterion (BIC) and adjusted *R* squared of different models are compared.

Analysis of residuals will be done by checking autocorrelation, hetero-scedasticity, and normality of residuals using diagnostic tests like the Ljung-Box test, Breusch-Pagan test, and Shapiro-Wilk test, respectively. For stationarity check, formulation of ARDL Models, hypotheses testing and analysis of the residuals, EVIEWS 10 will be used.

Need of the study with managerial implications

The textile industry in India is crucial for the economy, employing millions. Understanding the relationship between cotton and kapas prices and stock prices can provide valuable insights for policymakers, industry professionals, and investors. This knowledge can guide investment decisions, portfolio diversification, and risk management strategies, ultimately improving productivity and job creation.

Limitations of the study

The study examines cotton and kapas prices in India's textile industry, ignoring related commodities and stocks and utilising the ARDL model for short-run framing.

log returns have been computed which are graphically represented in figure 1.

After converting data in the log returns of daily closing prices of selected companies, cotton and kapas depict that the data

Examining the impact of prices of kapas and cotton on the stock prices of Page Industries

Page Industries Limited is a company based in Bangalore, India, that produces and sells underwear, lingerie, and socks. It holds the Jockey International license exclusively. It began selling Speedo swimwear in India and Sri Lanka under a license from Pentland Group in 2011.

Table 1 represents the outcomes of the ARDL model which is automatically selected from the models with 12 different lags, by EVIEWS 10 software based on AIC. The automatically selected model shows nine explanatory lagged variables and a constant. Among these explanatory variables, only the 5th lag value of

ANALYSIS, RESULTS AND DISCUSSION

Considering the textile industry in India, the price of cotton and kapas in the commodities market, particularly on the Multi Commodity Exchange (MCX), might influence the stock prices of textile companies in India. But the current price of cotton and kapas in the commodities market might not be reflected in the current stock prices of textile companies, rather it may be reflected in future stock prices. In other words, the current stock prices of textile companies might be affected by the lagged values or prices of kapas and cotton. For examining such kind of relationship, the Autoregressive Distributed Lag (ARDL) model has been implemented.

The generalized Autoregressive Distributed Lag (p, q) model is stated as follows:

$$Y_t = \gamma_{0i} + \sum_{i=1}^{p} \delta_i Y_{t-i} + + \sum_{i=0}^{q} \beta'_i Y_{t-i} + \varepsilon_{it} \quad (1)$$

where Y_t is a vector and the variables in (Xt) are allowed to be purely.

To make the data related to the prices of cotton, kapas and other top 5 selected textile companies of India stationary,

Table 1

OUTCOMES OF ARDL MODEL FOR PAGE INDUSTRIES WITH 12 LAGS DYNAMIC REGRESSORS OF COTTON AND KAPAS PRICE

Dependent Variable: NLPAGE				
Method: ARDL				
Date: 07/10/23 Time: 16:06				
Sample: 4/01/2021 3/31/2023				
Included observations: 522				
Maximum dependent lags: 12 (Automatic selection)				
Model selection method: Akaike info criterion (AIC)				
Dynamic regressors (12 lags, automatic): NLCOTTON NLKAPAS				
Fixed regressors: C				
Number of models evaluated: 2028				
Selected Model: ARDL(1, 0, 6)				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob.***
NLPAGE(–1)	–0.004467	0.044035	–0.101450	0.9192
NLCOTTON	–0.020276	0.031436	–0.645002	0.5192
NLKAPAS	–0.013414	0.040284	–0.332982	0.7393
NLKAPAS(–1)	0.034275	0.040271	0.851107	0.3951
NLKAPAS(–2)	–0.015748	0.040270	–0.391064	0.6959
NLKAPAS(–3)	–0.006819	0.040277	–0.169293	0.8656
NLKAPAS(–4)	0.028060	0.040245	0.697233	0.4860
NLKAPAS(–5)	0.135301	0.040275	3.359414	0.0008
NLKAPAS(–6)	0.075215	0.040687	1.848615	0.0651
C	0.000364	0.000732	0.497509	0.6190
R-squared	0.032050	Mean dependent var		0.000428
Adjusted R-squared	0.015036	S.D. dependent var		0.016736
S.E. of regression	0.016610	Akaike info criterion		–5.338692
Sum squared resid	0.141251	Schwarz criterion		–5.257128
Log-likelihood	1403.399	Hannan-Quinn criteria.		–5.306746
F-statistic	1.883686	Durbin-Watson stat		2.001454
Prob(F-statistic)	0.052074			

Note: * p-values and any subsequent tests do not account for model selection.
Source: Computation Using EVIEWS 10.

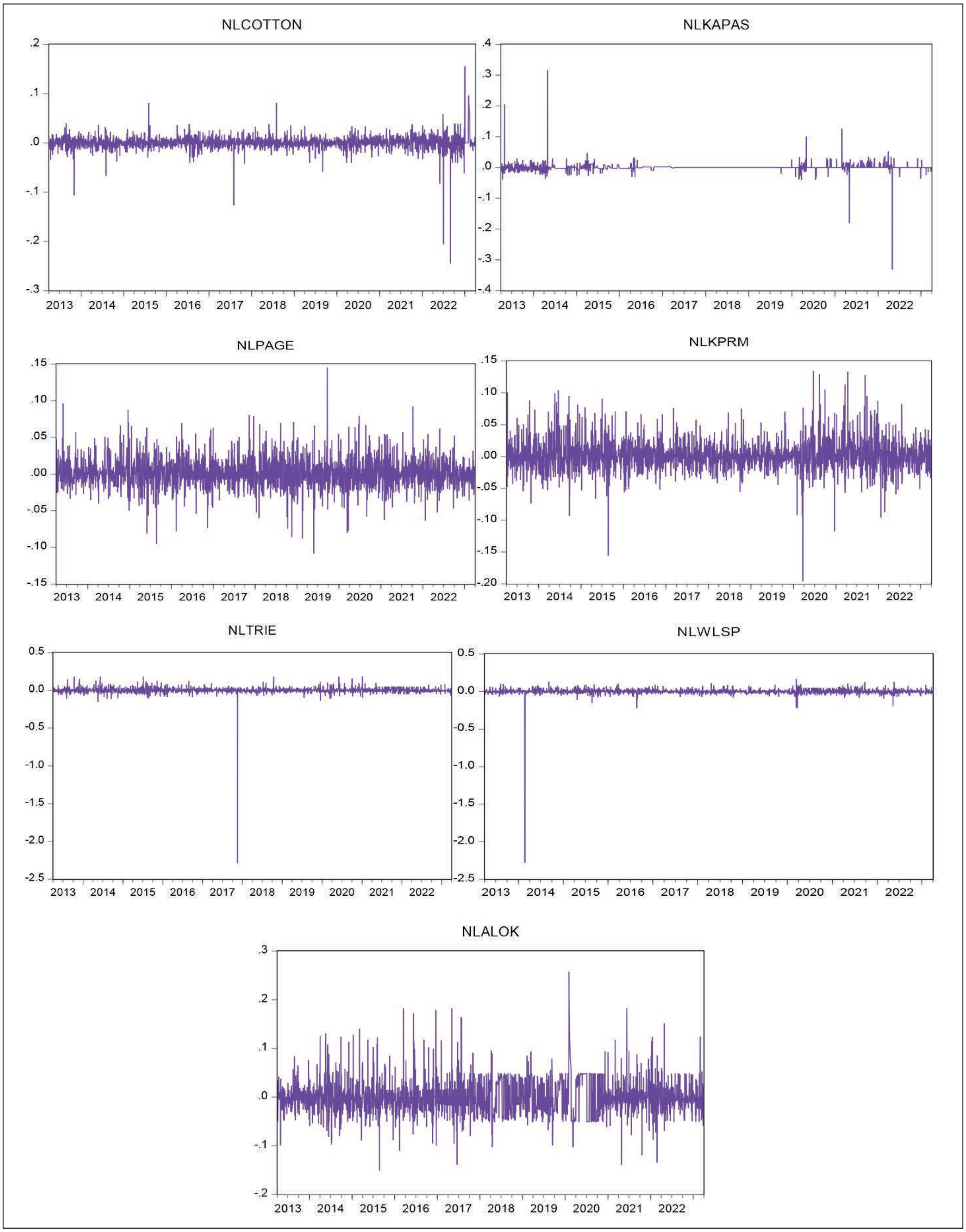

Fig. 1. Graphs of Log Returns of prices of cotton, kapas and other top 5 selected textile companies based on market capitalization

kapas seems significant as its *p* value is less than 0.05. Moreover, the *R*-squared, i.e. coefficient of determination, is 0.032 which depicts that the explanatory variables can explain 3.5% of the variation of dependent variables i.e. stock prices of Page Industries. The model is reframed by eliminating the non-significant explanatory lags. The outcomes of the reformulated model are mentioned in table 2.

Table 2 illustrates the selected model which includes the 5^{th} and 6^{th} lag of Kapas price. In other words, the current stock price of Page Industries is affected by the 5^{th} and 6^{th} lag price of Kapas. Although the coefficient of these lags is significant as the p values are less than 0.05, the *R* squared is 0.028068 which implies that the explanatory variables namely the 5th and 6th lag price of kapas can explain only hardly 3% of the variation of dependent variables i.e., stock prices of Page Industries.

Examining the impact of prices of kapas and cotton on the stock prices of KPR Mill

KPR Mill is a publicly traded, vertically integrated company that specializes in a wide range of products, including yarn, fabrics, garments, and even white crystal sugar. KPR has 40 years of experience in the textile industry, which has allowed them to leave an indelible mark on the industry. KPR Mill produces an extensive line of textile goods, including ready-to-wear garments, fabrics, and compact, melange, carded, polyester, and combed yarn, which it sells to customers all over the world.

Table 3 represents the outcomes of the ARDL model which is automatically selected from the models with 12 different lags, by EVIEWS 10 software based on AIC. The automatically selected model shows three explanatory lagged variables and a constant. Among these explanatory variables, only the present value of cotton seems significant as its *p* value is less than 0.05.

Moreover, the *R*-squared, i.e., coefficient of determination, is 0.0107 which depicts that the explanatory variables can explain only 1.1% of the variation of dependent variables i.e., stock prices of KPR Mill. The model is reframed by eliminating the non-significant explanatory lags. The outcomes of the reformulated model are mentioned in table 4.

Table 4 shows the selected model which includes only the current price of cotton. In other words, the current stock price of KPR Mill is affected by the current price of cotton. Although the coefficient of these lags is significant as the *p* values are less than 0.05, the *R* squared is 0.00355 which implies that the

Table 2

OUTCOMES OF ARDL MODEL FOR PAGE INDUSTRIES WITH SIGNIFICANT LAGS OF COTTON AND KAPAS PRICE

Dependent Variable: NLPAGE
Method: Least Squares
Date: 07/11/23 Time: 16:59
Sample: 4/01/2021 3/31/2023
Included observations: 522

Variable	Coefficient	Standard Error	t-Statistic	Prob.*
NLKAPAS(–6)	0.073396	0.039957	2.076885	0.0468
NLKAPAS(–5)	0.137804	0.039960	3.448599	0.0006
R-squared	0.028068	Mean dependent var		0.000428
Adjusted R-squared	0.026199	S.D. dependent var		0.016736
S.E. of regression	0.016515	Akaike info criterion		–5.365238
Sum squared resid	0.141832	Schwarz criterion		–5.348925
Log-likelihood	1402.327	Hannan-Quinn criteria.		–5.358848
Durbin-Watson stat	2.014877			

Note: * p-values and any subsequent tests do not account for model selection.
Source: Computation Using EVIEWS 10.

Table 3

OUTCOMES OF ARDL MODEL FOR KPR MILL WITH 12 LAGS DYNAMIC REGRESSORS OF COTTON AND KAPAS PRICE

Dependent Variable: NLKPRM
Method: ARDL
Date: 07/10/23 Time: 16:18
Sample: 4/01/2021 3/31/2023
Included observations: 522
Maximum dependent lags: 12 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (12 lags, automatic): NLCOTTON NLKAPAS
Fixed regressors: C
Number of models evaluated: 2028
Selected Model: ARDL(1, 0, 0)

Variable	Coefficient	Standard Error	t-Statistic	Prob.*
NLKPRM(–1)	0.036195	0.043832	0.825767	0.4093
NLCOTTON	0.096130	0.046708	2.058128	0.0401
NLKAPAS	–0.050916	0.060038	–0.848071	0.3968
C	0.001667	0.001090	1.529615	0.1267
R-squared	0.010791	Mean dependent var		0.001910
Adjusted R-squared	0.005062	S.D. dependent var		0.024793
S.E. of regression	0.024731	Akaike info criterion		–4.553922
Sum squared resid	0.316809	Schwarz criterion		–4.521297
Log-likelihood	1192.574	Hannan-Quinn criteria.		–4.541144
F-statistic	1.883643	Durbin-Watson stat		2.001095
Prob(F-statistic)	0.131308			

Note: * p-values and any subsequent tests do not account for model selection.
Source: Computation Using EVIEWS 10.

Table 4

OUTCOMES OF ARDL MODEL FOR PAGE INDUSTRIES WITH SIGNIFICANT LAGS OF COTTON AND KAPAS PRICE AS REGRESSOR				
Dependent Variable: NLKPRM				
Method: Least Squares				
Date: 07/12/23 Time: 16:41				
Sample: 4/01/2021 3/31/2023				
Included observations: 522				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob.***
NLCOTTON	0.103701	0.046533	2.228545	0.0263
R-squared	0.003552	Mean dependent var		0.001910
Adjusted R-squared	0.003552	S.D. dependent var		0.024793
S.E. of regression	0.024749	Akaike info criterion		–4.558125
Sum squared resid	0.319127	Schwarz criterion		–4.549968
Log-likelihood	1190.671	Hannan-Quinn criteria.		–4.554930
Durbin-Watson stat	1.928252			

Table 5

OUTCOMES OF ARDL MODEL FOR TRIDENT GROUP WITH 12 LAGS DYNAMIC REGRESSORS OF COTTON AND KAPAS PRICE				
Dependent Variable: NLTRIE				
Method: ARDL				
Date: 07/10/23 Time: 16:36				
Sample: 4/01/2021 3/31/2023				
Included observations: 522				
Maximum dependent lags: 12 (Automatic selection)				
Model selection method: Akaike info criterion (AIC)				
Dynamic regressors (12 lags, automatic): NLCOTTON NLKAPAS				
Fixed regressors: C				
Number of models evaluated: 2028				
Selected Model: ARDL(3, 2, 11)				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob.***
NLTRIE(–1)	0.219605	0.044075	4.982520	0.0000
NLTRIE(–2)	–0.076934	0.044955	–1.711341	0.0876
NLTRIE(–3)	0.064305	0.044129	1.457196	0.1457
NLCOTTON	0.025566	0.050704	0.504217	0.6143
NLCOTTON(–1)	0.052722	0.051528	1.023177	0.3067
NLCOTTON(–2)	–0.118903	0.050640	–2.348021	0.0193
NLKAPAS	0.027925	0.063372	0.440654	0.6597
NLKAPAS(–1)	0.084957	0.063358	1.340902	0.1806
NLKAPAS(–2)	0.021714	0.063444	0.342251	0.7323
NLKAPAS(–3)	–0.040279	0.063460	–0.634716	0.5259
NLKAPAS(–4)	–0.082341	0.063486	–1.296999	0.1952
NLKAPAS(–5)	–0.013333	0.063372	–0.210395	0.8334
NLKAPAS(–6)	–0.130696	0.063304	–2.064565	0.0395
NLKAPAS(–7)	0.203872	0.063612	3.204908	0.0014
NLKAPAS(–8)	0.090900	0.064075	1.418657	0.1566
NLKAPAS(–9)	0.005558	0.064183	0.086604	0.9310
NLKAPAS(–10)	0.013412	0.063870	0.209981	0.8338
NLKAPAS(–11)	–0.166695	0.063577	–2.621913	0.0090
C	0.001138	0.001157	0.983776	0.3257
R-squared	0.105075	Mean dependent var		0.001318
Adjusted R-squared	0.073050	S.D. dependent var		0.027062
S.E. of regression	0.026055	Akaike info criterion		–4.421522
Sum squared resid	0.341459	Schwarz criterion		–4.266549
Log-likelihood	1173.017	Hannan-Quinn criteria.		–4.360823
F-statistic	3.281015	Durbin-Watson stat		1.989124
Prob(F-statistic)	0.000007			

Note: * p-values and any subsequent tests do not account for model selection.
Source: Computation Using EVIEWS 10.

explanatory variable i.e., the current price of cotton can explain only hardly 0.4% of the variation of dependent variables i.e., stock prices of KPR Mill.

Examining the impact of prices of kapas and cotton on the stock prices of Trident Group India

The Trident Group of Companies manufactures home textile products, paper products, chemicals, and yarn solutions, and is one of India's leading global textile fabric conglomerates. There is no competition for Trident Group on a global scale. Trident, based in the Indian city of Ludhiana, Punjab, produces more terry towels and paper made from wheat straw than any other company in the world.

Table 5 represents the outcomes of the ARDL model which is automatically selected from the models with 12 different lags, by EVIEWS 10 software based on AIC. The automatically selected model shows three explanatory lagged variables and a constant. Among these explanatory variables, only the present value of cotton seems significant as its *p* value is less than 0.05. Moreover, the *R*-squared, i.e. coefficient of determination, is 0.1050 which depicts that the explanatory variables can explain 10.5% of the variation of dependent variables i.e. stock prices of Trident Group India. The model is reframed by eliminating the non-significant explanatory lags. The outcomes of the reformulated model are mentioned in table 6.

Table 6 shows the selected model which includes the 2nd lag of cotton price and the 6th, 7th and 11th lag of kapas price. In other words, the current stock price of Trident Group India is affected by the 2nd lag of cotton price and the 6th, 7th and 11th lag of kapas price.

Although the coefficient of these lags is significant as the *p* values are less than 0.05, the *R* squared is 0.034056 which implies that the explanatory variables namely the 2nd lag of cotton price and 6th, 7th and 11th lag of kapas price can explain only 3.5% of the variation of dependent variables i.e., stock prices of Trident Group India.

Examining the impact of prices of kapas and cotton on the stock prices of Welspun India

One of India's most dynamic and rapidly expanding multinational corporations, Welspun Group operates in the line pipe, home textile product, infrastructure, warehousing, steel, oil and gas, advanced textile, and flooring solution industries.

Table 7 represents the results of the ARDL model which is automatically selected from the models with 12 different lags, by EVIEWS 10 software based on AIC. The automatically selected model shows three explanatory lagged variables and a constant. Among these explanatory variables, only the present value of cotton seems significant as its *p* value is less than 0.05. Moreover, the *R*-squared, i.e. coefficient of determination, is 0.120415 which depicts that the explanatory variables can explain only 12.05% of the variation of dependent variables i.e. stock prices of Welspun India Ltd. The model is reframed by eliminating the non-significant explanatory lags. The outcomes of the reformulated model are mentioned in table 8.

Table 8 shows the selected model which includes the 2nd lag of the stock price of Welspun India Ltd., the 7th, 8th and 11th lag of the kapas price. In other words, the current stock price of Welspun India Ltd is affected by the 2nd lag of the stock price of Welspun

Table 6

OUTCOMES OF ARDL MODEL FOR TRIDENT GROUP INDIA WITH SIGNIFICANT LAGS OF COTTON AND KAPAS PRICE AS REGRESSOR

Dependent Variable: NLTRIE
Method: Least Squares
Date: 07/14/23 Time: 16:48
Sample: 4/01/2021 3/31/2023
Included observations: 522

Variable	Coefficient	Standard Error	t-Statistic	Prob.*
NLCOTTON(–2)	–0.083819	0.050137	–2.011792	0.0452
NLKAPAS(–6)	–0.130904	0.064561	–2.027611	0.0431
NLKAPAS(–7)	0.174189	0.064580	2.697263	0.0072
NLKAPAS(–11)	–0.153567	0.064546	–2.379168	0.0177
R-squared	0.034056	Mean dependent var		0.001318
Adjusted R-squared	0.028462	S.D. dependent var		0.027062
S.E. of regression	0.026674	Akaike info criterion		–4.402627
Sum squared resid	0.368556	Schwarz criterion		–4.370001
Log-likelihood	1153.086	Hannan-Quinn criteria.		–4.389848
Durbin-Watson stat	1.569976			

Table 7

OUTCOMES OF ARDL MODEL FOR KPR MILL WITH 12 LAGS DYNAMIC REGRESSORS OF COTTON AND KAPAS PRICE

Dependent Variable: NLWLSP
Method: ARDL
Date: 07/10/23 Time: 16:38
Sample: 4/01/2021 3/31/2023
Included observations: 522
Maximum dependent lags: 12 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (12 lags, automatic): NLCOTTON NLKAPAS
Fixed regressors: C
Number of models evaluated: 2028
Selected Model: ARDL(2, 0, 11)

Variable	Coefficient	Standard Error	t-Statistic	Prob.*
NLWLSP(–1)	0.037446	0.044158	0.848017	0.3968
NLWLSP(–2)	–0.099855	0.044087	–2.264969	0.0239
NLCOTTON	0.037135	0.050533	0.734869	0.4628
NLKAPAS	–0.073172	0.064908	–1.127321	0.2601
NLKAPAS(–1)	–0.023727	0.064924	–0.365449	0.7149
NLKAPAS(–2)	–0.010497	0.064699	–0.162242	0.8712
NLKAPAS(–3)	0.012731	0.064682	0.196821	0.8440
NLKAPAS(–4)	–0.080903	0.064601	–1.252358	0.2110
NLKAPAS(–5)	0.005476	0.064588	0.084780	0.9325
NLKAPAS(–6)	0.026202	0.064576	0.405753	0.6851
NLKAPAS(–7)	0.413895	0.064592	6.407790	0.0000
NLKAPAS(–8)	–0.214715	0.067087	–3.200556	0.0015
NLKAPAS(–9)	–0.055670	0.067651	–0.822903	0.4110
NLKAPAS(–10)	0.074199	0.065294	1.136378	0.2563
NLKAPAS(–11)	–0.152102	0.064860	–2.345099	0.0194
C	–0.000534	0.001175	–0.454670	0.6495
R-squared	0.120415	Mean dependent var		–0.000458
Adjusted R-squared	0.094340	S.D. dependent var		0.027960
S.E. of regression	0.026608	Akaike info criterion		–4.385002
Sum squared resid	0.358254	Schwarz criterion		–4.254499
Log-likelihood	1160.485	Hannan-Quinn criteria.		–4.333887
F-statistic	4.618085	Durbin-Watson stat		1.977661
Prob(F-statistic)	0.000000			

Note: * p-values and any subsequent tests do not account for model selection.
Source: Computation Using EVIEWS 10.

Table 8

OUTCOMES OF ARDL MODEL FOR WELSPUN INDIA LTD. INDIA WITH SIGNIFICANT LAGS OF COTTON AND KAPAS PRICE AS REGRESSOR				
Dependent Variable: NLWLSP				
Method: Least Squares				
Date: 07/14/23 Time: 17:03				
Sample: 4/01/2021 3/31/2023				
Included observations: 522				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob.***
NLWLSP(–2)	–0.113765	0.041505	–2.740972	0.0063
NLKAPAS(–7)	0.417806	0.064051	6.523069	0.0000
NLKAPAS(–8)	–0.201239	0.064055	–3.141662	0.0018
NLKAPAS(–11)	–0.144501	0.064142	–2.252831	0.0247
R-squared	0.109133	Mean dependent var		–0.000458
Adjusted R-squared	0.103974	S.D. dependent var		0.027960
S.E. of regression	0.026467	Akaike info criterion		–4.418234
Sum squared resid	0.362849	Schwarz criterion		–4.385608
Log-likelihood	1157.159	Hannan-Quinn criteria.		–4.405455
Durbin-Watson stat	1.908473			

Source: Computation Using EVIEWS 10.

Table 9

OUTCOMES OF ARDL MODEL FOR ALOK INDUSTRIES LTD. WITH 12 LAGS DYNAMIC REGRESSORS OF COTTON AND KAPAS PRICE				
Dependent Variable: NLALOK				
Method: ARDL				
Date: 07/10/23 Time: 16:39				
Sample: 4/01/2021 3/31/2023				
Included observations: 522				
Maximum dependent lags: 12 (Automatic selection)				
Model selection method: Akaike info criterion (AIC)				
Dynamic regressors (12 lags, automatic): NLCOTTON NLKAPAS				
Fixed regressors: C				
Number of models evaluated: 2028				
Selected Model: ARDL(1, 0, 0)				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob.***
NLALOK(–1)	0.058107	0.043797	1.326740	0.1852
NLCOTTON	0.040933	0.060447	0.677174	0.4986
NLKAPAS	0.099627	0.077572	1.284319	0.1996
C	–0.001121	0.001408	–0.796219	0.4263
R-squared	0.007500	Mean dependent var		–0.001058
Adjusted R-squared	0.001752	S.D. dependent var		0.032051
S.E. of regression	0.032023	Akaike info criterion		–4.037070
Sum squared resid	0.531206	Schwarz criterion		–4.004444
Log-likelihood	1057.675	Hannan-Quinn criteria.		–4.024291
F-statistic	1.304805	Durbin-Watson stat		1.995383
Prob(F-statistic)	0.272079			

Note: * p-values and any subsequent tests do not account for model selection.
Source: Computation Using EVIEWS 10.

India Ltd., 7th, 8th and 11th lag of the kapas price. Moreover, the coefficient of these lags is significant as the *p* values are less than 0.05, and the *R* squared is 0.109133 which implies that the selected explanatory variables can explain only 11% of the variation of dependent variables i.e., stock prices of Welspun India Ltd.

Examining the impact of prices of kapas and cotton on the stock prices of Alok Industries

Table 9 represents the results of the ARDL model which is automatically selected from the models with 12 different lags, by EVIEWS 10 software based on AIC. The automatically selected model shows three explanatory lagged variables and a constant. Among these explanatory variables, only the present value of cotton seems significant as its *p* value is less than 0.05.

Moreover, the *R*-squared, i.e., coefficient of determination, is 0.0075 which depicts that the explanatory variables can hardly explain only 0.7% of the variation of dependent variables i.e., stock prices of Alok Industries. The model cannot be reframed as none of the lags is statistically significant.

After framing the ARDL models with significant lags, it is essential to examine the existence of a long-run correlation between the stock prices of textile companies and the prices of major raw materials i.e., cotton and kapas. For this long run form and bound test has been applied. The outcomes of the bound test are mentioned in table 10.

Table 10 depicts that the value of F-statistics in a bound test of all the selected textile companies is more than the upper bound of a 5% level of significance. Henceforth, stock prices of selected textile companies

Table 10

OUTCOMES OF LONG-RUN FORM AND BOUND TEST				
F-Bounds Test		**Null Hypothesis: No levels of relationship**		
Stock prices of Page Industries, prices of cotton and kapas				
Test Statistic	**Value**	**Significance**	**I(0)**	**I(1)**
			Asymptotic: n=1000	
F-statistic	130.7683	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5
Stock prices of KPR Mill, prices of cotton and kapas				
Test Statistic	**Value**	**Significance**	**I(0)**	**I(1)**
			Asymptotic: n=1000	
F-statistic	122.6567	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5
Stock prices of Trident Group India, prices of cotton and kapas				
Test Statistic	**Value**	**Significance**	**I(0)**	**I(1)**
			Asymptotic: n=1000	
F-statistic	35.29554	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5
Stock prices of Welspun India, prices of cotton and kapas				
Test Statistic	**Value**	**Significance**	**I(0)**	**I(1)**
			Asymptotic: n=1000	
F-statistic	74.96433	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5
Stock prices of Alok Industries, prices of cotton and kapas				
Test Statistic	**Value**	**Significance**	**I(0)**	**I(1)**
			Asymptotic: n=1000	
F-statistic	116.0406	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5

Source: Computation Using EVIEWS 10.

are correlated with the lag price of cotton and kapas in the long run.

CONCLUSION

From the above analysis and results it can be witnessed that the stock prices of Page Industries are affected by lags of kapas only but the model seems weak as the *R*-squared is 0.0280 in the short-run. Similarly, the stock price of KPR Mill is affected only by the current price of cotton, the stock price of Trident Group is affected by the 2^{nd} lag of cotton, 6^{th}, 7^{th} and 11^{th} lag of kapas, with 0.034 R-squared and the stock price of Welspun India Ltd. is affected by 2^{nd} lag of Welspun India's stock price itself, 7^{th}, 8^{th} and 11^{th} kapas price with 0.11 *R*-squared in short-run. While considering the results of the ARDL model the model for Alok Industries cannot be reframed due to the absence of significant lags. All the ARDL models for the short run are considered as too weak as the coefficient of determination and adjusted *R*-squared are too low. On the other hand, while testing the data with long-run form and bound test (mentioned in table 10) of all the stock prices of selected textile companies, closing prices of cotton and kapas in the commodities market seems correlated but weak.

In the short run, stock prices of textile companies may be influenced by a wide range of factors such as quarterly earnings reports, company news, market sentiment, and short-term fluctuations in the overall stock market. Instead, the prices of cotton and kapas in the commodities market are driven by immediate supply and demand factors, weather conditions, geopolitical events, and changes in the global economy. These short-term factors might not always align perfectly with the performance of textile companies, leading to a weaker correlation between stock prices and commodity prices over shorter periods.

Additionally, stock prices can be influenced by market speculation and short-term trading activities, which can cause volatility and create divergence from underlying commodity prices.

Similarly, in the long run, the performance of textile companies is more likely to be influenced by the cost of their primary raw material, which is cotton in this case. As the textile industry heavily relies on cotton or kapas as a key input, changes in the cost of this raw material can significantly impact the profitability and overall performance of textile companies. Over time, the supply and demand dynamics for cotton and kapas tend to have a more pronounced effect on their prices, which then affects the profit margins and financial health of textile companies. As a result, in the long run, the correlation between stock prices of textile companies and cotton/kapas prices becomes more apparent and robust. It's essential to remember that correlations can change over time and might not always be stable due to varying market conditions, industry trends, and external events. Investors and analysts should consider multiple factors and conduct in-depth research to understand the relationships between different assets and industries accurately.

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Application of negative wound pressure therapy to skin grafts after coverage of uncertain granular sites: a case series

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ABSTRACT – REZUMAT

Application of negative wound pressure therapy to skin grafts after coverage of uncertain granular sites: a case series

The split thickness skin graft (STSG) is one of the most popular tools used in reconstructive surgery. Developed for the first time by Olier in 1872, with perpetually improving techniques, this graft has since facilitated the reconstruction of skin defects. Negative wound pressure therapy (NPWT) is a therapeutic procedure that has been widely used for decades; it stabilizes the wound environment, improves tissue perfusion by stimulating granulation and angiogenesis, and reduces bacterial load and, consequently, wound edema. This case series of 3 patients aimed to show the advantages of applying NPWT over STSGs after the coverage of uncertain granular sites. The intake rate was 95% on average, with rapid wound healing, no hematoma formation, no need for regrafting, and no pain or signs of infection.

Keywords: *split thickness skin graft, negative wound pressure therapy, uncertain granular sites*

Aplicarea terapiei cu presiune negativă a plăgii pe grefe de piele după acoperirea zonelor granulare incerte: studiu de caz

Grefa de piele cu grosime parţială (STSG) este unul dintre cele mai populare instrumente utilizate în chirurgia reconstructivă. Dezvoltată pentru prima dată de Olier în 1872 şi îmbunătăţită în mod continuu, această grefă a facilitat de atunci reconstrucția defectelor pielii. Terapia cu presiune negativă a plăgii (NPWT) este o tehnică terapeutică utilizată pe scară largă de zeci de ani, care stabilizează mediul plăgii, îmbunătățește perfuzia tisulară prin stimularea granulaţiei și a angiogenezei și reduce încărcătura bacteriană și, în consecință, edemul plăgii. Aceast studiu de caz realizat pe 3 pacienți și-a propus să demonstreze avantajele aplicării NPWT față de STSG, după acoperirea zonelor granulare incerte. Rata de admisie medie a fost de 95%, cu vindecare rapidă a rănilor, fără formare de hematom, fără necesitatea de regrefare și fără durere sau semne de infecție.

Cuvinte-cheie*: grefă de piele cu grosime parţială, terapie cu presiune negativă a plăgii, zone granulare incerte*

INTRODUCTION

Skin grafting is an indispensable procedure in reconstructive surgery that is used in the surgical treatment of traumatic and burn defects, oncologic resections, diabetic foot ulcers, chronic venous leg ulcers, release of skin contracture and pressure sores [1].

The procedure of skin grafting involves transferring free tissues that are nonvascularized with different thicknesses from a donor site to a remote recipient site anywhere else in the body [2]. Grafts can be classified according to their thickness or their host-donor relationship. The most popular type of graft used in practice is the autogenous graft, which is harvested from the same person who receives it. Skin grafts can be either split or full-thickness, each of which has its advantages and disadvantages. Split-thickness grafts usually require expensive equipment and are less aesthetic but have better take-in rates than full-thickness grafts [3].

There are several factors on which graft survival depends, including the patient's general status, bed quality and healing environment [4].

The patient's status, including hematological parameters (hemoglobin, thrombocytes), albumin and total protein concentrations and inflammatory parameters, is generally very important and needs to be optimized before surgery [5]. The bed quality and healing environment directly affect the graft intake rate since the graft does not have its blood supply. The survival of the grafts consists of the following 3 common steps: imbibition, inosculation [6, 7] and revascularization. The most critical phase is the revascularization step, which can be influenced by many factors [8]. The most common causes of STSG loss are hematoma or seroma formation underneath, friction/shear forces between the bed and the graft, malpositioning of the graft and infection.

Currently, there are no methods that can ensure a successful graft intake rate of 100%. Conventionally, STSGs are covered with dressings [9], that maintain moisture balance and are nonadherent, with or without a tie-over dressing. Nevertheless, in the last decade, the technique of negative pressure wound therapy (NPWT) using reticulated open cell foam has gained more popularity in this area [10].

The main aim of this research was to assess the positive impact of negative wound pressure therapy on skin grafts made from textile material after coverage of uncertain granular sites.

MATERIALS AND METHODS

In addition to vacuum-assisted wound closure, negative pressure wound therapy using reticulated open-cell foam (NPWT/ROCF) is a technique that consists of a versatile closed sealed system that applies continuous or discontinuous underatmospheric pressure through a reticulated open cell foam over a surface. NPWT/ROCF can be used to manage different types of acute or chronic open wounds, but in more recent years, it has also been adapted for closed wounds, such as skin grafts or closed surgical incisions [11].

NPWT aims to stabilize the wound environment, improve tissue perfusion by stimulating granulation and angiogenesis, reduce the bacterial load and consequently wound edema, prevent surgical dehiscence and reduce the risk of seroma or hematoma formation [12, 13].

Considering that there are now lighter, disposable NPWT systems, such as the KCL V.A.C. therapy system, an important advantage of using them over grafts is earlier postoperative patient discharge, shorter hospital stays and lower expenses [13–15].

Based on the scientific design, a multidisciplinary team of specialists within the INCDTP developed a biomaterial with elastomeric yarn (with longitudinal direction elasticity and physicomechanical characteristics – table 1) that responds to the following requirements imposed by its usage in the clinical field (postsurgical recovery): nonirritant surface in contact with the skin; comfort – lack of coarse material seams and joints; tolerance at human body contact; malleability – adaptability; resistance to chemical and thermal agents; and reusability (table 2). The main purpose of noninvasive medical devices with an elastopsis is to ensure external and controllable pressure against the application location of the body.

Table 1

THE PHYSICOMECHANICAL CHARACTERISTICS OF THE TEXTILE YARNS

Characteristic		Cotton yarn	Elastomer yarn
Length density	dtex	24	No. 32/36
	Nm	1/4	
Breakage load (gf)		867.2	958.3
Break elongation (%)		12.1	785
Twist (t/m)		250	-

Table 2

THE SPECIFIC TECHNICOFUNCTIONAL REQUIREMENTS OF THE TEXTILE MATERIAL

Characteristic	The usage domain symbol		
	RPO	TRL	TAC
Elasticity	very good	very good	very good
Compactness	very small	very large	very large
Handle	very soft	soft	soft
Compression capacity	very good	very good	very good
Permeability to			
– liquids	very good	good	good
– vapours	good	good	good
– perspiration	good	good	good
– air	very good	very good	very good

Note: RPO – postsurgical recovery; TRL – treatment and recovery of the locomotor, muscular and bone systems; TAC – circular system treating and recovering.

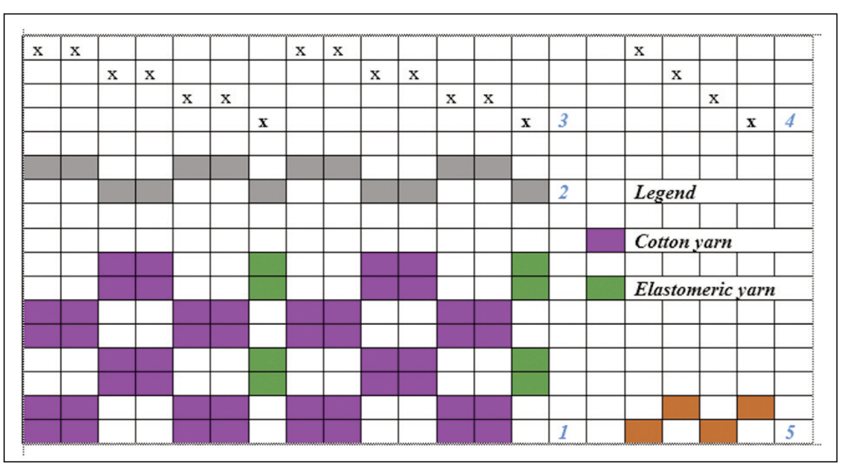


Fig. 1. The programming scheme of the textile structure: 1 – pattern (with yarn symbolizing on shedding); 2 – drawing in reed; 3 – drawing in the leaves; 4 – leaves (hardness) piecing; 5 – cams

The programming scheme of the textile structure used for this application is presented in figure 1.

This research was focused on the complex and complete design of the woven fabric and was conducted on technological lines, including specific laboratory pieces of equipment and machinery. This type of material bears upkeeping treatments, which can be performed through successive washing, drying, and autoclaving cycles. Its technical, biofunctional and biomedical characteristics are suitable for foreseen application and fulfil the requirements imposed by the legislation in force for this category of medical devices.

RESULTS AND DISCUSSION

Patient 1

A 70-year-old male was referred to our clinic because of an extended cutaneous defect of the abdomen after eventration. The patient had undergone open cholecystectomy 11 months prior and experienced postoperative complications such as eventration and skin necrosis 10 months later. The abdominal wall was covered with Prolene mesh, followed by a necrectomy, after which the defect in the abdominal wall was extended (figure 2, *a*).

The patient was known to have multiple pathologies, such as arterial hypertension, class II NYHA heart failure, aortic insufficiency, tricuspid insufficiency, atherosclerosis, anemia, undergoing was receiving treatment for all of the above conditions. On admission to our clinic, his blood analysis revealed moderate microcytic anemia (*Hb* = 9.8 g/dl, *MCV* = 69.6 fl) and a normal serum ALB concentration (3.7 g/dl).

The defect was covered with NPWT/ROCf for 5 weeks and was changed every 7 days before the patient was admitted to our clinic. The hospitalization time was 2 nights. The surgery was performed under general anesthesia; the wound was degranulated and covered with an STSG harvested from the anterolateral side of the left thigh. A few staples were affixed to the graft margins, and NPWT was applied (50 mmHg). The patient was discharged the next day after surgery, with no local or general immediate postoperative complications. The NPWT was continued for 5 days and then stopped (figure 2, *b*). He achieved 98% integration of the graft, with good epithelization and no further complications (figure 2, *c* and *d*).

Patient 2

A 46-year-old female presented to the emergency department (ER) for distal 1/3 left calf fasciitis (figure 3, *a*) after local trauma that had occurred 6 weeks prior. The patient had neglected the local wound and was highly uncooperative in the ER.

The patient was known to have untreated type 2 diabetes mellitus, Cluster A personality disorder and poor personal hygiene. On admission to our clinic, blood analysis revealed severe leukocytosis (39000/ml), thrombocytosis (778000/ml), hypoalbuminaemia (3.3 g/dl), hyponatremia (128 mmol/l), severe hyperglycaemia (553 mg/dl) and coagulopathy (*PT* = 17.3 sec, *INR* = 1.46).

The patient underwent multiple surgical interventions in which the infected tissues were removed, resulting in a large cutaneous defect on the antero-lateral side of the left calf and the dorsal forefoot (figure 3, *b*). The defect was covered with NPWT/ROCf at 75 mmHg for 3 weeks, which was changed every 4–5 days. Immediately before STSG coverage, blood analysis revealed that the patient's leukocyte count was normal, and mild anemia (*Hb* = 10.6 g/dl), thrombocytosis (590.000/ml), hypoalbuminaemia (3.3 g/dl), and hyperglycemia (210 mg/dl) were detected.

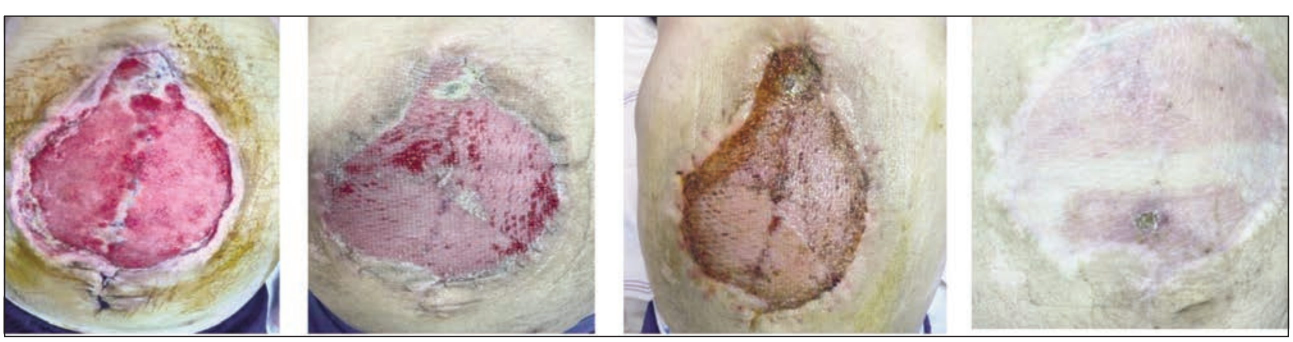
Considering the improvement in the patient's general status and local wound site and her good blood analysis results, she was treated by surgery in which the defect was covered with an STSG harvested from the anterolateral side of her right thigh (figure 3, *c*) and on which NPWT was applied with a pressure of 50 mmHg. The NPWT was removed after 5 days. The graft had a 95% integration rate (figure 3, *d*) and good epithelization, especially at uncertain granular sites.

The patient was discharged after another 5 days. This long hospitalization period was due to the septic pathology, the need for multiple operations and, moreover, her difficult compliance.

The staples and sutures were removed after 21 days, and the local evolution was favourable with no further local or general complications (figure 3, *e*).

Patient 3

A 21-year-old female who was a victim of a car crash presented with polytrauma in the ER, hemorrhagic shock, dissection of the aorta at the emergence of the iliac artery, haemodynamic instability, severe craniocerebral trauma, severe vertebral trauma (L3 fracture), severe pulmonary contusions, urinary bladder and vaginal rupture, severe pelvic trauma with extended abdominal wall ischemia and quasiamputation of the tongue. The patient had an unfavourable



a *b* *c* *d*

Fig. 2. Stages of wound healing – Patient 1

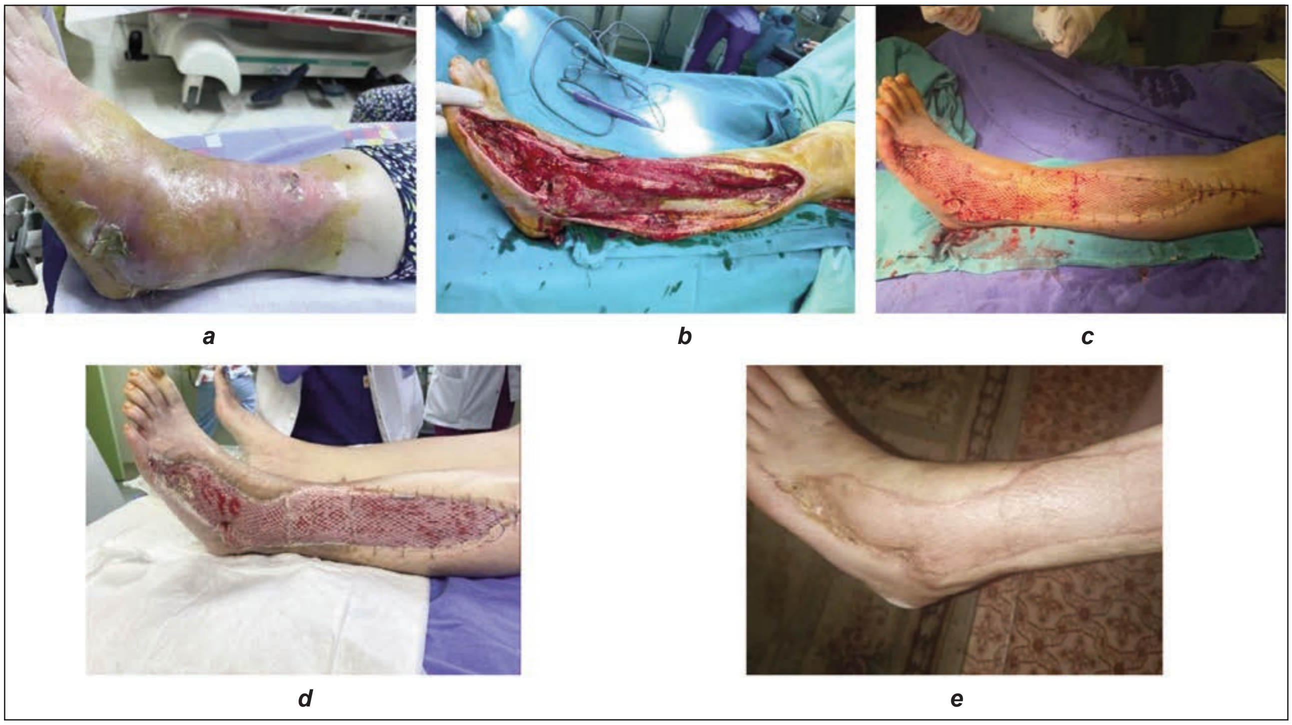


Fig. 3. Stages of wound healing – Patient 2

evolution and underwent multiple surgeries, including ileostomy (due to bowel necrosis), an amputated left lower limb (middle third level) and vertebral osteosynthesis (L3).

The area of extended abdominal wall ischemia became necrotic, and the patient developed a large abdominal defect (figure 4, *a*). The necrotic tissue was excised and debrided, and the defect was covered with NPWT/ROCf at 50 mmHg pressure for 3 weeks, which was subsequently changed every 5 days (figure 4, *b*).

After 3 weeks, the wound was clean and granulated, with no local inflammation or pathological secretions (figure 4, *c*). Blood analysis revealed moderate normocytic anemia (*Hb* = 9.81 g/dl), mild leukocytosis (10000/ml) and normal albuminemia (4.13 g/dl). Consequently, the defect was covered with an STSG harvested from the anterolateral side of the patient's

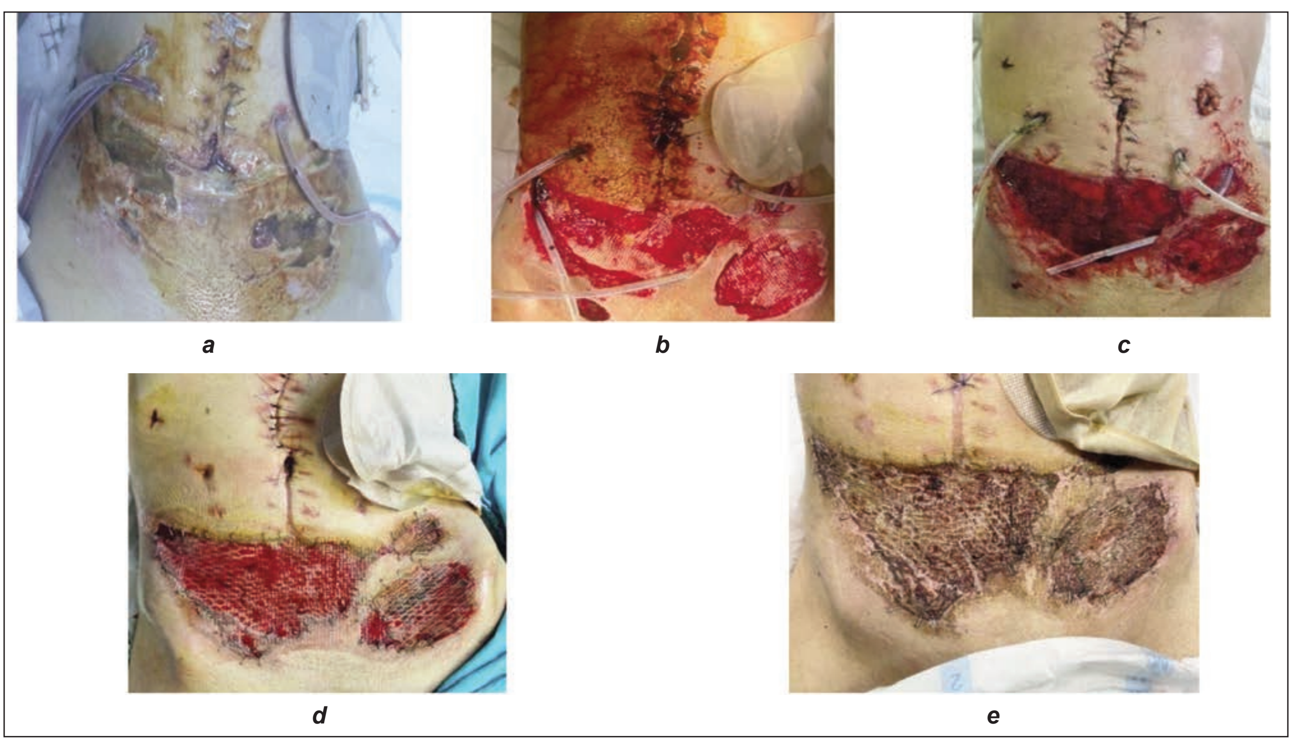


Fig. 4. Stages of wound healing – Patient 3

right thigh on which NPWT was applied with 50 mmHg pressure. The NPWT was removed after 7 days. The graft had a 98% integration rate and good epithelization with local complications (figure 4, *d*).

Even though the patient had multiple comorbidities due to the polytrauma she endured, the local abdominal evolution was favourable, with good results 3 weeks after surgery when the staples were removed (figure 4, *e*).

The intake rate was approximately 95–100 %, with rapid wound healing, no hematoma formation, no need for regeneration, and no pain or signs of infection.

CONCLUSION

The use of NPWT over STSGs after covering uncertain granular sites in patients with multiple pathologies resulted in uniform graft adherence, most likely due to improved inosculation, no hematoma or seroma formation, no need for regrafting, early ambulation of the patients due to the stabilizing effect of NPWT with shorter hospital stays and therefore lower expenses. Nevertheless, it is important to consider specific characteristics, such as the extent of the wound, the presence of infection, the amount of exudate and, most importantly, the patient's compliance, before applying NPWT. In our opinion, NPWT/ROCF can be considered a first-line pre- and postoperative therapy for STSGs.

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