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Structural and mechanical behaviour of glass fibre reinforced polyester composites

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ABSTRACT – REZUMAT

Structural and mechanical behaviour of glass fibre reinforced polyester composites

In this research, an investigation was conducted on the mechanical properties of polyester resin composites produced by three different methods: hand lay-up, Resin Transfer Moulding (RTM) and Sheet Moulding Compound (SMC) methods, reinforced with randomly distributed discontinuous and continuous glass fibre mat. Firstly, tensile strength and elastic module were found to determine the composite plates' mechanical properties. Impact strength was determined by the Charpy impact test. To determine the deformation on the materials after impact, the samples exposed to low-speed drop weight were applied the 3-point bending test and their strength losses were determined. It was determined that the increase in fibre volume fractions increased the impact strength of the composite materials. However, the use of filler materials in composite structures decreased the mechanical properties and impact strength of composites.

Keywords: *polymer composite, SMC, RTM, hand lay-up, impact strength*

Comportamentul structural și mecanic al compozitelor poliesterice ranforsate cu fibre de sticlă

În această lucrare, a fost efectuată o investigație asupra proprietăților mecanice ale compozitelor din rășină poliesterică produse prin trei metode diferite: aplicare manuală, turnare prin transfer de rășină (RTM) și metode de turnare în foi (SMC), armate cu văl de fibre de sticlă discontinuu și continuu, distribuit aleatoriu. În primul rând, s-au determinat rezistența la tracțiune și modulul de elasticitate pentru a analiza proprietățile mecanice ale plăcilor compozite. Rezistența la impact a fost determinată prin testul de impact Charpy. Pentru a determina deformarea materialelor după impact, probele expuse la greutatea de cădere la viteză mică au fost supuse testului de încovoiere în 3 puncte și au fost analizate pierderile de rezistență ale acestora. S-a stabilit că creșterea fracțiilor volumice de fibre a majorat rezistența la impact a materialelor compozite. Cu toate acestea, utilizarea materialelor de inserție în structura compozitelor a diminuat proprietățile mecanice și rezistența la impact ale acestora.

Cuvinte-cheie: *compozit polimeric, SMC, RTM, aplicare manuală, rezistență la impact*

INTRODUCTION

Today, the automotive industry is one of the largest and most significant sectors in the world, and it has become a major consumer of engineering materials. Although metallic materials are predominantly used in this sector, the cultural and economic changes in recent years have significantly influenced both material preferences and design choices. The development of polymer composite materials has become an important supportive parameter for this change [1, 2]. Four factors are very important in the widespread use of composite materials in the automotive industry: weight saving, security, product quality, production ease and flexibility [3]. The high energy absorption ability of composite materials makes them more advantageous than classic materials such as aluminium and steel, and because of these properties, their usage has increased in automotive parts that are exposed to collisions [4]. A chassis made of a composite material absorbs 80% more energy than a steel chassis in the case of a collision [5].

The easy moulding property of composites provides several advantages. The production of big structural complex parts as a whole eliminates the necessity of part combining and montage, which allows materials to be produced with higher resistance and lower cost. Moulding processes are easy, and colouring during moulding decreases the production time and cost, and allows more colour options and aesthetic features. As a result, composite materials are being used in the production of outer body parts in the automotive industry [6].

Automotive manufacturers are currently under pressure to produce low-cost automobiles that are resistant to environmental factors, have a high security level, provide very good comfort and equipment, and consume less fuel. Under these circumstances, composite materials are considered to be the most convenient materials that can be used instead of aluminium and steel. The easiest method for establishing lightweight materials without concession from strength is the use of carbon fibre-reinforced composites. However, carbon fibres are expensive for automotive applications. On the other hand, glass fibre has found a very prevalent application area in the automotive industry together with thermoplastic and thermoset resins, due to its high rigidity and low cost [7, 8]. Owing to new developments in production processes and moulding techniques, glass fibre mats are being used in lightweight and high-performance automotive parts [9]. Some important moulding methods in the production of automotive composites are the hand lay-up method, sheet moulding compounds (SMC), bulk moulding compounds (BMC) and resin transfer moulding (RTM). The products produced using these methods are used inside beams, ceiling and bottom panels, exterior body panels, bumpers, and mudguards. While a ready fibre–resin mixture is used in the production of these parts with SMC and BMC methods, discontinuous and continuous fibre mats, woven, knitting, and unidirectional fabrics can be used as reinforcement with other methods such as RTM and hand lay-up [10]. Generally, automotive composites are expected to exhibit high impact strength, high tensile strength, high fatigue resistance, and strength preservation at different temperatures.

Collision resistance is particularly important in automotive parts, and research has generally focused on the impact strengths and mechanical properties of automotive composites. Simunovich et al conducted a comprehensive study on this subject [11]. In this study, the damage behaviour and propagation properties of random glass fibre mat–polyester resin composite materials were determined experimentally, and the damage behaviour of the composite parts was modelled using the DYNA3D simulation program. Santulli et al. [12] investigated the impact strengths in glass fibre–polypropylene thermoplastic composites by the Charpy test. In another study, Piry et al. [13] analysed the impact strengths and damage of glass fibre–polyester resin composites produced by the SMC method. The impact strength when the fibre distribution and fibre volume fraction were changed in the structure was theoretically determined using the EXPRESS simulation program. The loading amounts for initialising a crack and the total energy amounts for the structure to fracture were theoretically calculated, and the results were compared with experimental data. Oldenbo et al. [14] investigated the mechanical properties and fracture toughness of standard and low fibre volume fraction glass fibre–polyester resin SMC composites and found that SMC composites with lower densities are more resistant to small collisions. In a similar study, Gregl et al. [15] found that the Young's modulus was 20% lower when 10% of glass spheres were added to the SMC composition as a filler. Sheu et al. [16] found that 30% weight was saved when glass fibre-vinyl ester composites produced by the RTM method were used in bus bodies that operated with electricity, and they studied the mechanical properties and impact strengths of glass fibre–vinyl ester composites. Kim and Lee [17] studied the relation between surface qualities and shrinkage ratios after curing glass fibre-polyester resin composite parts produced by the RTM method. They experimentally measured the surface qualities and formations of the surface contour lines related to the fibre volume fraction, and then designed and produced the bus inner panels according to the obtained results. Studies on RTM glass fibre-polyester composites have mainly focused on the shrinkage and warpage problems of these materials after curing [18, 19].

Recently, Karahan et al. investigated low velocity impact [20], bending [21] and compression [22] properties of glass-vinyl ester composites. Zahid et al. [23] experimentally investigated the interlaminar shear strength of glass fibre-reinforced thermoplastic polyurethane (TPU) and epoxy-based thermoset composites enhanced with multi-walled carbon nanotubes (MWCNTs) and compared the performance of thermoplastic and thermoset composites. Karahan et al. [24] studied the impact and mechanical properties of hybrid composites made with natural and glass fibres. They found that the impact properties increased in hybrid structures. Karahan and Karahan [25] investigated the impact properties of hybrid composites woven from synthetic fibres, including glass, carbon, and aramid, and compared these with 100% glass fibre composites. Karahan et al. [26] investigated the effects of resin type on the mechanical properties and impact resistance of glass fibre composites.

The purpose of this study is to investigate the impact resistance of polyester resin composites used in the automotive industry, reinforced with randomly discontinuous and continuous glass fibre mats and glass fibres produced by hand lay-up, RTM, and SMC moulding methods. The mechanical properties of the composite plates were determined for this purpose. The impact strength was determined using the Charpy test. To determine the deformation of the materials after impact, the samples exposed to a low-speed weight drop were applied a 3-point flexural bending test, and their strength losses were determined.

EXPERIMENTAL

The reinforcement materials and their properties that were used in hand lay–up and RTM methods are given in table 1. CE 92 N8 type unsaturated polyester was used as a resin. Methyl Ethyl Ketone Peroxide (50% active) was used for curing with a ratio of 2%, and 6% Cobalt Naphthenate was used with a ratio of 0.25% as hardener and catalyst. In the SMC method, two ready compounds with different fibre volume fractions were used. The compound was in the form of a non-cured layer including fibre, resin and other filler and additives. The ratios of used SMC composite contents are given in table 2.

Hand lay-up, RTM and SMC moulding methods were used in the production of composite plates with dimensions of 300×300×4 mm. In table 3, the reinforcement elements and resin amounts in plates produced by hand lay-up and RTM methods can be found. In the hand lay-up operation, resin was

Table 1

THE REINFORCEMENT MATERIAL TYPES USED IN HAND LAY-UP AND RTM SAMPLES			
Material type	**Glass fibre type**	**Weight (g/m^2)**	**Supplier**
Randomly continuous glass fibre mat-U850	E-glass continuous filament	300	Vetrotex-Saint Gobain
Randomly discontinuous glass fibre mat-EMAT-1	E-glass discontinuous fibre	450	Cam Elyaf Inc.
Randomly discontinuous stitched glass fibre mat	E-glass discontinuous fibre	450	Cam Elyaf Inc.

Table 2

SMC COMPOSITE RATIOS AND PLATE THICKNESS OPTIMIZATION		
SMC materials	**SMC-1**	**SMC-2**
Discontinuous glass fibre (%)	22	28
Polyester resin (%)	26	28
Calcium Carbonate filler (%)	48	40
Pigment and thickener additives (%)	4	4
Total (%)	100	100
The thicknesses of finished plates (mm)	3.8	4

applied to glass fibre mats by a roll and left for curing. In the RTM method, resin injection was performed at a pressure of 3 bar, and the material was left under pressure at room temperature for 45 minutes to cure. In the SMC method, moulding was carried out under a pressure of 60 kg/cm^2 and a temperature of 140ºC. The samples were left to cure for 5 minutes. To determine the mechanical properties of the materials, their tensile strength and modulus were primarily measured. For this purpose, the breaking load and breaking strain were first determined. The tests were conducted using an HTE Hounsfield tension test device with 50 kN capacity, according to ASTM D638 standards. Tensile strength and elastic modulus were calculated using equations 1 and 2, respectively:

$$\sigma_C = \frac{F}{w \cdot t} \tag{1}$$

where σ_C is tensile strength (MPa), F – maximum load (N), w – sample width (mm), and t – sample thickness (mm).

$$E_C = \frac{\sigma_C}{\varepsilon} \ ; \quad \varepsilon = \frac{\Delta l}{l_0} \tag{2}$$

Here, E_C is elastic modulus, ε – breaking strain, l_0 – initial sample length (mm), and Δl – breaking elongation (mm).

In order to determine the impact resistance, a low-speed weight drop method was used. Spherical-ended weights of 1 kg, with a 45 mm diameter, were dropped from 1 m onto the samples. The strength losses were determined using a 3-point flexural bending test. Samples were supported from 2 sides during the weight drop as shown in figure 1.

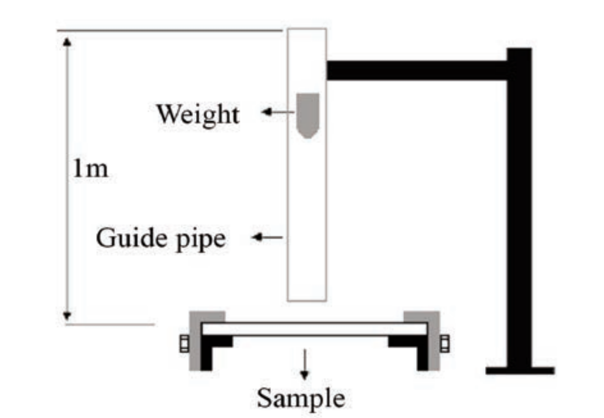


Fig. 1. Fixing of the samples from two sides during weight drop

The losses in mechanical properties of the samples after impact were determined by a 3-point bending test. The 3-point bending tests were performed using an Instron 4301 device according to ASTM D790 standard. The bending strength and bending modulus were calculated using equations 3 and 4, respectively. Here, σ_{CF} is the bending strength of the composite plate, E_{CF} – the bending modulus of the composite plate, F – maximum force (N), l – composite

Table 3

REINFORCEMENT ELEMENTS AND FIBRE VOLUME FRACTIONS IN HAND LAY-UP AND RTM COMPOSITE PLATES					
Production method	**Reinforcement materials**	**Total weight of reinforcement materials (g)**	**Weight of finished plate (g)**	**Fibre volume fraction (%)**	**Thickness of finished plate (mm)**
Hand lay-up	3 plies EMAT-1 discontinuous mat	121.5	587.85	20.66	4.4
RTM-1	3 plies U850 continuous mat	81	442.24	18.32	3.6
RTM-2	2 plies stitched mat + 1 ply U850 continuous mat	108	486.73	22.18	4

plate length (mm), w – plate width (mm), t – plate thickness (mm), m – tan α, is the slope of the load-elongation curve of the elastic region.

The impact strength of the samples was determined using a KSG-70 type Charpy test device in accordance with DIN 53453 standard. The samples were tested without notches. Following the Charpy tests, impact strength was calculated using equation 5. Here, K_C represents the impact strength (J/m^3), A_C – the fracture energy (J), l – the composite plate length (mm), w – the plate width (mm), and t – the plate thickness (mm).

$$\sigma_{CF} = \frac{3 \cdot F \cdot l}{2 \cdot w \cdot t^2} \quad (3)$$

$$E_{CF} = \frac{m \cdot l^3}{4 \cdot w \cdot t^3} \quad (4)$$

$$K_C = \frac{A_C \cdot 10^9}{w \cdot t \cdot l} \quad (5)$$

RESULTS AND DISCUSSION

To determine the mechanical properties of the composite plates produced using different methods, the tensile load and breaking strain were initially measured. Based on these results, the tensile strength and elastic modulus were calculated using equations 1 and 2. The results are presented in table 4. In the hand lay-up method, a discontinuous and randomly distributed mat was used, resulting in a composite plate with approximately 20% fibre volume fraction. The tensile strength of this plate was around 50 MPa, but a 20% deviation in strength and modulus values is noteworthy. The reason for this phenomenon is attributed to air voids in the plate, which weaken the structure. Figure 2 shows the air voids within the composite plate structure produced using the hand lay-up method.

In the structure produced by randomly distributed felt, fibres gather during the resin impregnation, leading to resin-rich regions and deteriorating the homogeneity of the structure. This can be considered as another factor for the deviation between the values. No air voids are left in the composite plate structure produced by the RTM moulding method, so the structure is denser. The fibre volume fraction is about 18% in the RTM-1 composite plates produced using continuous felt. The volume fraction of this plate is lower compared to the hand lay-up method, but the tensile strength is 12% higher, and the elastic modulus is 50% higher. This shows that the stiffness of the continuous felt reinforced composite plate produced by the RTM method is higher. Moreover, the low standard deviation demonstrates the homogeneity of the structure.

Continuous mat reinforced RTM composites are a good solution for obtaining high strength and high stiffness at the same time. However, due to the high cost of continuous mats, they are used together as a hybrid with discontinuous felts in the RTM process while producing the parts for the automotive industry. Practical applications have shown that if discontinuous, randomly distributed felts are used in the RTM process, fibres disintegrate during resin injection, which prevents a homogeneous structure from being obtained. For this reason, stitched discontinuous randomly distributed felts have been developed. These structures are generally suitable for resin injection but cannot be used alone. They are generally used together with continuous felts. In the RTM-2 composite plate, two layers of stitched, randomly distributed felts were used together with one layer of continuous, randomly distributed felt. The fibre volume fraction in this felt is about 22%. Although this ratio is 4% higher than that of the RTM-1 composite plate, the increase in tensile strength is not significant. However, the elastic modulus is 37% higher. But there has been a 17% standard deviation in the modulus values of the RTM-2 composites.

Although the fibre volume fraction of the SMC-1 composite plate is 22%, its tensile strength has been

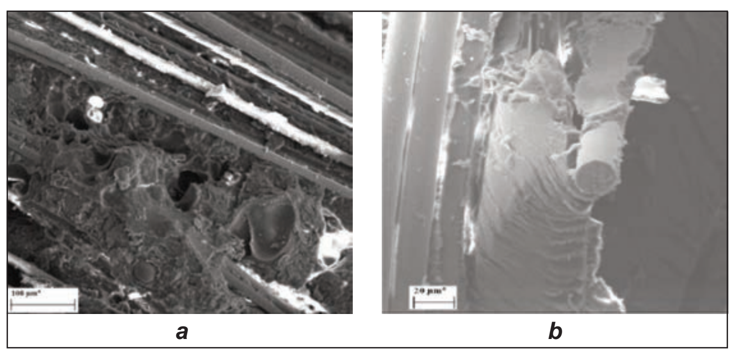


Fig. 2. The air voids between the fibres of the composite plate are produced by the hand lay-up method and resin-rich regions: *a* – x400; *b* – x1000

Table 4

MECHANICAL PROPERTIES OF COMPOSITE PLATES FROM HAND LAY-UP, RTM, AND SMC METHODS				
Production method	**Maximum load, F (kN)**	**Breaking strain, ε**	**Tensile strength, σ_C (MPa)**	**Elastic Modulus, E_C (MPa)**
Hand lay-up	4.43 ± 0.96	0.090 ± 0.01	50.30 ± 10.92	587.20 ± 101.92
RTM-1	4.06 ± 0.13	0.060 ± 0.01	56.44 ± 1.80	891.47 ± 71.54
RTM-2	4.65 ± 0.40	0.048 ± 0.005	58.15 ± 4.99	1227.64 ± 214.47
SMC-1	2.65 ± 0.081	0.044 ± 0.003	34.89 ± 1.062	790.46 ± 58.29
SMC-2	5.77 ± 0.22	0.070 ± 0.01	72.18 ± 2.75	984.89 ± 127.76

determined to be around 35 MPa. Since it is produced under high pressure, no air voids are present in the structure. However, in the SMC composition, a significant amount of calcium carbonate is used as a filler alongside fibre and resin. Calcium carbonate behaves like air voids in the structure and decreases the strength significantly (figure 3). As shown in figure 3, calcium carbonate particles negatively affect fibre-matrix interface adhesion within the structure. Figure 4 compares the SMC composite with the hand lay-up and RTM composites. However, considering the elastic modulus value, it seems that calcium carbonate increases the stiffness. The fibre volume fraction in the SMC-2 plate is 28%. The 6% increase in the ratio raised the tensile strength more than twofold. However, the increase in elastic modulus compared with the SMC-1 plate is 24%. The decrease in the filler ratio and the increase in the resin ratio cause the ductility of the structure to increase slightly. Although there is a significant increase in strength due to the glass fibre volume fraction, the same increase did not occur in the stiffness of the material.

The most important performance parameters in automotive composites are impact strength and the amount of energy required for fracture. The impact strengths of the materials produced for this purpose were determined using the Charpy test. The impact

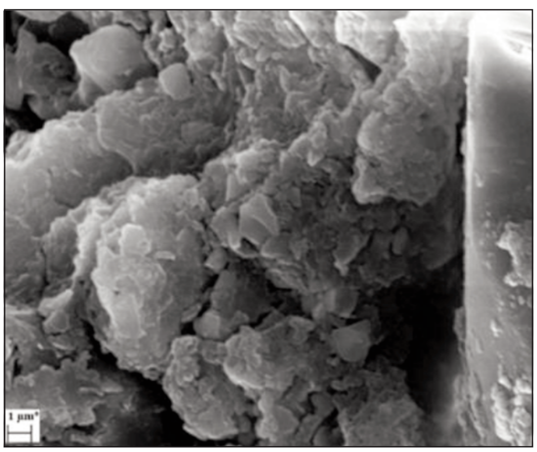


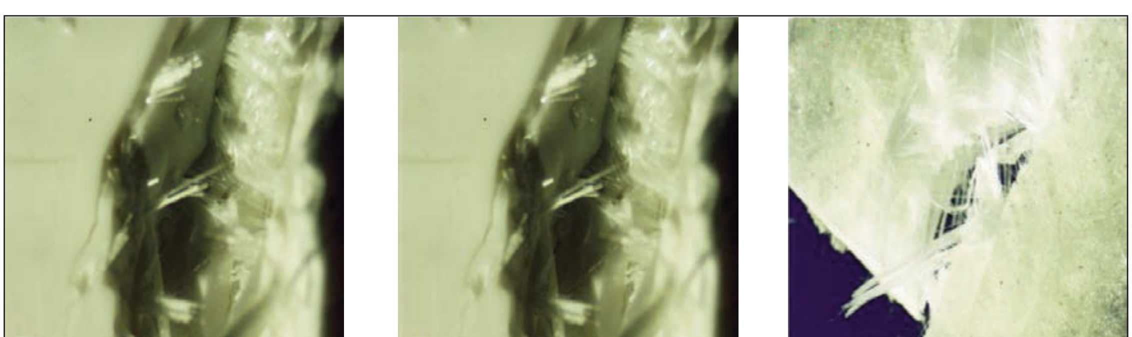
Fig. 3. Calcium carbonate particles in SMC structure and fibre-matrix interface (×10,000)

Table 5

IMPACT STRENGTHS OF COMPOSITE PLATES FROM HAND LAY-UP, RTM, AND SMC METHODS

Production method	Fracture energy, A_C (J)	Impact strength, K_C (kJ/m^3)
Hand lay-up	1.16 ± 0.38	478.16 ± 155.73
RTM-1	1.18 ± 0.21	596.68 ± 102.92
RTM-2	1.61 ± 0.32	731.06 ± 145.46
SMC-1	0.64 ± 0.11	304.17 ± 51.45
SMC-2	1.39 ± 0.18	629.87 ± 84.74

strengths were calculated using equation 5. The results are in table 5. When the results were analysed, it was seen that the minimum impact strength was observed in the SMC-1 composite material. According to this result, a high filler content decreases the toughness of the structure. In SMC composites, the impact strength and toughness of the structure increase in relation to the fibre volume fraction. Although a large amount of air voids are present in composite plates produced by the hand lay-up method, they exhibit greater impact strength compared with the SMC-1 composite materials. However, there is approximately a 30% deviation in the impact strength values of the composites produced with the hand lay-up method. The reason for this phenomenon is the resin–rich regions formed due to air voids and disordered distribution of fibres in the structure. The impact strength in the RTM-1 continuous felt-reinforced composite material is greater than that produced with the hand lay-up method, despite its lower fibre volume fraction. In RTM-2 composite material, a 4% increase in fibre volume fraction results in a 23% increase in fracture strength. The hybrid structure used in the RTM-2 composite material offers several advantages: The stitched mat increases the fibre volume fraction and toughness, while the discontinuous mat prevents rupture after fracture and increases the ductility of the material at the same time. Figure 5 illustrates the fracture of the RTM composite material, revealing a brittle fracture. As a result, the energy required for breaking increases. In figure 6, while the fibres of discontinuous felt break completely after impact, the thinner filaments in



a *b* *c*

Fig. 4. The comparison of surface and inner structures of:
a – SMC; *b* – RTM; *c* – hand lay-up composites

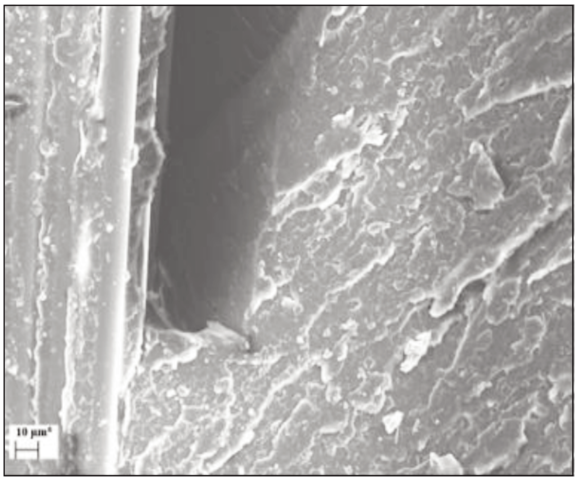


Fig. 5. Brittle fracture behaviour in RTM composite structure (×1000)

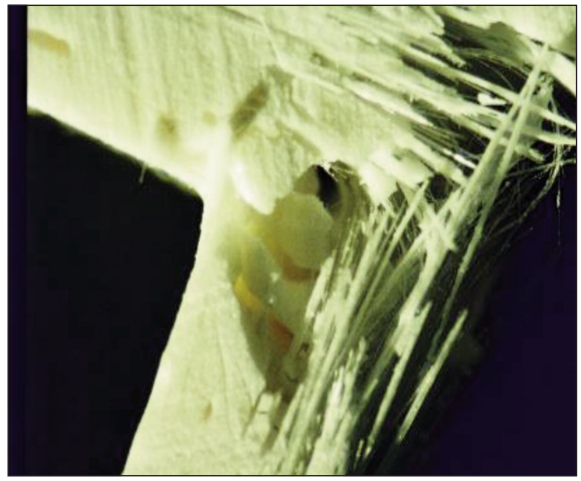


Fig. 6. The fracture in the RTM-2 composite part after impact

the continuous remain intact, maintaining the structure's integrity.

Fracture toughness is an extremely important parameter, especially for automotive parts where collision is important. However, while information such as Poisson's ratio and elastic modulus is needed to find this value, it is certainly a parameter directly related to the impact energy. Therefore, a comparison based on the impact energy value instead of finding the value gives almost the same trend [27].

The impact strength and elastic modulus of the composite plates produced by hand lay-up, RTM and SCM methods are compared in figure 7. As seen in the figure, the impact strength increases similarly to the elastic modulus. However, this trend is not valid for SMC-1 plates. The toughness of the structure is very low due to the excessive amount of filler in SMC-1 composite parts. However, with a 6% increase in the fibre volume fraction, the toughness and energy absorption capability of the structure increase by approximately twofold. In this case, it can be concluded that the increase in the fibre volume fraction has the greatest effect on impact strength [28–31].

In automotive composites, one of the biggest problems, especially in exterior body and bonnet parts, is the small bumps during parking. This causes small cracks in the composite parts, decreasing the strength of the structure. In this study, this problem was simulated by a low-speed weight drop method. The bending strength and modulus values of the weight-dropped samples were determined using a 3-point flexural bending test, and losses in strength and modulus values were compared to parts that did not undergo weight drop. Bending strength and modulus were calculated using equations 3 and 4, respectively. Results are given in table 6. According to these results, bending strength and modulus increase with increasing fibre volume fraction, but losses in bending strength occur after impact. Composite parts produced using the hand lay-up method have low bending strength, but due to their ductile structure, the loss in bending strength after the impact is low. Moreover, the bending strength of RTM composites increased threefold with a 4% increase in fibre volume fraction. However, as the fibre volume fraction increases, the post-impact loss in bending strength also increases. It was observed that bending strength was halved in RTM-2 composite parts. Interestingly, the decrease in bending modulus is limited. The simultaneous decrease in displacement value and strength limits the change in modulus. This phenomenon can be observed in the load-displacement curve in figure 8. Cracks that occur in the structure after a weight drop decrease the structure's elasticity, and rupture occurs where the cracks accumulate. In this case, both bending and displacement decrease.

In SMC composites, a 6% increase in the fibre volume fraction results in a threefold increase in bending strength. The loss in bending strength also increases after impact due to the higher fibre volume fraction, but this loss is less significant than in RTM composites. The decrease in bending modulus is approximately 5%, similar to the other composites. As a result, it can be concluded that while the fibre volume fraction increases, the bending strength improves, but the post-impact bending strength losses also increase. Moreover, significant changes do not occur in the bending module after impact.

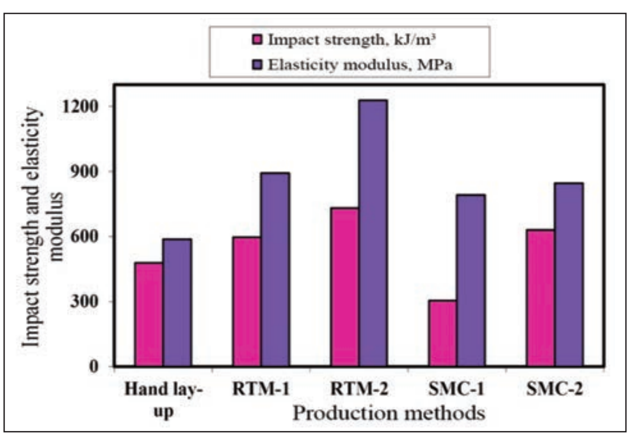


Fig. 7. The impact strengths and elasticity modules of Hand lay-up, RTM and SMC composites

Table 6

3-POINT BENDING TEST RESULTS FOR COMPOSITE PLATES FROM HAND LAY-UP, RTM, AND SMC METHODS						
Production method	**Bending strength, σ_{CF} (MPa)**		**% difference**	**Bending modulus, E_{CF} (MPa)**		**% difference**
	Non-impacted	**Impacted**		**Non-impacted**	**Impacted**	
Hand lay-up	28.92±7.2	27.01±7.5	6.6	658±132	621±137	5.6
RTM-1	25.83±2.8	21.08±4.2	18.3	1143±86	1086±94	4.9
RTM-2	76.53±4.8	34.56±5.1	54.8	2276±287	2162±264	5
SMC-1	15.27±2.5	15.11±2.2	1.04	976.9±72	922±86	5.5
SMC-2	50.88±6.1	42.34±5.7	16.8	1687±182	1618±195	4.1

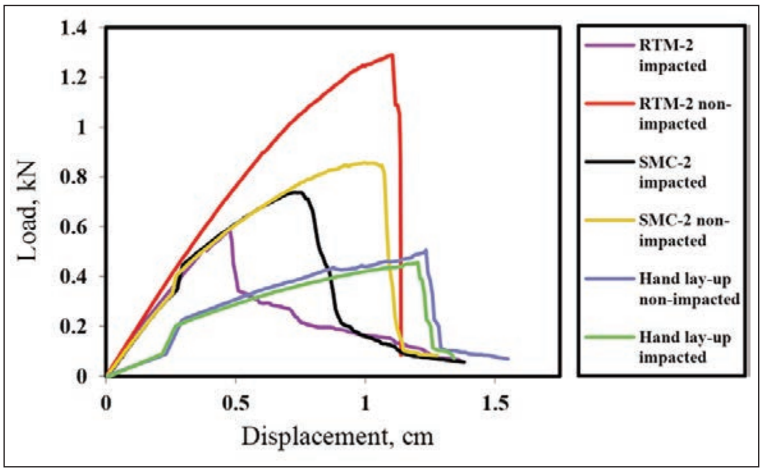


Fig. 8. Load-displacement results of the 3-point bend test results applied to impacted and non-impacted samples

CONCLUSION

The following conclusions were drawn from this study:

- With increasing fibre volume fraction, mechanical properties and impact strength improve. However, calcium carbonate used as a filler reduces the mechanical properties and impact strength of the composite structure, making it more brittle. It is very difficult to maintain homogeneity in composite parts produced by the hand lay-up method. The mechanical performance of such parts is limited, and they should not be used in critical applications where strength is required. The mechanical properties of composite parts produced using the RTM method increase with fibre volume fraction. Such parts can be used in applications requiring high performance. Their energy-absorbing capability and impact strength are higher compared with composites produced using the hand lay-up and SCM methods. However, RTM composites lose most of their strength after impact.
- The mechanical properties of SCM composites improve with fibre volume fraction. However, due to the high filler content in its structure, compared to RTM composites, the mechanical properties and energy absorbing capability decrease more when the fibre volume fraction is low. As fibre volume fraction increases, these disadvantages diminish. Moreover, the strength losses of SMC composites after impact are smaller than those of RTM composites. Although strength losses occurred after impact, the losses in modulus were very limited.

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The use of thermography to measure the cooling performance of personal cooling systems

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ABSTRACT – REZUMAT

The use of thermography to measure the cooling performance of personal cooling systems

The thermoregulatory system is responsible for maintaining body temperature. When the body temperature is between 36.1ºC and 37.1ºC, our body is in a state of thermal well-being, and there is an exchange of body heat between our body and the ambience. When exposed to high temperatures, the body's heat exchange with the environment decreases, causing an increase in internal temperature. This requires a mechanism to assist the thermoregulatory system in maintaining the body's thermal well-being. Cooling garments help the body's thermoregulatory system reduce heat accumulation during stress. Cooling vests are the most used type of cooling garment because the trunk region is the area that has the most temperature receptors that regulate the body's internal temperature. The variation of cooling vests in the market differs depending on the cooling mechanism used. Thermography is a non-intrusive method of measuring surface temperature. It is an excellent choice for qualitative and quantitative analysis without disrupting an object's performance. This study used thermography to evaluate the performance of five cooling vests with different cooling mechanisms. The results showed that data obtained from thermography analysis can be compared to a standardised method for assessing the performance of personal cooling systems.

Keywords: *cooling devices, infrared thermography, personal cooling systems, thermal manikin, thermal imaging*

Utilizarea termografiei pentru măsurarea performanței de răcire a sistemelor personale de răcire

Sistemul de termoreglare este responsabil pentru menținerea temperaturii corpului. Atunci când temperatura corpului este cuprinsă între 36,1ºC și 37,1ºC, corpul nostru se află într-o stare de bunăstare termică și există un schimb de căldură corporală între corpul nostru și mediul înconjurător. Atunci când este expus la temperaturi ridicate, schimbul de căldură al organismului cu mediul înconjurător scade, provocând o creștere a temperaturii interne. Acest lucru necesită un mecanism care să asiste sistemul de termoreglare în menținerea bunăstării termice a organismului. Îmbrăcămintea cu efect de răcire ajută sistemul de termoreglare al organismului să reducă acumularea de căldură în timpul stresului. Vestele de răcire sunt cel mai utilizat tip de îmbrăcăminte cu efect de răcire, deoarece regiunea trunchiului este zona care are mai mulți receptori de temperatură care reglează temperatura internă a corpului. Varietatea de veste de răcire de pe piață diferă în funcție de mecanismul de răcire utilizat. Termografia este o metodă neintruzivă de măsurare a temperaturii suprafeței. Este o alegere excelentă pentru analiza calitativă și cantitativă, fără a perturba performanța unui obiect. Acest studiu a utilizat termografia pentru a evalua performanța a cinci veste de răcire cu diferite mecanisme de răcire. Rezultatele au arătat că datele obținute din analiza termografică pot fi comparate cu o metodă standardizată de evaluare a performanței sistemelor personale de răcire.

Cuvinte-cheie*: dispozitive de răcire, termografie cu infraroșu, sisteme personale de răcire, manechin termic, imagistică termică*

INTRODUCTION

Clothing plays a crucial role in regulating body temperature based on the environment and physical activity, according to ISO 11079:2007 [1]. In a moderate thermal environment, the body's thermoregulatory system maintains balance by regulating skin temperature, internal temperature, and the sweating system. The standard specifies two stress situations: stress due to cold and stress due to heat. To prevent heat stress, it is essential to wear appropriate clothing or use an external mechanism to help retain or dissipate body heat.

The clothes we wear impact our body's ability to regulate temperature. Clothes with thermoregulatory properties can help maintain a stable body temperature for the wearer. In cold weather situations, it's important for clothing to have good insulation to prevent heat loss from the body. In hot weather situations, the clothing should be breathable and able to transmit moisture to keep the wearer cool. Personal cooling systems can help regulate body temperature by dissipating body heat in stressful situations caused by excessive heat.

Cooling vests

Cooling garments are intelligent clothing designed to adapt to the environment using a thermal mechanism to cool when the user's body temperature increases. These garments are an excellent example of how technology can enhance comfort and well-being. Different types of personal cooling systems are available in the market, but vests are the most used due to their ergonomic design and ease of use [2–4]. Cooling vests differ in that the cooling mechanism dissipates heat [5]. The most used cooling vests are liquid cooling vests, air circulation cooling vests, phase change material (PCM's) cooling vests, and evaporation cooling vests.

The effectiveness of personal cooling systems is evaluated using the ASTM F2371:2016 [6] standard, which measures cooling performance and duration using a thermal manikin. Additionally, thermography can determine the heat dissipation of a thermal manikin wearing a cooling vest, which complements the standard.

Infrared thermography

The electromagnetic spectrum is divided into different areas, known as bands, with varying wavelengths. These bands are characterised by the methods used to emit and detect electromagnetic radiation. The infrared region spans from 0.8 μm to 1000 μm and is divided into four segments: near-infrared (NIR), short-wavelength infrared (SWIR), mid-wavelength infrared (MWIR), and long-wavelength infrared (LWIR) [7]. The surface temperature of an object can be determined with a thermographic camera that detects the radiation in the wavelength range between 0.8–14 μm when the object's temperature is above 0ºC [8]. Thermal imaging cameras use the heat emitted by an object to create a thermographic image, which displays the surface temperature distribution through colour differences. The intensity of the image or colour corresponds with the amount of infrared radiation received from the object [9]. The radiation in the thermogram reflects the energy emitted, transmitted, and reflected from the object and its surrounding environment [10].

Over the last two decades, the number of scientific publications related to infrared thermography in chemistry, engineering, and materials science has increased significantly. This measurement technique is highly advantageous as it enables the calculation of an object's surface temperature without any physical contact, making it a non-invasive and non-destructive process [11]. The amount of radiation received, as well as other parameters, determines the object's temperature.

MATERIALS AND METHODS

Method

This research involves using a thermal manikin and an infrared thermal camera to study the effectiveness of five different cooling vests. The manikin, which simulates the human body, is placed inside a climatic chamber under controlled environmental conditions and is outfitted with various cooling vests. The goal is to determine whether valuable data can be obtained through infrared analysis to assess the performance of different cooling vests and to compare this data with results obtained using a standardised method according to ASTM F2371-16 [12].

Equipment

Thermal manikin

The thermal manikin is a Newton's thermal manikin from Thermetrics LLC. Dimensions of the manikin correspond to an M size of a man. This manikin is made of plastic and simulates the body of an adult human of a height of 1.8 meters, with movable arms and legs. This manikin has 34 temperature sensors in the body, each with an independently controlled heating system capable of maintaining a constant temperature.

Climatic chamber

The thermal manikin is placed inside a climatic chamber model Walk-In that measures 9 meters in length, 2.8 meters in width, and 2.15 meters in height. This climatic chamber can be used at temperatures ranging from –30.0ºC to +60.0ºC, with a humidity range of up to 90% and an airspeed of 10 m/s.

Thermal Imaging Camera

With a thermographic camera, it is possible to measure the surface temperature of clothing. For this study, a Flir SC620 Western thermal infrared camera, a high-quality camera commonly used for research, has been used. Thermographic images will be treated with the software associated with the camera FLIR Tools, an easy program to analyse thermal images. Characteristics of this camera are:

- Working temperature: –40ºC to +500ºC.
- Spectral response: 7.5–13.0 um
- Thermal sensitivity: 0.065ºC at 30ºC.
- IR Resolution: 640 × 480
- Accuracy: ± 2.0ºC.

Experimental design

Experimental conditions

Environmental conditions used are 35.0ºC ± 0.5ºC of temperature, 40 ± 5% humidity, and an airspeed of 0.4 ± 0.1 m/s. The manikin is standing and in a static position. The body temperature of the manikin is 35.0ºC ± 0.5ºC, and it wears, under the vests, a sweat suit to maintain 100% humidity throughout the body.

Testing samples

Testing samples are the most representative cooling vests on the market. Table 1 presents the testing samples, the cooling mechanism, and the accessories used with each vest.

According to the measurements of the thermal manikin used, the appropriate size for the vests is M.

Technical procedure

Before dressing the manikin, it is necessary to prepare each vest. Table 2 presents the preparation of each testing sample.

The manikin is placed inside the climatic chamber under environmental testing conditions. It is wearing the sweating system to simulate the perspiration system of a person in the body of the manikin, according

Table 1

MAIN CHARACTERISTICS OF THE TESTED COOLING VESTS		
Cooling vests	**Cooling mechanisms**	**Accessories**
#1	Liquid circulation	Pump, cooling system, battery
#2	Air ventilation	Battery
#3	Phase change material (36ºC)	PCM's packs
#4	Evaporation	-
#5	Vortex tube	Compressed air generator

Table 2

PROCEDURE FOLLOWED TO PREPARE THE SAMPLES TO BE TESTED	
Cooling vests	**Preparation**
#1	Fill the reservoir with water. To charge the battery
#2	To charge the battery
#3	Place in a fridge at a temperature lower than 21.0ºC
#4	To immerse in cold water and drain
#5	To use a compressed air generator

to the ASTM F2370:2022 [13]. The manikin's sweating system includes a water reservoir, a pump that supplies water, a second skin suit, and plastic tubes that conduct the water from the reservoir to the manikin. The second skin suit is wet, with 100% humidity. The body temperature of the manikin is programmed at 35.0ºC with the software associated with the manikin.

Effective power test

A preliminary test measures the heat removal rate (effective power) according to the ASTM F2371-16 standard. Environmental conditions used are 35.0ºC ± 0.5ºC of temperature, 40 ± 5% humidity, and an airspeed of 0.4 ± 0.1 m/s. The manikin is standing and in a static position. The body temperature of the manikin is 35.0ºC ± 0.5ºC, and it wears a sweat suit to maintain 100% humidity throughout the body. The standard test consists of two parts. In the first part, the PCS Baseline test is performed with the manikin wearing the vest but with the cooling mechanism working. During this test phase, we measure the energy needed for the sweating manikin to maintain a body temperature of 35.0ºC. Once the energy stabilises, we conduct the PCS Performance test to determine the energy required by the sweating manikin to maintain a body temperature of 35.0ºC while wearing the vest with the cooling system activated. The effective power is calculated as the difference in energy between the PCS Baseline test and the PCS Performance test.

Infrared analysis with a thermal camera

In this part of the study, the manikin is wearing a cooling vest for testing, but the cooling system of each vest is not working yet. Under stable testing conditions, the test reaches steady-state conditions with the following parameters: climatic chamber at 35.0ºC ± 0.5ºC, 40 ± 5% humidity, 0.4 ± 0.1 m/s wind speed, and the manikin's body temperature at 35.0ºC ± 0.1ºC. These conditions are maintained for 30 minutes. Afterwards, the cooling system is activated, and a thermal image is captured. Thermal images are taken from 0.5 m from the manikin while the cooling system is running. For the test of cooling vest #4, the manikin wears the dry cooling vest, and after reaching steady-state conditions, the vest is soaked in cold water, drained, and worn by the manikin before the thermal image is taken. For the cooling vest #5 test, the manikin wears the cooling vest without the PCM. After arriving at steady state conditions, the PCM packages are inserted into the vest before the thermal image is taken. Before the test of the cooling vests, a test is conducted under the same conditions with the manikin in a nude state.

The thermal images are analysed using the FLIR Tools software. The software requires input of the parameters outlined in table 3 to investigate the thermal picture.

Table 3

VALUES USED IN THE SOFTWARE FLIR TOOLS	
Parameters	**Input values**
Distance	0.5 meters
Environmental temperature	35.0ºC
Reflected temperature	30.0ºC
Emissivity	0.9
Temperature scale	34.0–40.0ºC

RESULTS

Results according to ASTM F2371-16 are shown in table 4.

Table 4

EFFECTIVE POWER OF THE DIFFERENT COOLING VESTS TESTED	
Cooling vests	**Effective power (W/m^2)**
#1	175
#2	230
#3	171
#4	15
#5	8

Figures 1–6 present the thermal images captured during the second part of the study.

Table 5 presents the average surface temperature of the different cooling vests tested and taken from the software.

Fig. 1. Nude manikin

Fig. 2. Manikin with vest #1

Fig. 3. Manikin with vest #2

Fig. 4. Manikin with vest #3

Fig. 5. Manikin with vest #4

Fig. 6. Manikin with vest #5

Table 5

SURFACE TEMPERATURE OF THE COOLING VESTS AFTER THE TEST	
Cooling vests	**Surface temperature (ºC)**
Nude manikin	41
#1	33
#2	31
#3	33
#4	31 (upper part) / 36 (lower part) / 34 (complete vest)
#5	38

DISCUSSION OF RESULTS

When the effective power ranges from 165 to 540 W/m^2, only vests #1, #2, and #3 can provide cooling, as indicated in Table 4. When arranging the data based on effective cooling power from highest to lowest, the air ventilation vest (cooling vest #2) exhibits the highest cooling capacity, followed closely by the liquid cooling vest (cooling vest #1) and the PCM vest (cooling vest #3) with similar cooling power. The vortex tube vest (cooling vest #5) demonstrates the lowest effective cooling power.

A thermal camera captures and converts the temperature of an object into a thermal image, allowing us to obtain qualitative and quantitative information about its surface temperature. In a thermographic image, the darker the blue-black colour, the lower the surface temperature of the vest, which indicates that more cooling is being provided to the manikin. Our study's temperature scale indicates that white-yellow in the picture denotes a temperature close to 40ºC, and blue-black colour denotes the lowest temperature, close to 34ºC. Figure 1 represents the manikin without any kind of cooling vest. In this figure, the manikin is white-yellow, which means that it is the image of the manikin with the highest temperature, with an average surface temperature of 41ºC, according to table 4. Upon comparing the thermal images of the manikin wearing different cooling vests from figure 2 to figure 6, it is observed that the thermal image of the manikin wearing vest #5, in figure 6, displays colours of the vest that closely resemble the picture of the nude manikin with an average surface temperature of 38ºC. This implies that vest #5 has the lowest cooling performance among all tested cooling vests, as confirmed by both the standard test and the thermographic analysis. When analysing figure 5, it is evident that cooling vest #4 exhibits different colours in its upper and lower parts. The upper part appears in blue-black with a surface temperature of 31ºC, while the lower part is in red-orange colours, with a surface temperature of 36ºC. This indicates that the average surface temperature of this cooling vest is 34 ºC. The disparity in colour between the upper and lower parts of the vest suggests that the upper part provides more excellent cooling to the manikin than the lower part. This is because the cooling mechanism of vest #4 involves pre-treating the upper part with water, which it then absorbs and retains to provide greater cooling power. The effective power results are low at 15 W/m^2, as this is an average of the areas of the manikin covered by the vests. This includes both wet and dry regions of the vests. Upon examining figures 2, 3, and 4, it's evident

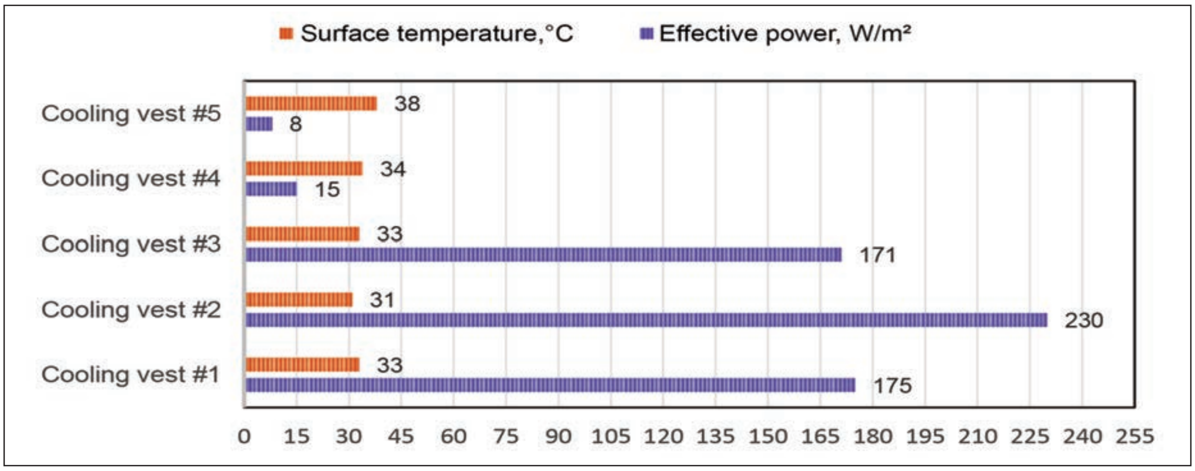

Fig. 7. Graphical comparison between the effective power and the surface temperature of the cooling vests tested

that the colour distribution is similar among all three vests. Vest #1 has a surface temperature of 33ºC, vest #2 has a temperature of 31ºC, and vest #3 has a temperature of 33ºC. When using a thermal camera, it is possible to measure the surface temperature of materials with an accuracy of 2°C, according to the camera's specifications.

Figure 7 compares the cooling power and surface temperature of the various tested cooling vests. Looking at figure 7, when arranging the data based on surface temperature, from lowest to highest, the air ventilation vest (cooling vest #2) exhibits the lowest temperature, followed closely by the liquid cooling vest (cooling vest #1) and the PCM vest (cooling vest #3) with the same surface temperature. The vortex tube vest (cooling vest #5) presents the lowest effective power. This finding aligns with the cooling power of each vest, which can be seen in figure 7, that the air-cooling vest has the highest cooling power, followed by the liquid cooling vest and PCM cooling vest with a similar effective power. Again, the vortex tube cooling vest, cooling vest #5, presents the worst performance, with the highest surface temperature.

CONCLUSIONS

The study aimed to use a thermal infrared camera to compare the cooling capabilities of five different cooling vests. To achieve this, a testing protocol using a thermal manikin with a thermographic camera was performed, and the results were compared with a standard testing method according to ASTM F2371 to verify that both testing methods can be complementary. In this study, the thermal infrared analysis and the standard test demonstrated that the air vest provided the highest cooling performance, and the vest that used the cooling mechanism of a vortex tube tested demonstrated the lowest cooling performance. PCM's cooling vest and the liquid circulation cooling vest exhibited similar behaviour in the thermal infrared analysis and the standard test. If we only consider the wet area, the evaporation vest has demonstrated good cooling performance with the thermal infrared analysis. However, with the standard test, the effective power is deficient because this test finds all the segments of the manikin covered by the vest, not only the wet areas.

The comparison results suggest that a thermal imaging camera can be an effective and straightforward method to evaluate the cooling performance of personal cooling systems. This approach can complement the standard ASTM method F2371. However, it's important to note that this study has limitations that should be considered in the future. The results and conclusions about cooling performance are based on comparing five cooling vests with different materials and designs. Therefore, future studies should aim to include an extended range of cooling vests available in the market.

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Predictive stock market analysis for Japanese textile companies using ARIMA model

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ABSTRACT – REZUMAT

Predictive stock market analysis for Japanese textile companies using ARIMA model

Predicting the stock prices of Japanese textile companies is crucial for several reasons. First, stock price trends provide valuable insight into the financial health and growth potential of these firms, especially in an industry subject to evolving consumer trends, technological advancements, and global competition. Investors rely on stock price predictions to make informed decisions, helping them maximise returns and manage risks effectively. The study aims to predict the stock prices of Japanese Textile Companies using the ARIMA Model by taking the top 10 textile companies listed on the Tokyo Stock Exchange (TSE) for a span of 10 years, i.e. 2014 to 2023. Upon evaluation of models, it was found that most of the corporations had either a negative impact or no impact of past lagged values on their present value, except for Global Style, which had a positive influence, maybe due to its distinct nature of textile products in comparison to other corporations. Similarly, Itochu was 91% affected by its own past lagged values, maybe due to its huge operations in textiles as well as other sectors distinct from textiles. Mostly due to lagged value of past residuals, all the corporations were negatively affected, but Global Style, Kuraray, Itochu and Yagi were positively impacted, and there was a huge impact seen in terms of Itochu.

Keywords*: textile industry in Japan, forecasting, ARIMA models, time-series, trade*

Analiza predictivă a pieței bursiere pentru companiile din industria textilă japoneză folosind modelul ARIMA

Predicția prețurilor acțiunilor companiilor din domeniul textil din Japonia este crucială din mai multe motive. În primul rând, tendințele prețurilor acțiunilor oferă informații valoroase despre sănătatea financiară și potențialul de creștere al acestor firme, în special într-o industrie supusă tendințelor de consum în continuă evoluție, progreselor tehnologice și concurenței globale. Investitorii se bazează pe predicțiile prețurilor acțiunilor pentru a lua decizii informate, ajutându-i să maximizeze randamentele și să gestioneze eficient riscurile. Studiul își propune să estimeze prețurile acțiunilor companiilor din sectorul textil japonez utilizând modelul ARIMA, luând în considerare primele 10 companii listate la Bursa de Valori din Tokyo (TSE) pentru o perioadă de 10 ani, adică perioada anilor 2014–2023. În urma evaluării modelelor, s-a constatat că majoritatea corporațiilor au avut fie un impact negativ, fie niciun impact al valorilor anterioare întârziate asupra valorii lor actuale, cu excepția Global Style, care a avut o influență pozitivă, poate datorită naturii sale distincte de produse textile în comparație cu alte corporații. În mod similar, compania Itochu a fost afectată în proporție de 91% de propriile valori anterioare întârziate, probabil datorită operațiunilor sale masive în domeniul textilelor, precum și în alte sectoare economice distincte față de sectorul textil. În principal din cauza valorii întârziate a reziduurilor anterioare, toate corporațiile au fost afectate negativ, însă companiile Global Style, Kuraray, Itochu și Yagi au fost afectate pozitiv, iar impactul asupra companiei Itochu a fost semnificativ.

Cuvinte-cheie*: industria textilă în Japonia, predicție, modele ARIMA, serii temporale, comerț*

INTRODUCTION

The history of Japanese textiles is deeply intertwined with the nation's cultural, social, and economic evolution [1, 2]. From the Nara period (710–794), when silk weaving techniques were imported from China, textiles became an essential part of Japanese craftsmanship and art [3]. Silk was highly prized, especially by the aristocracy, and the intricate patterns and vibrant colours reflected the influence of Chinese and Korean culture [4–6]. By the Heian period (794–1185), Japan developed its distinct textile art, particularly with the introduction of kasuri (ikat), shibori (tie-dye), and silk kimono production [7]. The Edo period (1603–1868) saw the flourishing of textile towns like Nishijin in Kyoto, famous for its brocade weaving [8]. The Meiji era (1868–1912) marked Japan's modernisation and the introduction of Western industrial textile machinery [9]. However, traditional techniques such as kimono dyeing, katazome (stencil dyeing), and hand-weaving have persisted, maintaining the unique and rich heritage of Japanese textiles [10, 11].

The current scenario of Japan's textile industry blends traditional craftsmanship with modern innovation [12]. While Japan's textile sector once thrived on large-scale production, global competition has shifted its focus toward high-quality, niche markets [14, 15]. Traditional techniques like shibori (tie-dye), kasuri (ikat), and Kyoto's renowned Nishijin-ori (brocade weaving) continue to thrive, preserved by artisans who emphasise craftsmanship and cultural heritage. At the same time, Japan has embraced cutting-edge textile technology, excelling in technical fabrics, sustainable fibres, and advanced manufacturing processes [16–18]. Japanese textile companies are pioneers in functional fabrics used in sportswear, medical fields, and eco-friendly materials, reflecting a strong commitment to sustainability and innovation. Collaborations between traditional artisans and modern designers have also led to a resurgence of interest in handcrafted fabrics, both domestically and globally [19]. This fusion of old and new allows Japan's textile industry to maintain its unique identity in a highly competitive global market [20].

Investing in Japanese textile companies presents a unique opportunity for investors due to the industry's rich blend of traditional craftsmanship and cutting-edge innovation [21]. Japan has a long-standing reputation for producing high-quality textiles, particularly in areas like shibori, kasuri, and Nishijin-ori, where artisanship remains a strong cultural and economic pillar [22, 23]. Alongside preserving these traditions, Japanese textile companies are at the forefront of developing advanced fabrics, such as high-performance and sustainable materials used in sportswear, healthcare, and environmental solutions. This combination of tradition and innovation positions Japanese textile companies in a unique and competitive niche within the global market.

Furthermore, predicting the stock prices of Japanese textile companies is crucial for several reasons. First, stock price trends provide valuable insight into the financial health and growth potential of these firms, especially in an industry subject to evolving consumer trends, technological advancements, and global competition [24]. Investors rely on stock price predictions to make informed decisions, helping them maximise returns and manage risks effectively. The ability to forecast stock movements also sheds light on how well these companies adapt to economic challenges, such as fluctuating raw material costs, trade policies, and environmental regulations. Additionally, Japanese textile companies are increasingly focusing on sustainability and innovation, which are critical factors for long-term growth in today's markets [25]. By predicting stock prices, investors can identify key opportunities in companies that are leading the charge in eco-friendly practices and technological advancements, ensuring their investments are aligned with future trends and market demands.

ARIMA (Auto Regressive Integrated Moving Average) is widely chosen to predict the stock prices of Japanese textile companies because of its proven effectiveness in handling time series data, particularly financial data like stock prices. ARIMA is especially useful because it can model data that exhibits trends, seasonality, and noise, common characteristics in stock market fluctuations [26]. The textile industry, like others, experiences periodic shifts influenced by economic conditions, global competition, and consumer trends, making ARIMA's ability to handle both stationary and non-stationary data highly advantageous. One of ARIMA's key strengths is its ability to forecast future values based on past patterns [27]. It relies on historical stock prices to predict future movements, making it particularly useful for industries like textiles, where market trends, raw material costs, and seasonal demand can impact stock performance. For Japanese textile companies, which balance traditional craftsmanship with modern innovation, ARIMA allows investors and analysts to capture both short-term fluctuations and long-term trends. Furthermore, ARIMA's flexibility in integrating different components (autoregression, differencing, and moving averages) makes it adaptable to a wide range of stock behaviours, improving accuracy and reliability in forecasting, which is essential for making informed investment decisions in a competitive and evolving market.

REVIEW OF LITERATURE

The stock market performance of Japanese textile companies is multifaceted, influenced by network centralisation, exchange rate fluctuations, macroeconomic conditions, and international trade policies. Understanding these factors can provide a comprehensive view of the industry's dynamics and potential stock market behaviour. The Japanese textile and apparel industry has seen significant changes in its B2B networks, particularly with the centralisation around hub companies due to the introduction of supply chain management systems and innovations in ICT and logistics technology. These centralisations have been linked to improved efficiency and potentially better stock performance due to streamlined operations [28, 29].

The short-term forecasting of stock prices impacts the investment strategies of Japanese textile companies by enabling them to make informed decisions on stock purchases and sales, anticipate market movements, and mitigate risks associated with the stock market [30].

The USD/JPY exchange rate has a notable impact on the B2B transactions within the industry. A strong yen correlates with an increase in the number of transactions, while a weak yen results in fewer transactions. This relationship suggests that fluctuations in the exchange rate can directly affect the operational dynamics and, consequently, the stock performance of textile companies [29, 31].

The performance of Japanese textile firms is also influenced by broader macroeconomic conditions. For instance, keiretsu financing and international diversification strategies have varying effects on profitability depending on the economic environment.

During times of economic scarcity, these strategic factors play a more significant role in determining financial outcomes [32]. Japan's textile industry is also affected by international trade policies and geopolitical factors. The shift from reliance on China to ASEAN countries for supplies and partnerships is a strategic move to mitigate risks and reduce costs. Japanese textile companies look for ASEAN suppliers, Textiles South East Asia, 2005 [33].

Japan has transitioned from being a major exporter to a significant importer of textiles. This shift is driven by the competitiveness of Chinese imports, which dominate the market due to lower costs and the absence of quotas. This has led to increased import values and a decline in domestic production competitiveness [34]. Specific sectors within the textile industry, such as automotive textiles, have seen growth due to increased demand from Japanese car manufacturers in the U.S. market. This sector's success reflects broader trends in the automotive industry and changing consumer preferences towards environmentally friendly products [35]. The global shift in production to low-cost countries has affected the Japanese textile industry. The industry now focuses more on managing global supply chains and retailing rather than production, which has influenced stock performance due to changing business models and competitive pressures [36].

In summary, global economic trends, including macroeconomic conditions, import-export dynamics, and sector-specific demands, play a crucial role in shaping the stock performance of Japanese textile companies.

The ARIMA model is widely used for time series forecasting in various fields such as finance, economics, and network throughput prediction. To analyse and predict stock market trends, the ARIMA model is a widely used time series forecasting method. It combines autoregressive and moving average components to capture temporal patterns in stock price data, making it suitable for short-term predictions. The ARIMA model is a robust tool for short-term stock market analysis, though its performance can be enhanced or outperformed by other models depending on the specific context and additional variables considered [37–44].

ARIMA models have shown strong accuracy for short-term and daily stock price predictions. For instance, the ARIMA model was effectively used to predict stock prices on the Bombay Stock Exchange (BSE) and National Stock Exchange (NSE) with high accuracy [45]. Similarly, it was found suitable for short-term forecasts of China Merchants Bank stock prices [46]. The process of building an ARIMA model involves ensuring data stationarity, typically through differencing, and selecting appropriate parameters (p, d, q) using criteria like AIC and BIC. For example, the ARIMA (0, 2, 1) model was chosen for Adobe stock prices based on these criteria, achieving a low Mean Absolute Percentage Error (MAPE) [42].

While ARIMA is effective, it may not always outperform other models. Neural network algorithms, for instance, have been found to better predict stock price changes compared to traditional ARIMA models [47]. Additionally, ARIMA-GARCH models, which account for volatility, can sometimes provide better forecasts than ARIMA alone [48]. ARIMA has been applied to various stock markets, including the Indonesian Stock Exchange for socially responsible investment stocks [49] and the Shanghai Stock Exchange Composite Index, incorporating additional variables like trading volume and exchange rates for more stable predictions [50].

The stock prices of textile companies are influenced by various factors, including macroeconomic conditions and commodity prices [51–54]. For instance, the volatility in crude oil prices significantly impacts the stock prices of Indian textile companies due to their dependency on petrochemical raw materials [51]. Additionally, the prices of commodities like cotton also affect the stock prices of textile companies, as shown in studies using the ARDL model [52].

For textile companies, external factors such as international trade agreements and macroeconomic policies also play a crucial role in stock price movements [54, 55]. The ARIMA model is a powerful tool for forecasting stock prices, its effectiveness can be enhanced by integrating it with other models to account for the complex factors influencing the textile industry [39, 42, 52, 56].

The seasonality of the textile industry significantly impacts the application of ARIMA models for stock price prediction. The textile industry experiences seasonal fluctuations, such as changes in cotton prices during pre-sowing and pre-harvesting periods. These fluctuations necessitate the use of ARIMA models to capture the seasonal patterns effectively [57]. Accurate seasonal forecasting helps textile companies make informed decisions about stocking or selling products to maximise profits. This is crucial in a highly volatile market where prices can fluctuate based on seasonal trends [58].

Research gap

Despite extensive research on stock market prediction, particularly with time-series models like ARIMA, there is a notable gap in focusing on specific industries within specific geographic contexts. Most studies have applied ARIMA to broad stock indices or major industries, leaving sectors like the textile industry, especially in Japan, underexplored. The Japanese textile market, which plays a critical role in the global fashion and apparel supply chain, experiences unique market dynamics influenced by factors such as seasonal demand, global trade policies, and technological advancements. However, predictive analysis tailored to this sector remains limited, hindering investors and businesses from making informed decisions based on industry-specific trends. This research seeks to address this gap by applying the ARIMA model to forecast stock prices of Japanese textile companies, providing a more nuanced and industry-targeted analysis. By doing so, it contributes to a better understanding of sector-specific stock behaviour within the context of Japan's unique economic and industrial framework.

Objectives of the study

- To develop an ARIMA-based model for forecasting stock prices of selected Japanese textile companies, aiming to enhance accuracy in predicting future stock market trends within this specific sector.
- To evaluate the performance of the ARIMA model by comparing forecasted results with actual stock price movements, determining its effectiveness in predicting short-term and long-term market fluctuations.
- To contribute to the limited literature on industry-specific stock market predictions, particularly in sectors like textiles, where predictive models are less frequently applied.

Significance of the study

Research on predictive stock market analysis for Japanese textile companies using the ARIMA model offers significant societal benefits by improving financial decision-making and economic stability. By providing accurate forecasts of stock prices specific to the textile sector, investors can make more informed decisions, reducing the risks of financial losses. This is particularly important for individual investors, pension funds, and other stakeholders whose wealth and plans are tied to the performance of such industries. Furthermore, better predictions can lead to increased confidence in the market, promoting more efficient capital allocation, which helps companies secure funding for innovation and sustainable growth. This research also benefits the broader economy, as the textile industry is a key player in Japan's industrial landscape, influencing employment and exports. Accurate market predictions contribute to the overall economic health, creating a ripple effect that strengthens not only businesses but also the livelihoods of workers and communities dependent on the textile sector.

Limitations of the study

- Data Availability and Quality: The predictive accuracy of the ARIMA model heavily depends on the availability and quality of historical stock market data. In this study, we relied on publicly available data, which may have certain limitations, such as missing values, inconsistencies, or reporting biases that could impact the model's performance. Additionally, the data used was limited to a specific period, which may not capture long-term trends or market anomalies.
- Exclusion of External Factors: The ARIMA model is purely time-series-based and does not account for external factors such as macroeconomic indicators (e.g., inflation, interest rates), global trade conditions, or company-specific events (e.g., management changes, mergers, supply chain disruptions). These factors could significantly influence the stock prices of textile companies in Japan, but they are beyond the scope of this study's analysis.
- Short-Term Predictive Focus: ARIMA models are more suited to short-term forecasting rather than long-term predictions. The predictive insights generated in this study primarily focus on near-term stock price movements, and the model may not perform well when extended to longer-term forecasting due to accumulating error and a lack of inclusion of long-term drivers of stock prices.
- Model Parameter Sensitivity: The performance of the ARIMA model is sensitive to the selection of parameters (p, d, q). While this study employed standard statistical techniques to identify the optimal parameters, alternative methods or parameter choices may yield different results. Additionally, ARIMA's reliance on past values may limit its adaptability in highly volatile or unprecedented market conditions.
- Market Volatility: Stock markets, including the Japanese textile sector, are subject to unexpected shocks and volatility (e.g., economic crises, pandemics, geopolitical events). The ARIMA model's reliance on historical data makes it less responsive to sudden changes in market conditions, and as a result, it may underperform during periods of high volatility or instability.
- Technological Limitations: This research utilised available computational resources and tools for model development and testing. However, more advanced machine learning models or hybrid approaches (e.g., integrating ARIMA with deep learning models like LSTM) might offer enhanced predictive accuracy but were not explored in this study due to the research scope and technological constraints.

RESEARCH METHODOLOGY

Research design

This research employs a quantitative approach to analyse and predict stock market trends of Japanese textile companies using the ARIMA (AutoRegressive Integrated Moving Average) model. The study is designed to explore the potential of time-series forecasting techniques, specifically ARIMA, in predicting stock prices, enabling better decision-making in the financial and investment sectors.

Data collection

The data for this research was collected from publicly available financial datasets and stock exchange platforms, focusing on the top 10 textile companies listed on the Tokyo Stock Exchange (TSE). The selection criteria for companies included their relevance in the textile industry, market capitalisation, and consistent availability of historical stock price data over 10 years (2014–2023). The source for selecting the companies was a manuscript publicly available on the textile industry by the EU-Japan Centre. The companies included were Teijin, Global Style, Itochu, Kuraray, Toyobo, Yagi, Takihyo, Toray, Sankyo Seiko, and

Toyota Tsusho. Except for Global Style, all the companies have 10 years of data.

Daily closing stock prices of these companies are obtained from financial platforms such as Investing.com, Yahoo Finance, Bloomberg, and similar sources. The dataset spans from January 1, 2014, to December 31, 2023. Each company had almost 2500 data points, and Global Textiles had 720 data points, summing to a total of 22,719 data points.

Data pre-processing

Before implementing the ARIMA model, the data undergoes several pre-processing steps:

- Handling Missing Data: Missing data points in stock prices are handled using forward fill, backwards fill, or interpolation methods to ensure the continuity of the dataset.
- Normalisation: The dataset is normalised to reduce the impact of extreme outliers, which could skew the model results.
- Stationarity Check: Since ARIMA requires a stationary time series, the Augmented Dickey-Fuller (ADF) test is conducted to check for stationarity. If the data is non-stationary, differencing is applied to achieve stationarity.

Model selection

The ARIMA model is selected for this study due to its effectiveness in time-series forecasting. ARIMA is a combination of three components:

- AR (AutoRegressive): Uses the dependency between an observation and several lagged observations.
- I (Integrated): Differencing the raw observations to make the time series stationary.
- MA (Moving Average): Models the dependency between an observation and a residual error from a moving average model applied to lagged observations.

The Box-Jenkins method is followed to identify the appropriate parameters for ARIMA, which include:

- Identification: Determining whether the time series data is stationary and identifying the order of differencing required.
- Estimation: Using the training data, the AR, I, and MA components are estimated using statistical software like Python's statsmodels package or other software like EViews, XLSTAT, Julia R, MATLAB, etc. This paper has utilised EViews 9.5.
- Diagnostic Checking: After fitting the model, residuals are checked to ensure they resemble white noise using techniques such as the Ljung-Box test.

Model evaluation

The performance of the ARIMA model is evaluated using several metrics to gauge its predictive accuracy, including Root Mean Square Error(RMSE), Plot of predicted values against actual values, Mean Absolute Percentage Error (MAPE), and residual analysis.

Software and tools

For this analysis, there are several software programs that could be used, including EViews, XLSTAT, MATLAB, Julia, Python, R, etc., but for ease and convenience, EViews 9.5 was employed for the analysis.

ANALYSIS, RESULTS AND DISCUSSION

To understand the nature of the Price data, looking at the price graphs becomes essential. From the visual estimation itself, it is evident that in figures 1 to 10, the data of the prices of the 10 textile companies taken for the study are not stationary. To make the data stationary, the data was differenced to the 1st level, and the graph adjacent to the price graphs depicts the stationary prices. The stationarity of the differenced prices was confirmed through the Augmented Dickey-Fuller (ADF) test.

After making the data stationary, it becomes essential to look at the ACF and PACF plots in the correlogram. From the values of ACF and PACF at 1st level difference, it was evident that the value of the d in (p,d,q) across the 10 companies is 1. Based on the ACF and PACF values, p and q were identified. Below is the decision table used to identify AR and MA terms and appropriate lag values.

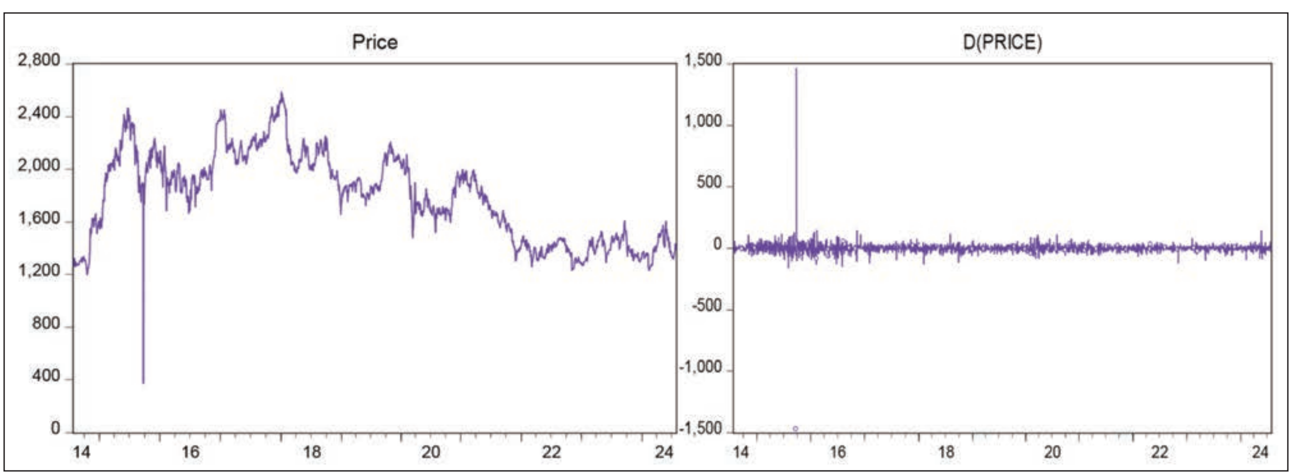


Fig. 1. Teijin price and stationary price

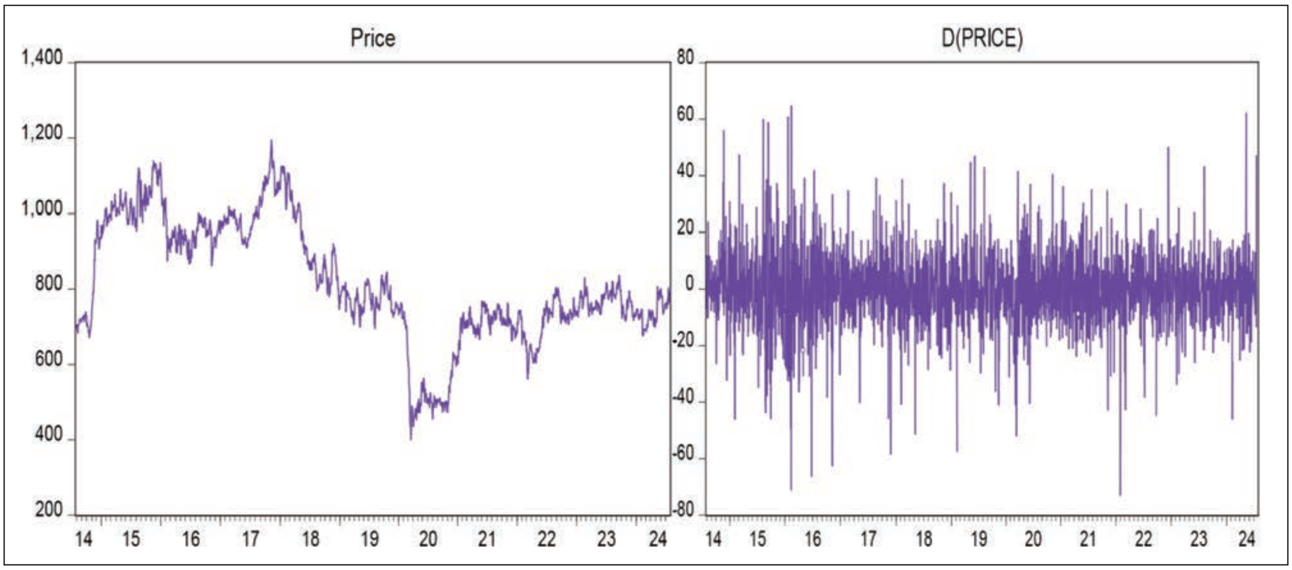


Fig. 2. Toray price and stationary price

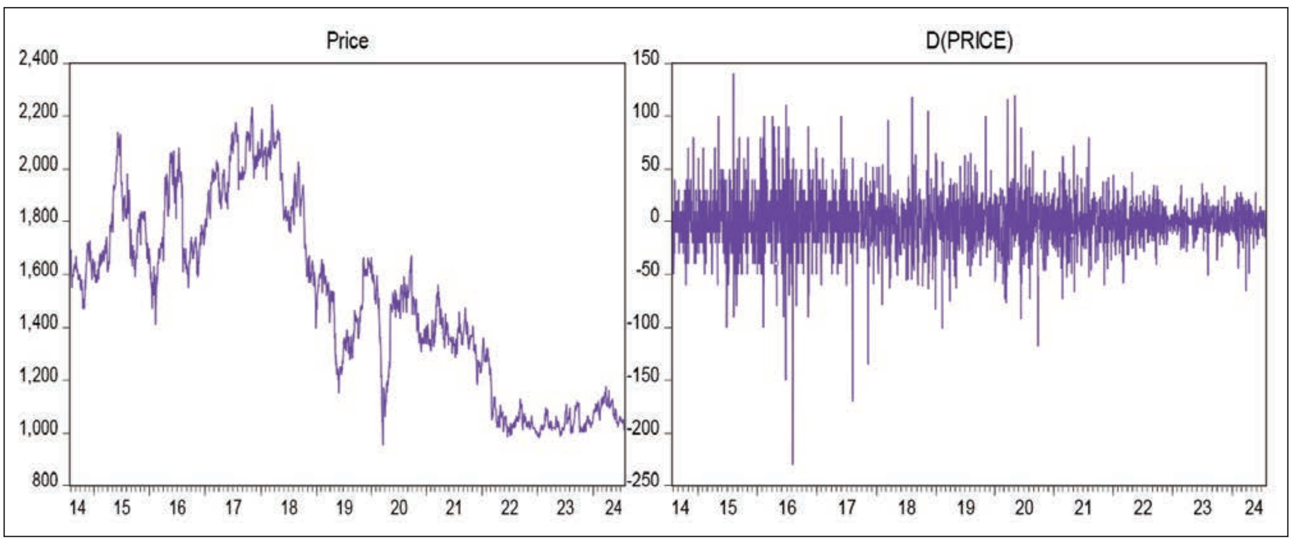


Fig. 3. Toyobo price and stationery price

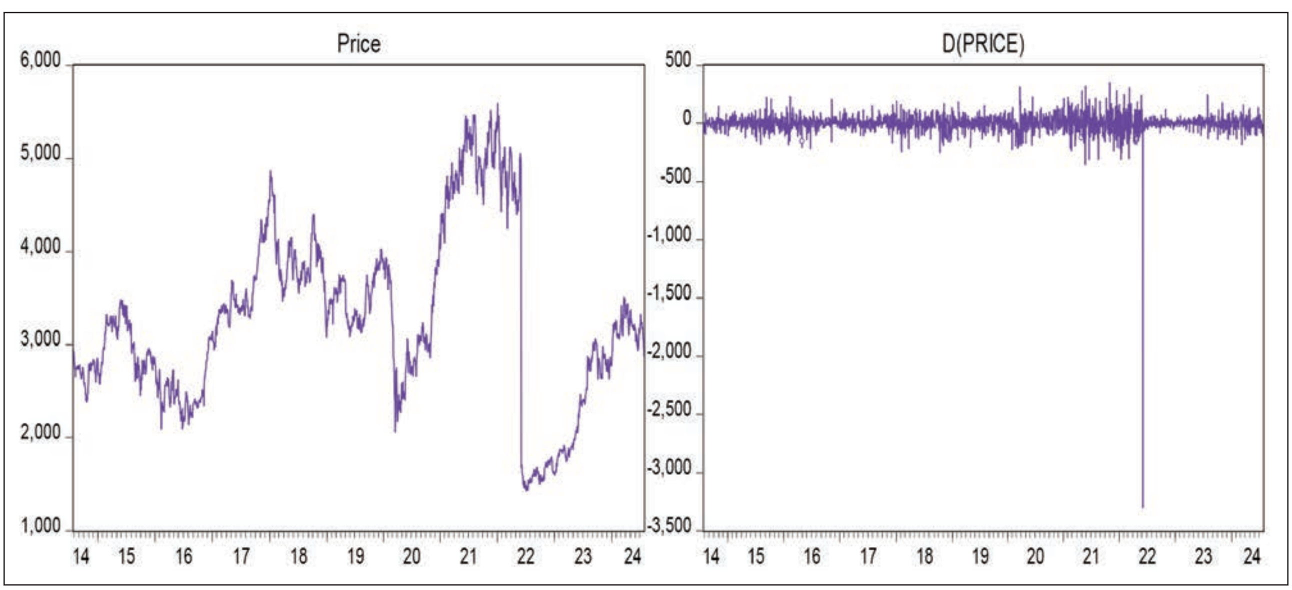


Fig. 4. Toyota Tsusho price and stationery price

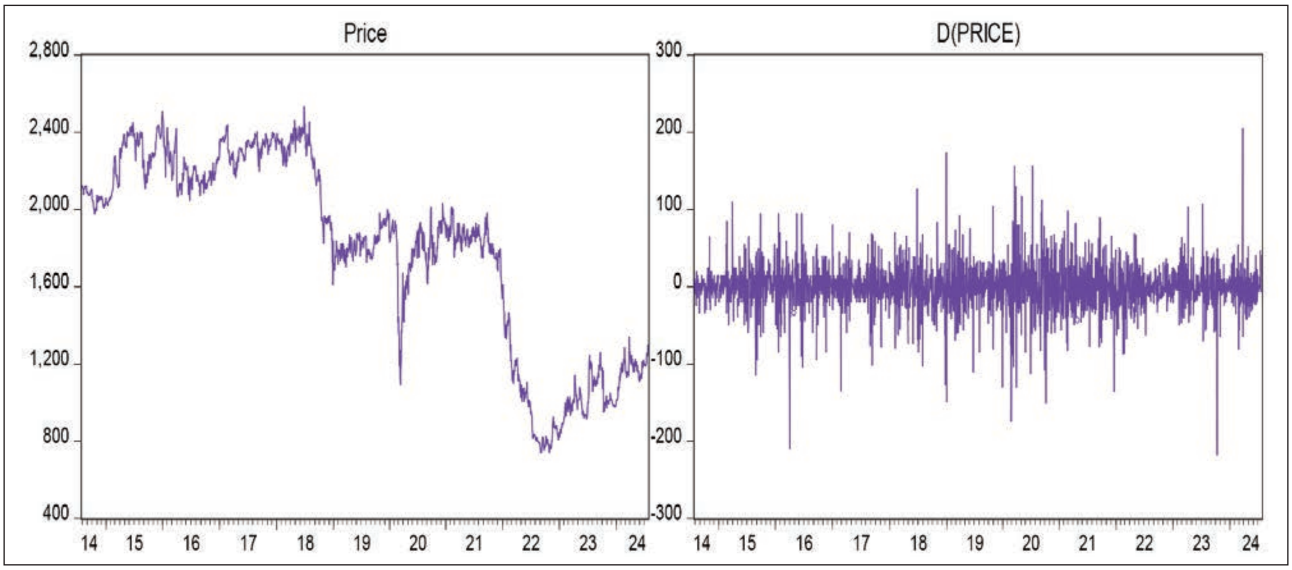


Fig. 5. The Takihyo price and the stationary price

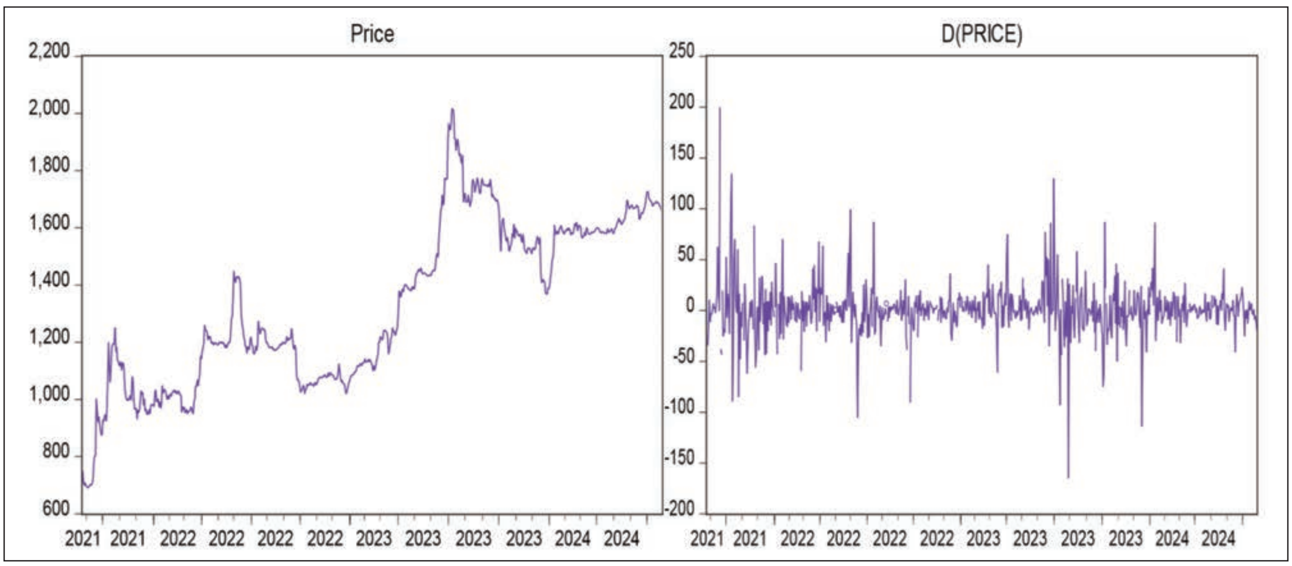


Fig. 6. Global style price and the stationary price

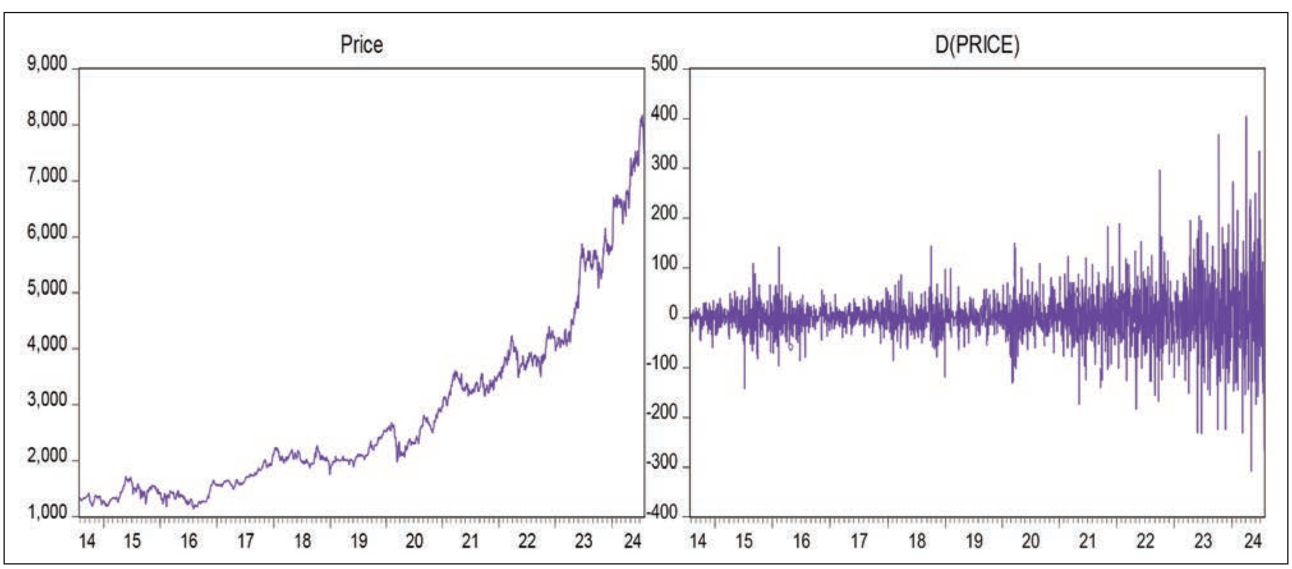


Fig. 7. Itochu price and the stationary price

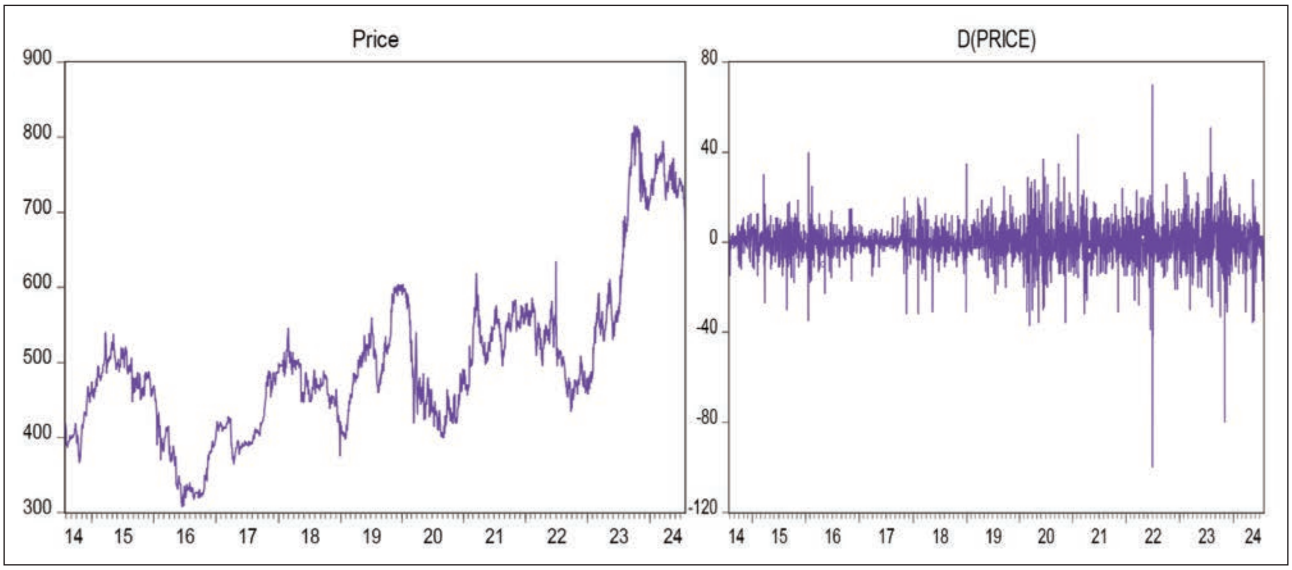


Fig. 8. Sankyo Seiko price and stationery price

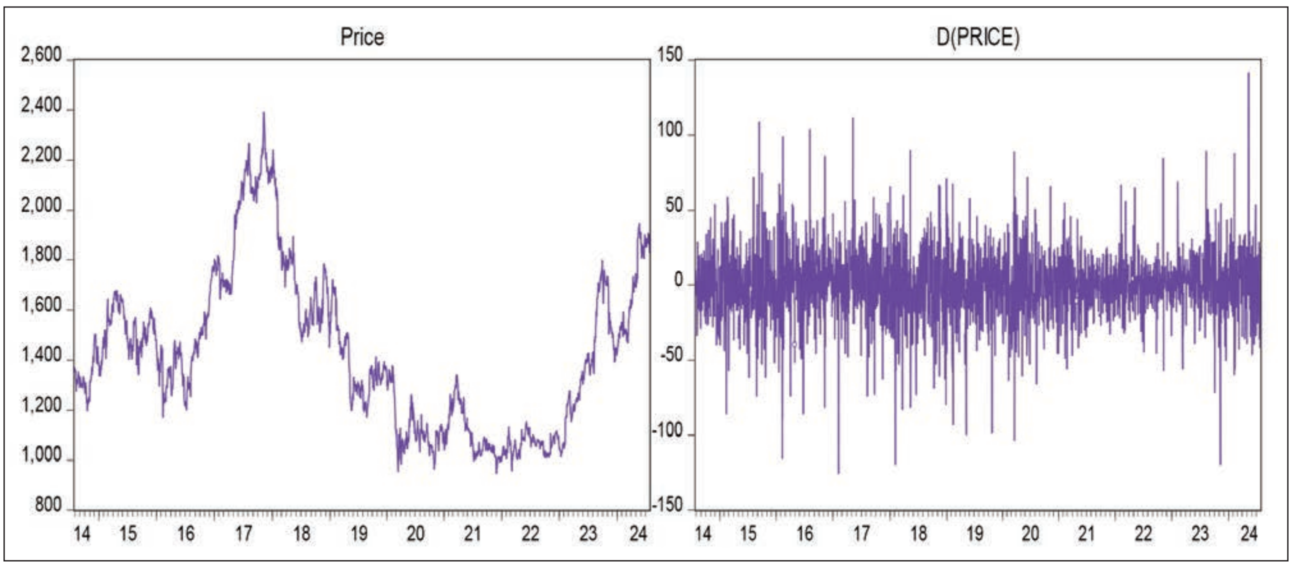


Fig. 9. Kuraray price and stationary price

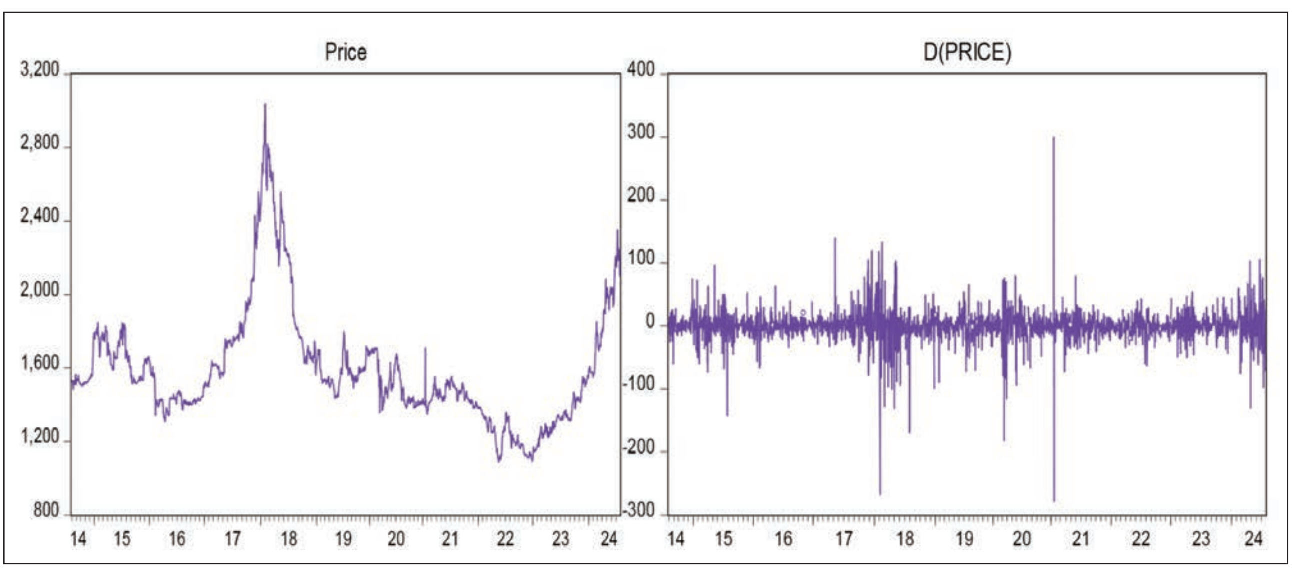


Fig. 10. Yagi price and stationary price

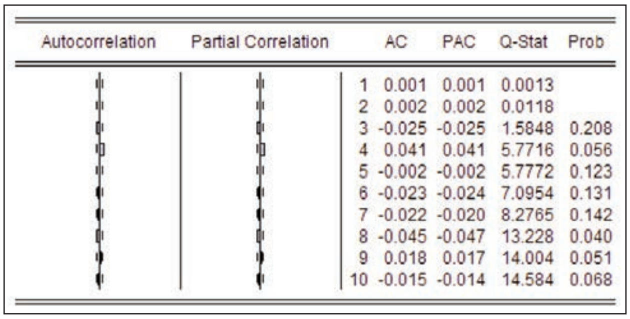
Table 1

DECISION TABLE						
Company name	**Notation**	**Akaike info criterion**	**Schwarz criterion**	**SIGMASQ**	**Adjusted R-squared**	**Significant terms**
Teijin	(0,1,1)	10.58565	10.59277	2310.572	0.123272	2
	(1,1,0)	10.61555	10.62267	2380.764	0.096638	2
	(1,1,1)	10.58443	10.59392	2305.852	0.124704	3
	(2,1,1)	**10.58337**	**10.59049**	**2305.302**	**0.125272**	**3**
	(3,1,1)	10.58594	10.59543	2309.343	0.123379	2
Global Style	(4,1,0)	9.329346	9.348594	653.9238	0.006386	2
	(4,1,4)	9.332155	9.357818	653.9234	0.004983	1
	(0,1,4)	9.329536	9.348783	654.0491	0.006196	2
	(5,1,5)	9.331708	9.357372	653.5419	0.005564	3
	(0,1,16)	9.324168	9.343416	650.3677	0.011789	2
	(16,1,0)	9.324136	9.343384	650.3503	0.011816	2
	(4,1,5)	9.324998	9.350661	649.2253	0.012132	3
	(5,1,4)	9.325139	9.350802	649.3184	0.01199	3
	(4,1,16)	**9.319075**	**9.344739**	**645.2401**	**0.018196**	**3**
Itochu	(6,1,0)	10.62936	10.63648	2413.95	0.000642	3
	(0,1,6)	10.62946	10.63658	2414.199	0.000539	3
	(0,1,7)	10.62932	10.63644	2413.853	0.000682	3
	(0,1,6)	10.62946	10.63658	2414.199	0.000539	3
	(7,1,0)	10.62929	10.63641	2413.788	0.000709	3
	(6,1,6)	**10.62503**	**10.63453**	**2401.394**	**0.005433**	**4**
	(6,1,7)	10.62863	10.63813	2410.205	0.001783	4
	(7,1,6)	10.62871	10.63821	2410.411	0.001698	4
	(7,1,7)	10.62898	10.63848	2411.02	0.001446	4
Kuraray	(4,1,0)	9.169508	9.176631	560.693	-0.000137	1
	(0,1,4)	9.169479	9.176603	560.6769	-0.000108	1
	(20,1,20)	**9.169388**	**9.178886**	**560.1582**	**0.000407**	**1**
	(4,1,20)	9.16966	9.179158	560.3167	0.000125	1
	(20,1,4)	9.169566	9.179064	560.2635	0.00022	1
Toyobo	(1,1,0)	9.395798	9.402921	703.0755	0.00018	2
	(0,1,1)	9.39584	9.402964	703.1053	0.000138	2
	(3,1,0)	9.394003	9.401126	701.8123	0.001976	2
	(0,1,3)	**9.393888**	**9.401012**	**701.7318**	**0.002091**	**2**
Yagi	(1,1,0)	9.30083	9.308044	639.3529	0.004355	2
	(0,1,1)	9.30136	9.308574	639.6922	0.003826	2
	(1,1,1)	9.299622	9.309241	638.0499	0.00597	4
	(2,1,0)	9.302442	9.309656	640.3842	0.002749	2
	(0,1,2)	9.302237	9.309451	640.2525	0.002954	2
	(1,1,2)	**9.298496**	**9.308115**	**637.3312**	**0.00709**	**3**
	(2,1,1)	9.29869	9.308309	637.4548	0.006897	3
Takihyo	(1,1,0)	9.667924	9.675047	922.961	0.007883	2
	(0,1,1)	**9.667635**	**9.674758**	**922.6942**	**0.00817**	**2**
	(1,1,1)	9.668131	9.677629	922.3965	0.008084	2
Toray	(3,1,0)	8.014305	8.021428	176.6146	0.000726	2
	(0,1,3)	8.014128	8.021251	176.5832	0.000903	2
	(3,1,3)	8.013402	8.0229	176.3101	0.00204	3
	(6,1,0)	8.01324	8.020364	176.4259	0.001793	2
	(0,1,6)	8.013173	8.020296	176.4139	0.001861	2
	(3,1,6)	**8.012315**	**8.021813**	**176.1181**	**0.003126**	**3**
	(6,1,3)	8.01238	8.021879	176.1296	0.003061	3
Sankyo Seiko	(1,1,0)	7.274954	7.282077	84.31934	0.021439	2
	(0,1,1)	7.273358	7.280482	84.1848	0.023	2
	(1,1,1)	7.272651	7.282149	84.05627	0.024092	3
	(3,1,0)	7.295584	7.302707	86.07754	0.001034	2
	(0,1,3)	7.2956	7.302723	86.07891	0.001018	2
	(3,1,3)	7.295568	7.305067	86.00556	0.00146	3
	(1,1,3)	7.273677	7.283175	84.14265	0.023089	3
	(3,1,1)	**7.27198**	**7.281478**	**83.99982**	**0.024747**	**3**
Toyota Tsusho	(7,1,0)	11.94521	11.95233	8998.995	0.001888	2
	(0,1,7)	**11.94515**	**11.95227**	**8998.468**	**0.001947**	**2**
	(7,1,7)	11.94594	11.95544	8998.188	0.001568	1

The appropriate order of AR and MA terms was chosen based on the lowest Akaike Info Criterion (AIC), Schwarz criterion, Volatility, and the highest adjusted R-squared value and number of significant terms. The values highlighted in the decision table are identified and chosen based on the discussed criterion. However, we should also look to see if the chosen model is overfitting in nature.

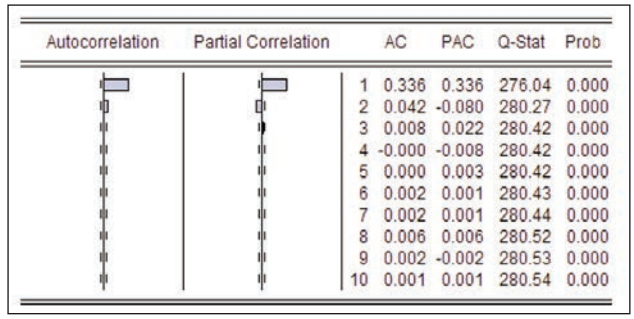
In the Box Jenkins method, the model should be parsimonious, so we will drop the higher value lags, but instead, we will be using lower lags for the analysis. For example, in Global Style, the most appropriate model seems (4,1,16), but (5,1,4) will be our choice. A similar case would be in Kuraray, based on our criteria (20,1,20) is the fittest model, but it will be better if we choose (0,1,4).

Now, after the identification and estimation of the most fit model, it becomes very essential to perform diagnostics on the models and check the residuals.



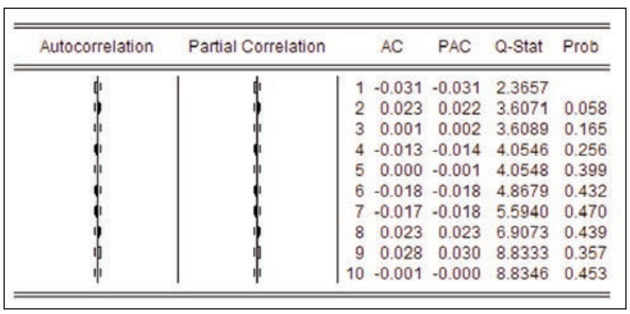
	AC	PAC	Q-Stat	Prob
1	0.001	0.001	0.0013	
2	0.002	0.002	0.0118	
3	-0.025	-0.025	1.5848	0.208
4	0.041	0.041	5.7716	0.056
5	-0.002	-0.002	5.7772	0.123
6	-0.023	-0.024	7.0954	0.131
7	-0.022	-0.020	8.2765	0.142
8	-0.045	-0.047	13.228	0.040
9	0.018	0.017	14.004	0.051
10	-0.015	-0.014	14.584	0.068

Fig. 11. Teijin correlogram of residuals



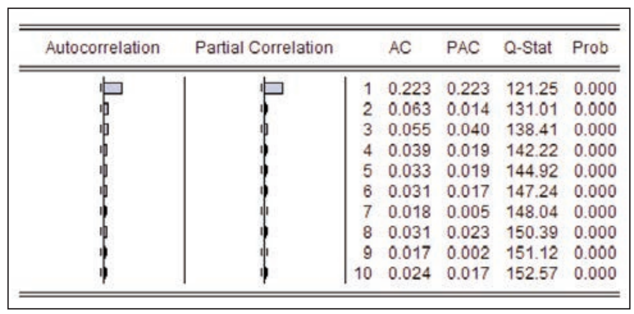
	AC	PAC	Q-Stat	Prob
1	0.336	0.336	276.04	0.000
2	0.042	-0.080	280.27	0.000
3	0.008	0.022	280.42	0.000
4	-0.000	-0.008	280.42	0.000
5	0.000	0.003	280.42	0.000
6	0.002	0.001	280.43	0.000
7	0.002	0.001	280.44	0.000
8	0.006	0.006	280.52	0.000
9	0.002	-0.002	280.53	0.000
10	0.001	0.001	280.54	0.000

Fig. 12. Teijin correlogram of residuals squared



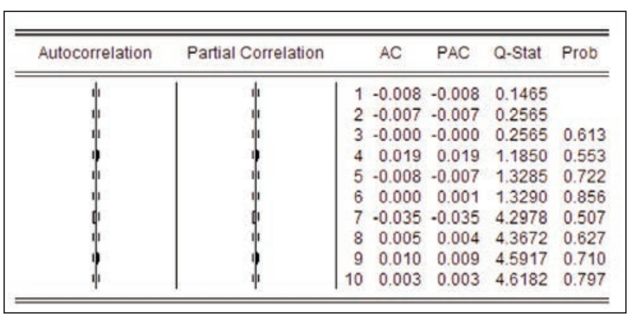
	AC	PAC	Q-Stat	Prob
1	-0.031	-0.031	2.3657	
2	0.023	0.022	3.6071	0.058
3	0.001	0.002	3.6089	0.165
4	-0.013	-0.014	4.0546	0.256
5	0.000	-0.001	4.0548	0.399
6	-0.018	-0.018	4.8679	0.432
7	-0.017	-0.018	5.5940	0.470
8	0.023	0.023	6.9073	0.439
9	0.028	0.030	8.8333	0.357
10	-0.001	-0.000	8.8346	0.453

Fig. 13. Toyobo correlogram of residuals



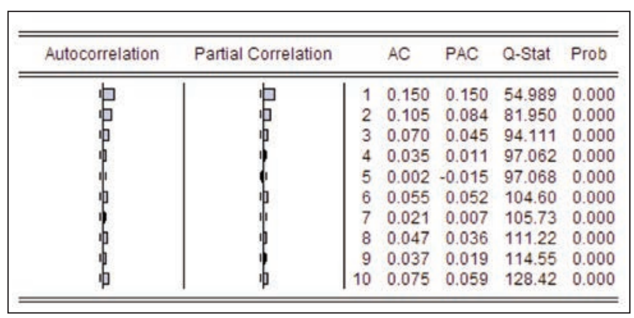
	AC	PAC	Q-Stat	Prob
1	0.223	0.223	121.25	0.000
2	0.063	0.014	131.01	0.000
3	0.055	0.040	138.41	0.000
4	0.039	0.019	142.22	0.000
5	0.033	0.019	144.92	0.000
6	0.031	0.017	147.24	0.000
7	0.018	0.005	148.04	0.000
8	0.031	0.023	150.39	0.000
9	0.017	0.002	151.12	0.000
10	0.024	0.017	152.57	0.000

Fig. 14. Toyobo correlogram of residuals squared



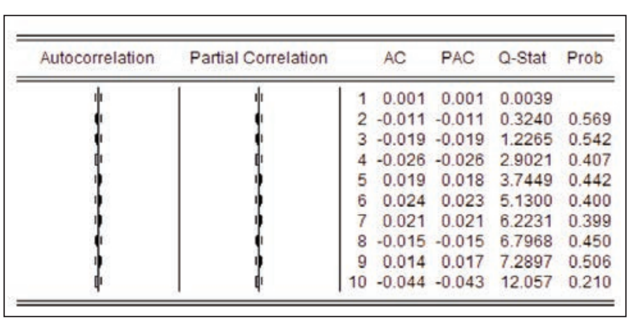
	AC	PAC	Q-Stat	Prob
1	-0.008	-0.008	0.1465	
2	-0.007	-0.007	0.2565	
3	-0.000	-0.000	0.2565	0.613
4	0.019	0.019	1.1850	0.553
5	-0.008	-0.007	1.3285	0.722
6	0.000	0.001	1.3290	0.856
7	-0.035	-0.035	4.2978	0.507
8	0.005	0.004	4.3672	0.627
9	0.010	0.009	4.5917	0.710
10	0.003	0.003	4.6182	0.797

Fig. 15. Toray correlogram of residuals



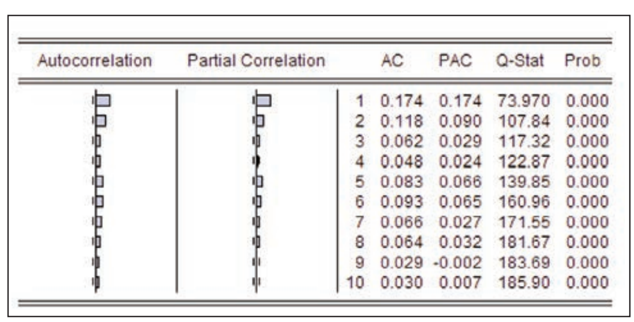
	AC	PAC	Q-Stat	Prob
1	0.150	0.150	54.989	0.000
2	0.105	0.084	81.950	0.000
3	0.070	0.045	94.111	0.000
4	0.035	0.011	97.062	0.000
5	0.002	-0.015	97.068	0.000
6	0.055	0.052	104.60	0.000
7	0.021	0.007	105.73	0.000
8	0.047	0.036	111.22	0.000
9	0.037	0.019	114.55	0.000
10	0.075	0.059	128.42	0.000

Fig. 16. Toray correlogram of residuals squared



	AC	PAC	Q-Stat	Prob
1	0.001	0.001	0.0039	
2	-0.011	-0.011	0.3240	0.569
3	-0.019	-0.019	1.2265	0.542
4	-0.026	-0.026	2.9021	0.407
5	0.019	0.018	3.7449	0.442
6	0.024	0.023	5.1300	0.400
7	0.021	0.021	6.2231	0.399
8	-0.015	-0.015	6.7968	0.450
9	0.014	0.017	7.2897	0.506
10	-0.044	-0.043	12.057	0.210

Fig. 17. The Takihyo correlogram of residuals



	AC	PAC	Q-Stat	Prob
1	0.174	0.174	73.970	0.000
2	0.118	0.090	107.84	0.000
3	0.062	0.029	117.32	0.000
4	0.048	0.024	122.87	0.000
5	0.083	0.066	139.85	0.000
6	0.093	0.065	160.96	0.000
7	0.066	0.027	171.55	0.000
8	0.064	0.032	181.67	0.000
9	0.029	-0.002	183.69	0.000
10	0.030	0.007	185.90	0.000

Fig. 18. The Takihyo correlogram of residuals squared

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.014	-0.014	0.4819	
		2	0.006	0.005	0.5560	0.456
		3	-0.010	-0.009	0.7838	0.676
		4	0.007	0.006	0.8902	0.828
		5	0.025	0.025	2.4141	0.660
		6	-0.025	-0.024	3.8921	0.565
		7	0.000	-0.001	3.8923	0.691
		8	0.010	0.011	4.1315	0.765
		9	-0.001	-0.002	4.1350	0.845
		10	-0.022	-0.022	5.2964	0.808

Fig. 19. Toyota Tshusho correlogram of residuals

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.001	-0.001	0.0007	0.978
		2	-0.001	-0.001	0.0028	0.999
		3	-0.001	-0.001	0.0040	1.000
		4	0.001	0.001	0.0061	1.000
		5	-0.000	-0.000	0.0065	1.000
		6	0.001	0.001	0.0089	1.000
		7	0.007	0.007	0.1464	1.000
		8	-0.001	-0.001	0.1474	1.000
		9	-0.001	-0.001	0.1481	1.000
		10	-0.001	-0.001	0.1500	1.000

Fig. 20. Toyota Tshusho correlogram of residuals squared

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.017	-0.017	0.7214	
		2	-0.014	-0.014	1.1791	0.278
		3	-0.009	-0.010	1.3785	0.502
		4	-0.001	-0.001	1.3792	0.710
		5	0.001	0.001	1.3822	0.847
		6	0.008	0.008	1.5273	0.910
		7	-0.021	-0.021	2.6248	0.854
		8	-0.020	-0.020	3.5870	0.826
		9	0.005	0.003	3.6386	0.888
		10	0.012	0.011	3.9680	0.914

Fig. 21. Kuraray correlogram of residuals

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.152	0.152	56.620	0.000
		2	0.119	0.098	91.367	0.000
		3	0.056	0.026	99.118	0.000
		4	0.038	0.016	102.74	0.000
		5	0.036	0.021	105.96	0.000
		6	0.020	0.005	106.92	0.000
		7	0.036	0.026	110.05	0.000
		8	0.043	0.031	114.55	0.000
		9	-0.005	-0.024	114.62	0.000
		10	0.001	-0.006	114.62	0.000

Fig. 22. Kuraray correlogram of residuals squared

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.000	-0.000	3.E-05	
		2	-0.001	-0.001	0.0052	
		3	-0.007	-0.007	0.1372	0.711
		4	-0.026	-0.026	1.8204	0.402
		5	-0.007	-0.007	1.9407	0.585
		6	-0.009	-0.009	2.1199	0.714
		7	-0.044	-0.044	6.6922	0.245
		8	-0.021	-0.022	7.7138	0.260
		9	0.005	0.005	7.7821	0.352
		10	-0.014	-0.016	8.2901	0.406

Fig. 23. Yagi correlogram of residuals

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.321	0.321	248.56	0.000
		2	0.052	-0.057	255.09	0.000
		3	0.052	0.059	261.71	0.000
		4	0.048	0.017	267.22	0.000
		5	0.085	0.072	284.61	0.000
		6	0.021	-0.034	285.68	0.000
		7	0.050	0.060	291.60	0.000
		8	0.086	0.051	309.48	0.000
		9	0.032	-0.015	311.98	0.000
		10	0.052	0.046	318.45	0.000

Fig. 24. Yagi correlogram of residuals squaredd

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.026	0.026	0.5017	
		2	-0.028	-0.029	1.0822	
		3	0.032	0.034	1.8284	0.176
		4	0.002	-0.001	1.8317	0.400
		5	-0.001	0.001	1.8319	0.608
		6	0.005	0.004	1.8478	0.764
		7	0.003	0.002	1.8528	0.869
		8	0.018	0.018	2.0793	0.912
		9	-0.064	-0.066	5.0616	0.652
		10	0.004	0.009	5.0744	0.750

Fig. 25. Global style correlogram of residuals

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.142	0.142	14.440	0.000
		2	0.067	0.048	17.634	0.000
		3	0.056	0.041	19.877	0.000
		4	0.033	0.017	20.636	0.000
		5	0.009	-0.003	20.695	0.001
		6	-0.006	-0.012	20.722	0.002
		7	0.009	0.009	20.784	0.004
		8	0.076	0.076	24.951	0.002
		9	0.068	0.050	28.314	0.001
		10	0.030	0.007	28.975	0.001

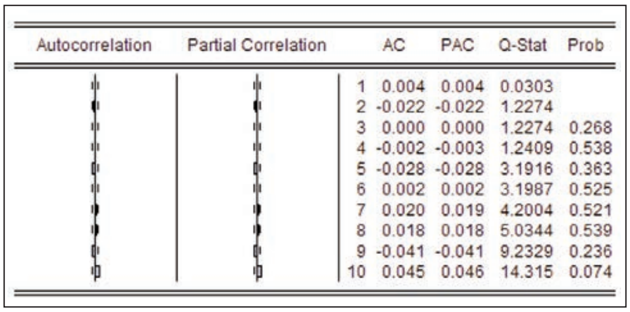
Fig. 26. Global style correlogram of residuals squared

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.006	-0.006	0.1028	
		2	-0.013	-0.013	0.4993	
		3	-0.008	-0.008	0.6512	0.420
		4	-0.006	-0.006	0.7400	0.691
		5	0.019	0.018	1.5790	0.664
		6	0.003	0.003	1.5995	0.809
		7	-0.044	-0.043	6.3055	0.278
		8	-0.004	-0.004	6.3375	0.386
		9	0.007	0.006	6.4431	0.489
		10	0.020	0.019	7.4177	0.492

Fig. 27. Itochu correlogram of residuals

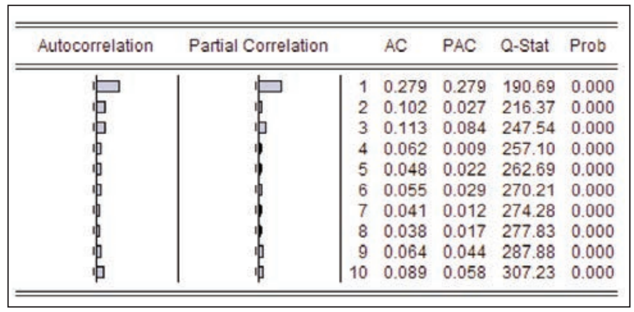
Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.154	0.154	58.290	0.000
		2	0.165	0.144	124.53	0.000
		3	0.194	0.156	216.24	0.000
		4	0.156	0.096	275.52	0.000
		5	0.101	0.028	300.31	0.000
		6	0.115	0.045	332.89	0.000
		7	0.192	0.133	423.74	0.000
		8	0.074	-0.006	437.02	0.000
		9	0.118	0.046	471.33	0.000
		10	0.108	0.026	499.81	0.000

Fig. 28. Itochu correlogram of residuals squared



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.004	0.004	0.0303	
		2	-0.022	-0.022	1.2274	
		3	0.000	0.000	1.2274	0.268
		4	-0.002	-0.003	1.2409	0.538
		5	-0.028	-0.028	3.1916	0.363
		6	0.002	0.002	3.1987	0.525
		7	0.020	0.019	4.2004	0.521
		8	0.018	0.018	5.0344	0.539
		9	-0.041	-0.041	9.2329	0.236
		10	0.045	0.046	14.315	0.074

Fig. 29. Sankyo Seiko correlogram of residuals



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.279	0.279	190.69	0.000
		2	0.102	0.027	216.37	0.000
		3	0.113	0.084	247.54	0.000
		4	0.062	0.009	257.10	0.000
		5	0.048	0.022	262.69	0.000
		6	0.055	0.029	270.21	0.000
		7	0.041	0.012	274.28	0.000
		8	0.038	0.017	277.83	0.000
		9	0.064	0.044	287.88	0.000
		10	0.089	0.058	307.23	0.000

Fig. 30. Sankyo Seiko correlogram of residuals squared

Above are the Correlograms depicting the residuals and their squares, to make the model parsimonious, in two of the cases, models of lower order have been chosen as discussed previously. What is very interesting to note is that we have witnessed an almost perfectly flat residuals chart for all 10 companies taken for the study. This confirms that the models chosen based upon AIC, SC, Sigma Squared, and Adjusted R-squared are a perfect fit.

However, we can observe from the residuals squared correlograms that in most of the cases there are spikes in mostly 1st value of ACF and PACF both except in the case of Kuraray (0,1,4). What can be attributed to this unique phenomenon is related to the impact of extraneous and confounding regressors. For ease of understanding, let's consider it as White noise.

Since the squared residuals do not seem to be serially correlated, we will go ahead with the chosen models. Figures 31–50 present the forecast evaluations of the chosen models.

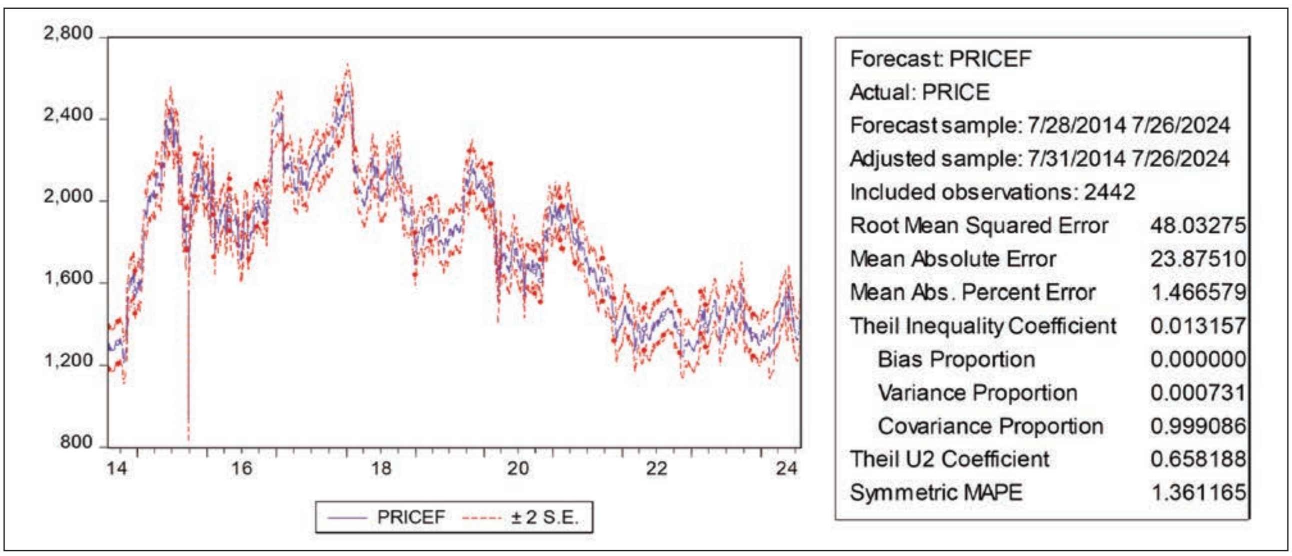


Fig. 31. Teijin forecast graph

Fig. 32. Teijin actual and forecast comparison graph

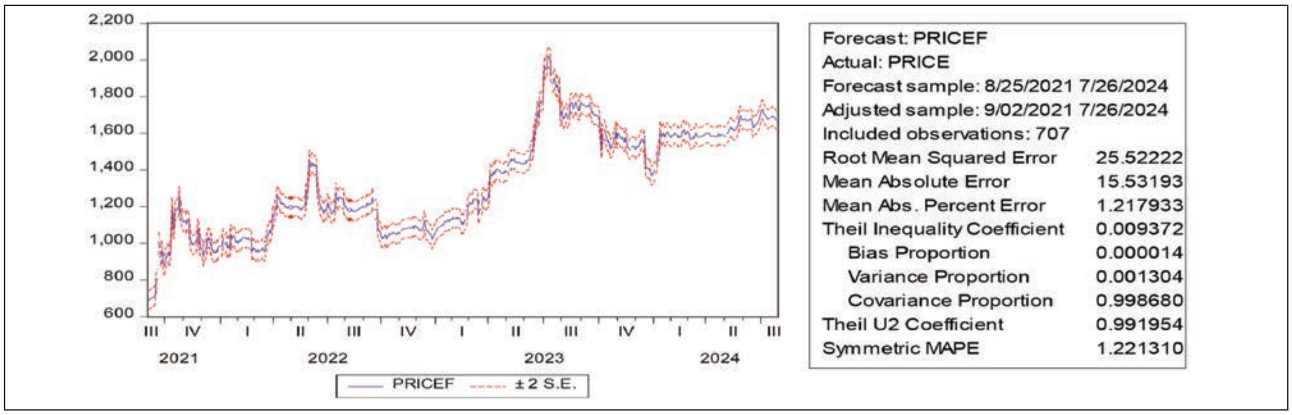


Fig. 33. Global style forecast graph

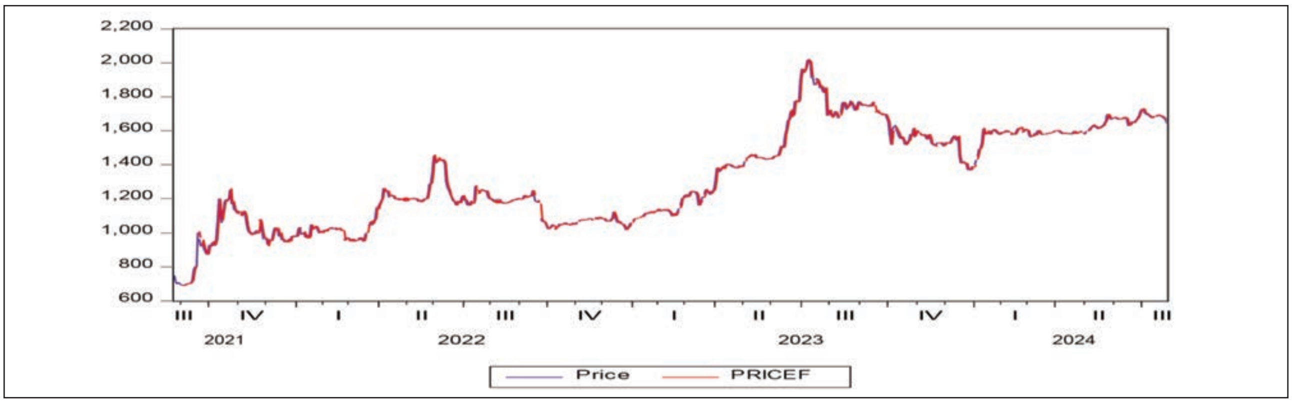


Fig. 34. Global style actual and forecast comparison graph

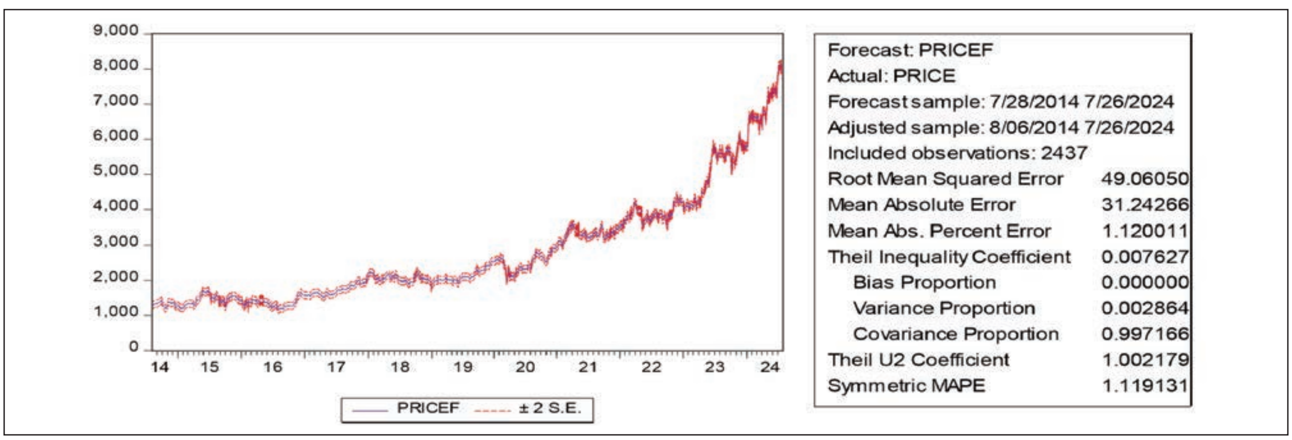


Fig. 35. Itochu forecast graph

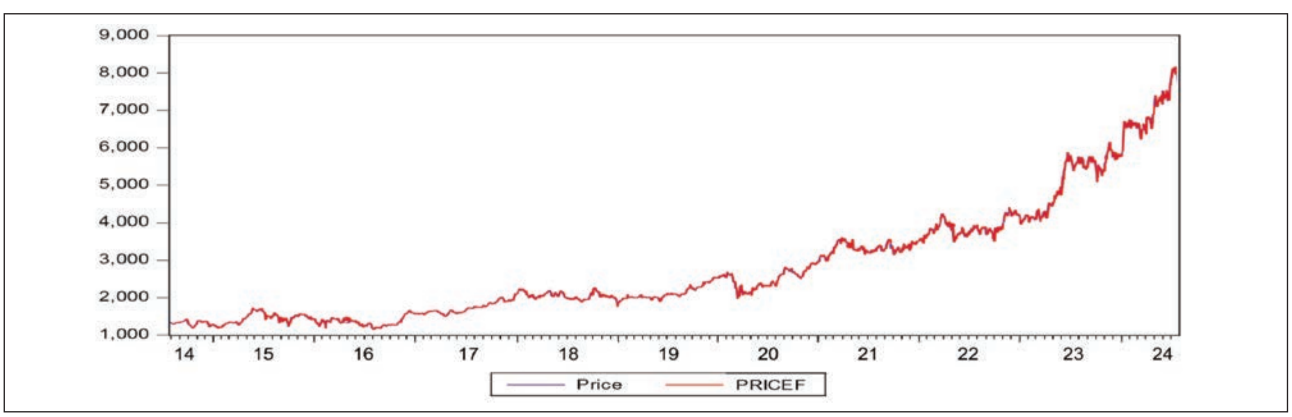


Fig. 36. Itochu actual and forecast comparison graph

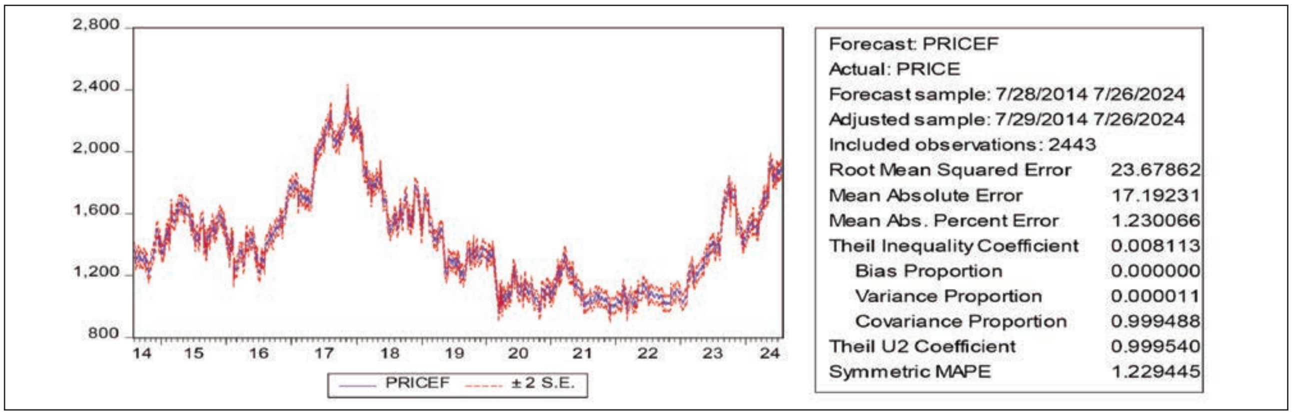


Fig. 37. Kuraray forecast graph

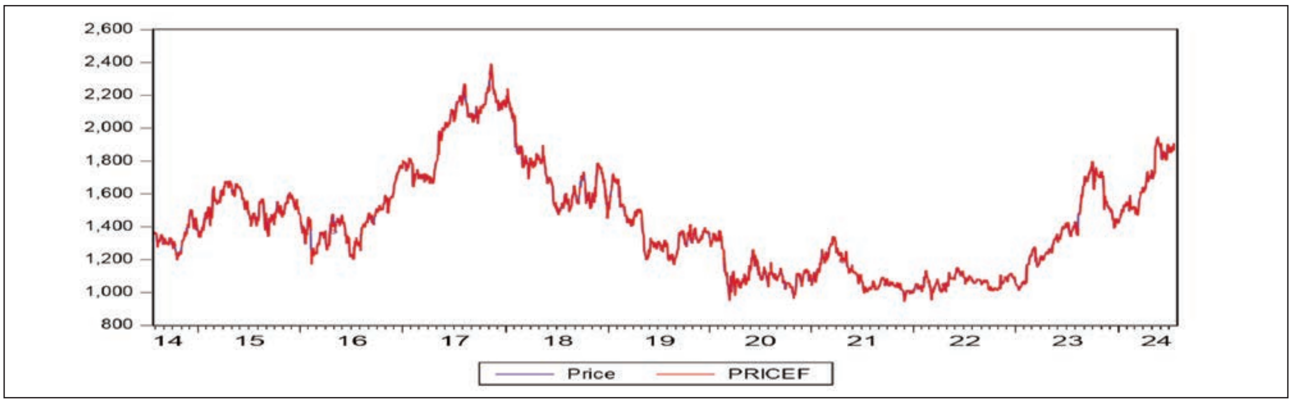


Fig. 38. Kuraray actual and forecast comparison graph

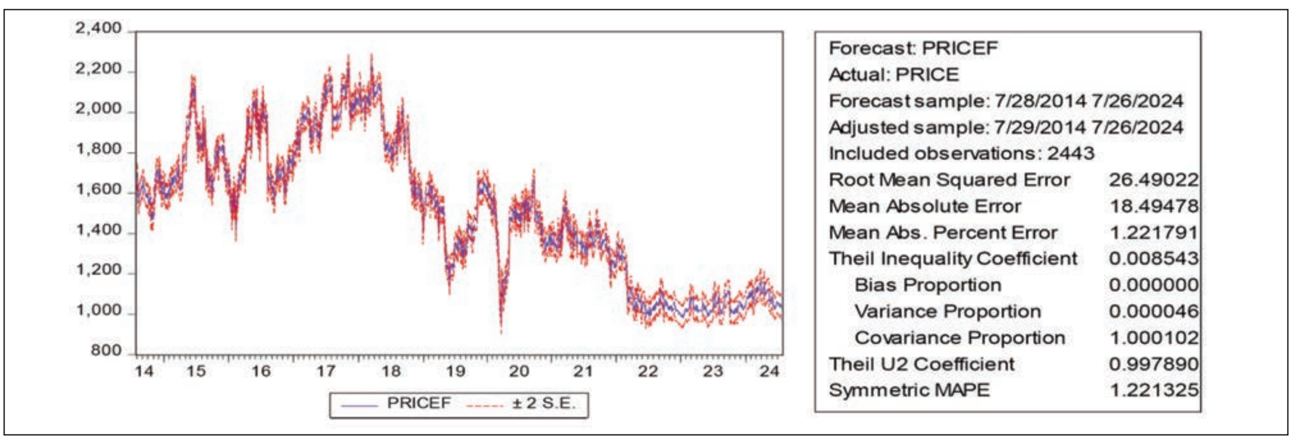


Fig. 39. Toyobo forecast graph

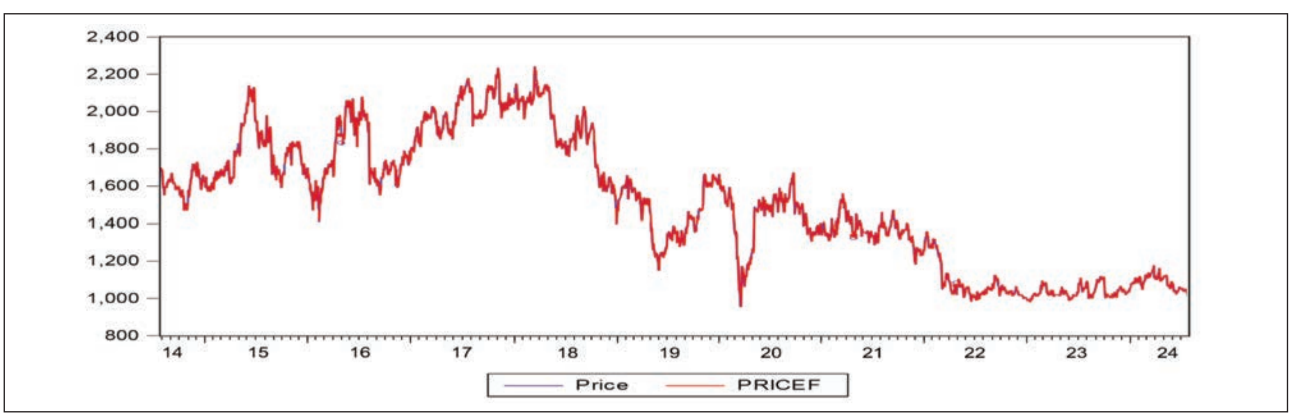


Fig. 40. Toyobo actual and forecast comparison graph

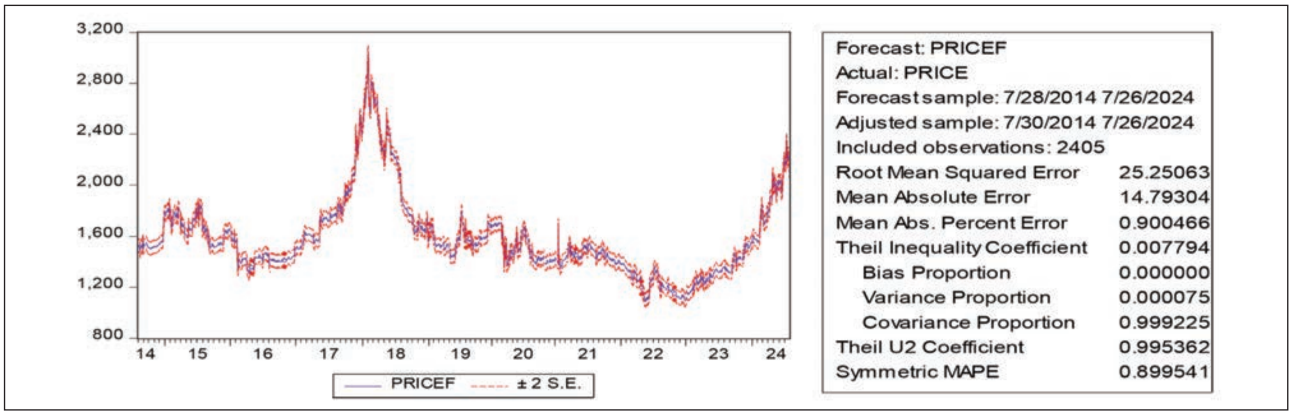


Fig. 41. Yagi forecast graph

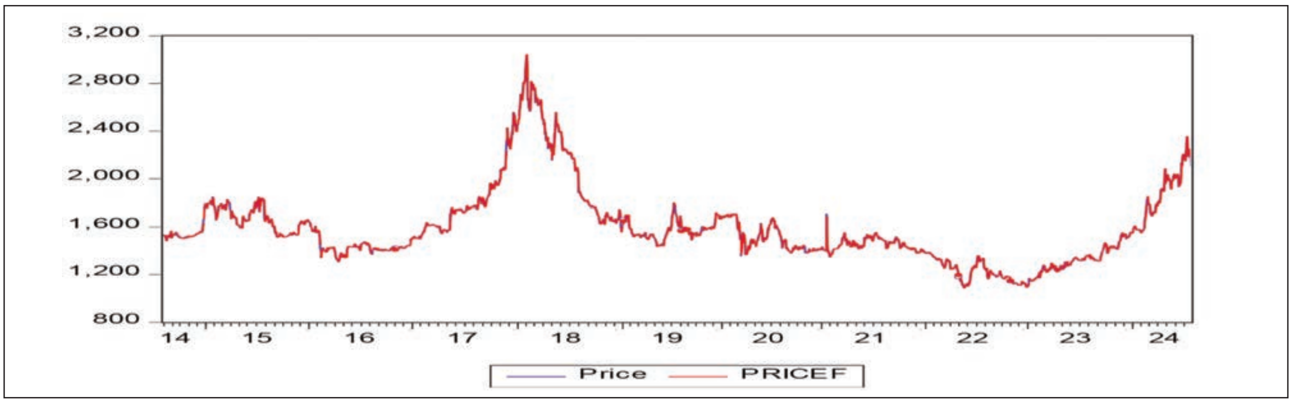


Fig. 42. Yagi actual and forecast comparison graph

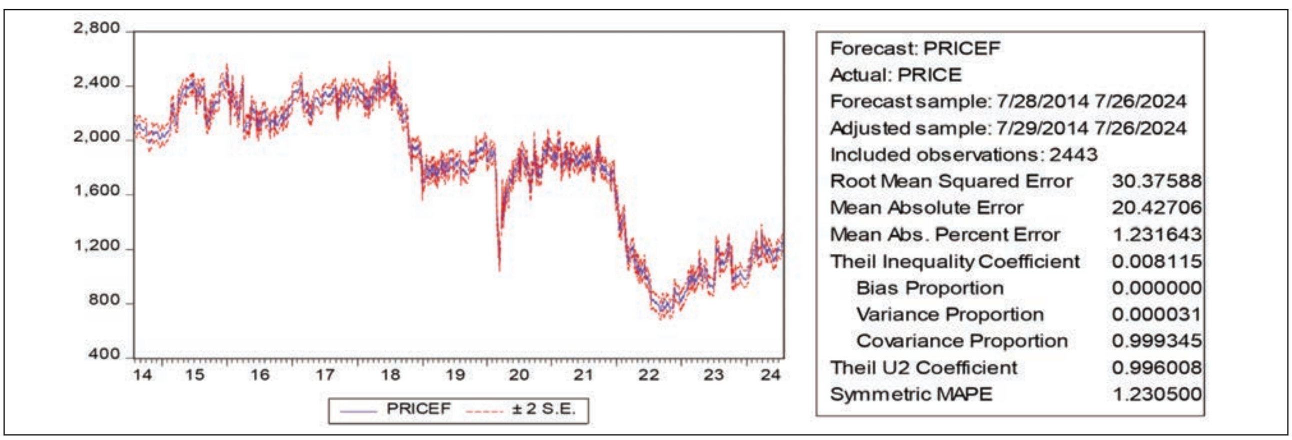


Fig. 43. Takihyo forecast graph

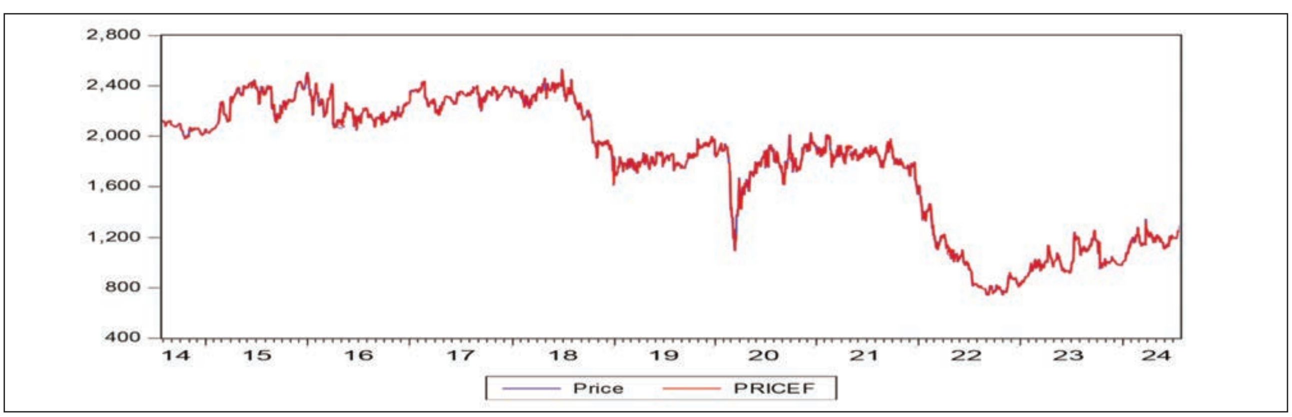


Fig. 44. Takihyo actual and forecast graph comparison

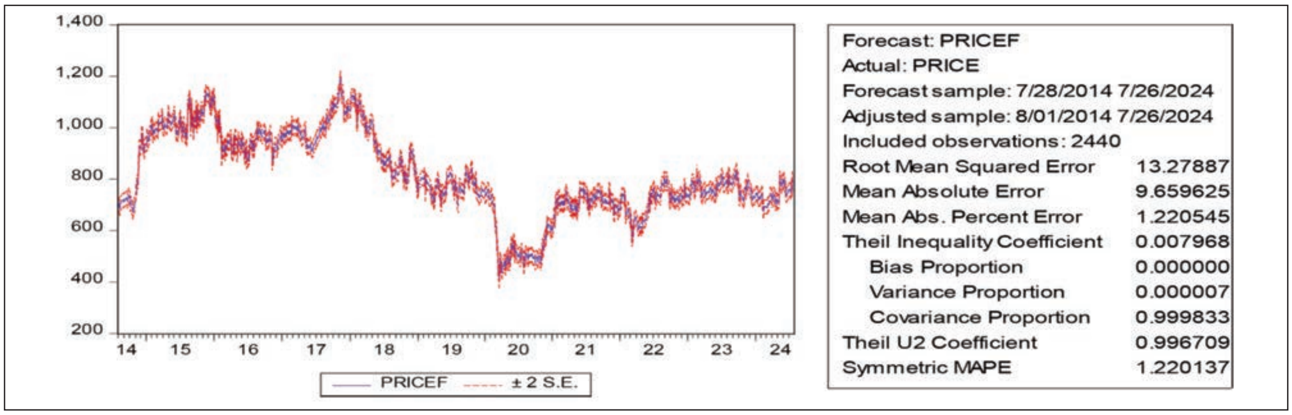


Fig. 45. Toray forecast graph

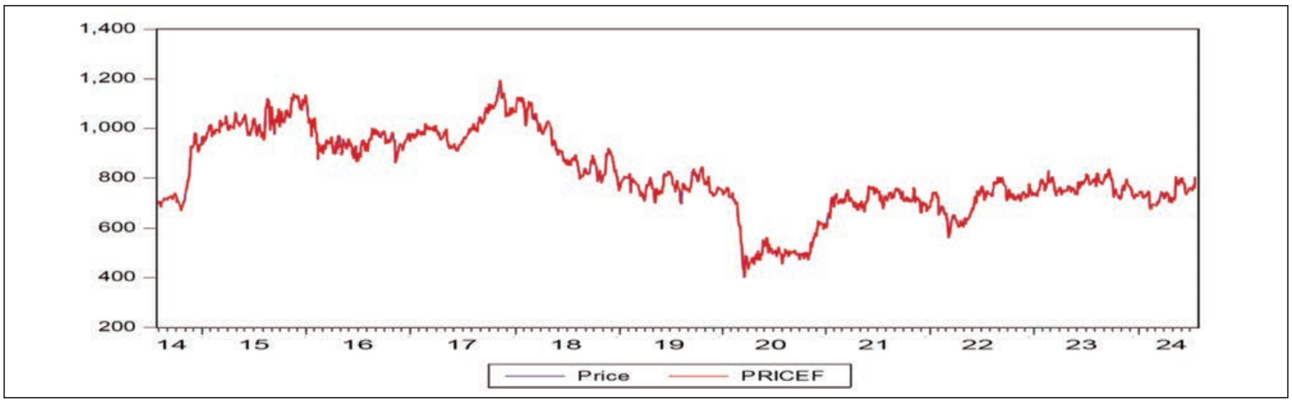


Fig. 46. Toray actual and forecast comparison graph

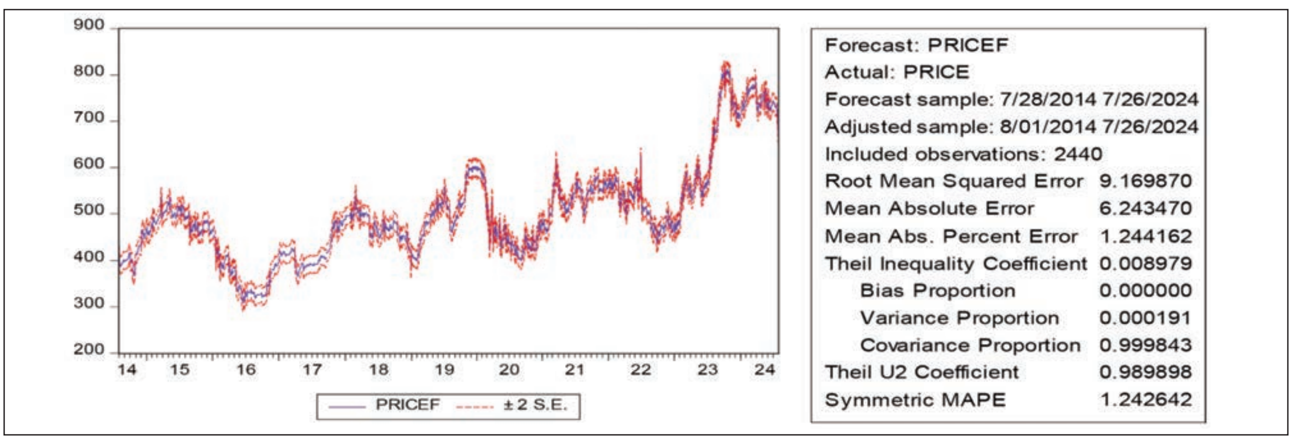


Fig. 47. Sankyo Seiko forecast graphh

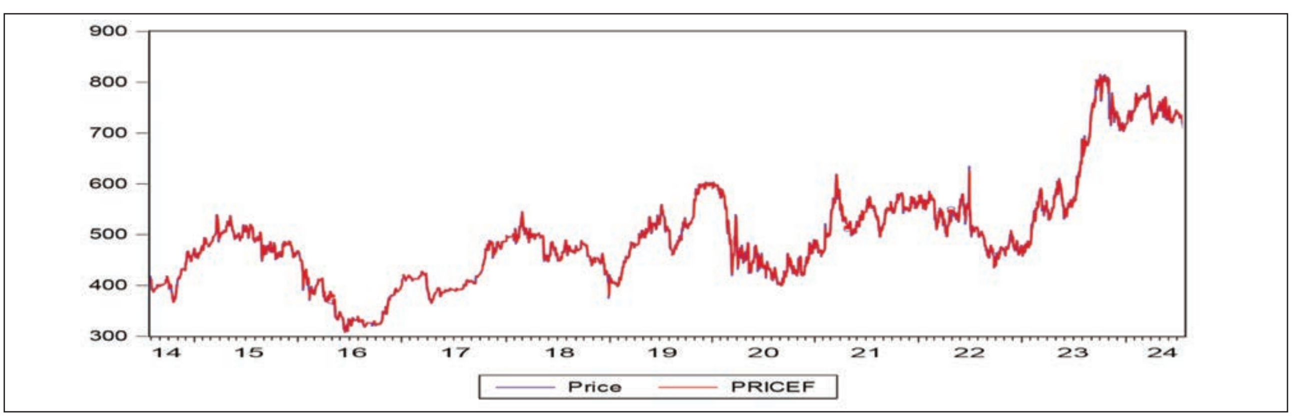


Fig. 48. Sankyo Seiko actual and forecast comparison graph

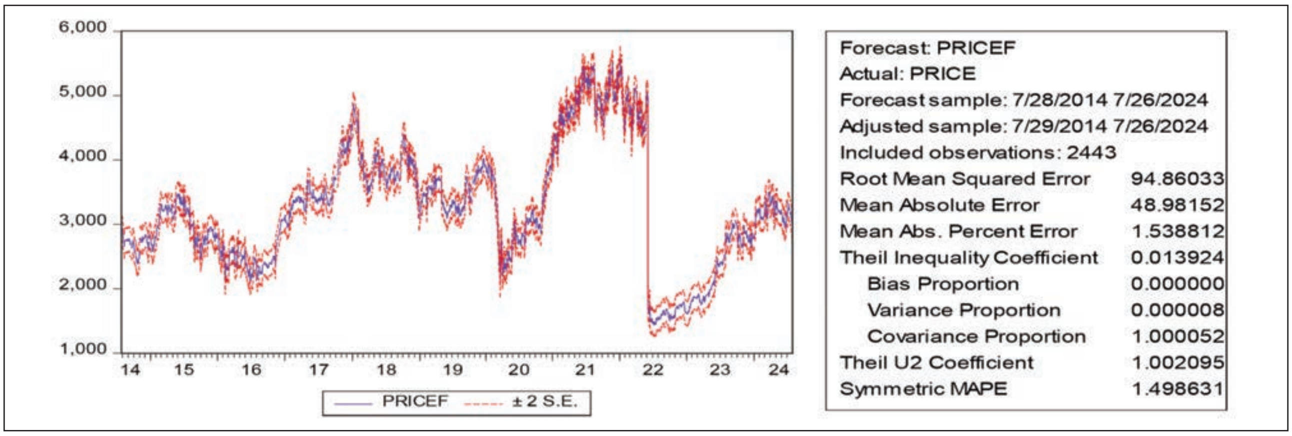


Fig. 49. Toyota Tsusho forecast graph

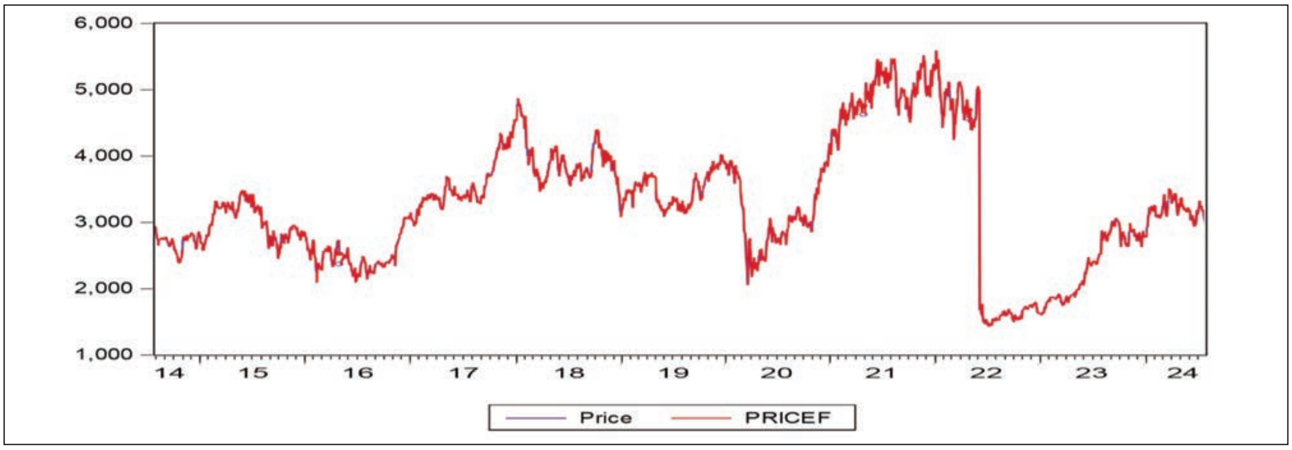


Fig. 50. Toyota Tsusho Actual and Forecast Comparison Graph

From the Symmetric MAPE value, it is clear that the forecasted values are likely precise, and the value is always around 1.5 or below. Mean error values are also very low, and it is mostly around 1 and 1.4. In the case of Yagi, we have achieved excellent forecasting statistics. It is also to be noted that the statistics prove some room for imperfections, which signifies that our chosen models are not overfitting in nature.

From comparison graphs, it is also evident that the values between the forecasted and actual values are quite similar, and the difference is quite low. The accuracy can also be estimated from the Covariance Proportion value of the forecast statistics, which is in all cases approximately equivalent to 1.

Now let us look at the nature of the model and the Prices of the 10 companies chosen for the study through a table.

Before moving further to the values discussed in table 2, we should first understand a few things in advance. The notation denotes the order of ARIMA

Table 2

MODEL PREDICTIONS OF AUTOCORRELATIONS

Company name	Notation	Intercept	AR (p)	MA(q)
Teijin	(2,1,1)	0.053521	–0.0511	–0.37764
Global Style	(5,1,4)	1.22291	0.084719	0.096148
Itochu	(6,1,6)	2.513588	–0.9099	0.873841
Kuraray	(0,1,4)	0.196592	-	0.027223
Toyobo	(0,1,3)	–0.27654	-	–0.05487
Yagi	(1,1,2)	0.259149	–0.06773	0.057988
Takihyo	(0,1,1)	–0.34529	-	–0.09649
Toray	(3,1,6)	0.027799	–0.04093	–0.05358
Sankyo Seiko	(3,1,1)	0.101501	–0.04698	–0.16094
Toyota Tsusho	(0,1,7)	–0.02031	-	–0.05296

forecasting in the form (p,d,q). The intercept denotes the constant term, signifying the average value of the price of the first difference when all the other values are constant.

The AR(p) denotes the autoregressive term of order p, meaning the current value of the first differenced price is influenced by its past p values. The MA(q) denotes the moving average of order q, meaning the current value of the differenced price is influenced by the residual of q periods ago. The coefficients of AR and MA denote the direction and strength of the influence of AR and MA on future values.

This should be noted that a positive coefficient of AR and MA leads to a positive value in the present, and a negative value suggests a negative relationship.

Now coming to the values of the table, firstly we should acknowledge that except for Itochu, none of the companies have a Significant intercept P-value at a 95% confidence level. In most cases, either the present values are not impacted by the AR term, that is, the autoregressive values of the past or are negatively impacted, except in the case of Global Style. It is also surprising to note that the present values are impacted less than 10% in all the cases, except Itochu, having a negative impact of almost 91%.

When taking into consideration MA terms, that is the impact due to past residuals or error terms, it has a certainly higher impact on present value than AR terms. Mostly, it is also negatively impacting the present values, but also positive in some cases, like Global Style, Kuraray, Itochu and Yagi. Again, Itochu is highly impacted by the MA terms, with an impact of almost 87%.

At this moment, it is also very important to note that none of the terms in Kuraray were found statistically significant, but still, the model accurately predicts the values. Additionally, it should be noted that the textile industry is impacted by its past values and residuals for up to a week.

CONCLUSION, RECOMMENDATIONS AND SUGGESTIONS

Japan has had a rich legacy of textiles for more than 1000 years and has been maintained even though it was not formally part of the Silk Route trade, along with all the historical crests and troughs Japan faced, including events revolving around before and after the Meiji Revolution. Like other industries, the textile industry also thrived in Japan, and in 2022, it was the 20th largest textile exporter in the world with an export of $8.11 billion. One thing that needs to be noted here is that Japan is a world leader and the largest producer of technical textiles.

Not much study about the Japanese textile sector as a whole has been conducted regarding the stock prices of Japan's major textile companies. 10 companies were studied, chosen based on the document on textiles published by the EU-Japan centre based on market capitalisation, with almost 10 years of historical data from 2014 to 2024 studied through appropriate ARIMA models identified through the Akaike info Criterion, Schwarz Criterion, Sigma squared value and R-squared value. The companies chosen included Teijin, Global Style, Itochu, Kuraray, Toyobo, Yagi, Takihyo, Toray, Sankyo Seiko, and Toyota Tsusho. Except for Global Style, all the companies have 10 years of data. The (p, d, q) values of the analysis included (2,1,1), (4,1,16), (6,1,6), (20,1,20), (0,1,3), (1,1,2), (0,1,1), (3,1,6), (3,1,1), (0,1,7) respectively in the order as the corporations are previously mentioned. To make the model parsimonious, higher values were dropped, and values of lower order were preferred. After identification of the appropriate models, it was diagnosed for the presence of any squared residuals was diagnosed. In all the cases, no presence was established. However, in squared analysis, except for Kuraray, a spike in the first value of ACF and PACF was observed, attributed to extraneous and confounding nature variables (considering white noise for simplicity), and it should be noted that squared residuals were not serially correlated. Upon evaluation of models, it was found that most of the corporations had either a negative impact or no impact of past lagged values on their present value, except for Global Style, which had a positive influence, maybe due to its distinct nature of textile products in comparison to other corporations. Similarly, Itochu was 91% affected by its own past lagged values, maybe due to its huge operations in textiles as well as other sectors distinct from textiles. Mostly due to lagged value of past residuals, all the corporations were negatively affected, but Global Style, Kuraray, Itochu and Yagi were positively impacted, and there was a huge impact seen in terms of Itochu.

On average, all the Japanese textiles taken into consideration are impacted by their past values and residuals by almost a week. It can be noted that most of the Japanese textile corporations react to the market dynamics and macroeconomic variables similarly but the reason for the difference in reaction is due to the structure of the corporations where most of the corporations have a deep-rooted textile legacy with similar scale of operations in other sectors as well, this makes stock prices vulnerable to muti fluctuations due to varied reasons. ARIMA seemed to be a fine model in order to analyse and predict stock prices, but it has been established by many studies that machine learning models, in most cases, have better accuracy in predictions. One of the most common Machine Learning models is LSTM. This model is a derivative of RNN. Due to a lack of training and constraints on various fronts, employing machine learning models didn't seem feasible. However, there are several advanced models like Support Vector Model (SVM), Recurrent Neural Network (RNN), Long Short-Term Memory (LSTM), Artificial Neural Network (ANN), Random Forest decision tree, XGBoost, etc., that could have been used and may be more efficient than ARIMA. This paper was a novel step in understanding the movement of textile companies in a freely traded financial market, which is reflective of the sentiments of the corporation. Future researchers are recommended to consider the gaps and limitations of this study and then work on the hidden aspects that this paper was unable to identify and address. It is suggested that the use of machine learning seems imperative, but all the models have their accuracy, efficiency and limitations under certain circumstances, along with outperforming capabilities in some situations.

Hence, researchers would be required to evaluate the proper scenario and then employ the preferred model. But one major limitation of this research is its inability to account for external factors that can significantly influence the stock prices of Japanese textile companies. The model primarily focuses on historical price data, overlooking variables such as fluctuations in raw material costs, exchange rates, changes in trade policies, and evolving consumer preferences for sustainable products. These external factors can lead to sudden, unpredictable market movements, reducing the accuracy of purely time series-based predictions. Future studies may address this limitation by integrating external macroeconomic indicators and sentiment analysis to enhance predictive accuracy and better capture the complexities of the market. Similarly, in the present era of machine learning, while the ARIMA model is suitable for time series analysis due to its simplicity and effectiveness in capturing linear trends, it has limitations in predicting complex, non-linear stock price movements. The model relies heavily on the assumption of stationarity and cannot effectively handle sudden market changes or intricate patterns influenced by external factors. As a result, it may fall short in forecasting highly volatile or irregular stock prices of Japanese textile companies. Future research could explore advanced machine learning models, such as Long Short-Term Memory (LSTM) networks, which are better equipped to learn non-linear dependencies and capture long-term trends, potentially offering greater robustness and accuracy in predictive analysis.

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A new method for developing interactive courses in smart textiles

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ABSTRACT – REZUMAT

A new method for developing interactive courses in smart textiles

This paper presents the essential aspects of the impact of intensive learning materials using online interactive courses and mobilities for learning organised in the ADDTEX Erasmus+ project for involving students in transnational cooperation-based working groups for smart textile prototype development. The e-learning tools and methods (interactive videos, quizzes and smart prototype development), in both asynchronous and synchronous formats, used in the framework of the ADDTEX Erasmus+ project revealed a successful acceptance of the end-users (students and young researchers) attending the online courses through the ADDTEX platform providing Massive Open Online Courses (MOOCs) and hackathons organized in comparison with classical teaching methods without digitilased courses and practical prototype development. Also, the on-site summer school organised in Prato, Italy, came with the possibility of working in transnational teams and contributing to the documentation and creation of prototypes and appropriate business plans. At the end of this activity, the students presented the prototypes and business canvas model developed in teams and received rigorous feedback from smart textile industry specialists. The asynchronous learning format allowed students and young researchers to familiarise themselves with green and digital transitions and smart textiles in the EU context. The synchronous e-learning organised in the hackathon format allowed students to interact with companies and clusters and solve the challenges proposed by the industry. The lesson content on ADDTEX MOOC has been delivered in an attractive format using interactive videos, graphics, animation and videos with digital teachers explaining the course.

Keywords: *green, digital, smart, transition, e-learning, textile*

O nouă metodă pentru dezvoltarea cursurilor interactive pentru textile inteligente

Această lucrare prezintă aspecte esențiale ale impactului cursurilor interactive pentru învățare intensivă online și mobilitățile de învățare organizate în cadrul proiectului ADDTEX Erasmus+ implicând studenți în grupuri de lucru bazate pe cooperare transnațională pentru dezvoltarea de prototipuri de textile inteligente. Instrumentele și metodele de e-learning (videoclipuri interactive, chestionare și dezvoltarea de prototipuri inteligente), atât în format asincron, cât și sincron, utilizate în cadrul proiectului ADDTEX Erasmus+ au arătat o acceptare cu succes din partea utilizatorilor finali (studenți și tineri cercetători), care au participat la cursurile online prin intermediul platformei ADDTEX, care oferă Cursuri Online Masive Deschise (MOOC), și hackathon-uri organizate în comparație cu metodele clasice de predare, fără cursuri digitalizate și dezvoltare practică de prototipuri. De asemenea, școala de vară organizată în Prato, Italia, a adus posibilitatea de a lucra în echipe transnaționale și contribuie la documentarea și crearea unor prototipuri și planuri de afaceri adecvate. La finalul acestei activități, studenții au prezentat prototipurile și planurile de afaceri utilizând modelul business canvas dezvoltate în echipe și au primit un feedback riguros din partea specialiștilor din industria textilă. Formatul de învățare asincronă le-a permis studenților și tinerilor cercetători să se familiarizeze cu tranziția verde și digitală și cu textilele inteligente în contextul UE. Învățarea online sincronă organizată în format hackathon le-a permis studenților să interacționeze cu companii și clustere și să rezolve provocările propuse de industrie. Conținutul lecțiilor de pe MOOC-ul ADDTEX a fost livrat într-un format atractiv, utilizând videoclipuri interactive, grafică, animație și videoclipuri cu profesori care au explicat cursul.

Cuvinte-cheie: *verde, digital, inteligent, tranziție, e-learning, textile*

INTRODUCTION

The technical textiles industry in the EU-27 is crucial, contributing about 30% of the total textile turnover and experiencing a notable 27% increase in overall textile production. To support this industry, current and future employees should enhance their knowledge by taking courses in technical textiles. This includes learning about the development of smart textiles and utilising digital, green, and smart specialisation. These educational opportunities can be accessed through MOOCs, digital assessments, and short intensive learning events such as bootcamps and hackathons.

In general, MOOCs (Massive Open Online Courses) provide access to online courses for learners, offering flexibility for students and citizens without requiring formal registration at an institution. This approach facilitates knowledge sharing within civil society. The online courses are open-licensed, free of charge, and allow open entry, meaning attendees do not need to provide any prior information about diplomas or certificates. The ADDTEX MOOCs developed are sustainable because future learners can choose specific study programs related to smart textiles in the context of digital and green transitions.

“Bootcamp” is frequently used in ICT programming and focuses on developing digital skills. It represents a specialised, intensive training program centred on high-impact educational courses [1]. These courses aim to equip students with practical, job-ready tech skills within a short timeframe [2], with the ultimate goal of enhancing participants’ technical knowledge and soft skills [3]. The benefits of participating in such a bootcamp include an immersive learning experience, tailored guidance for prototype development, opportunities for students to network with industry professionals, and access to career coaching and support [2]. Interestingly, the concept of a bootcamp originated from the U.S. Army forces that intensively train troops to achieve optimal performance within a short time [3].

The main objective of the ADDTEX Erasmus+ project was to develop a Massive Open Online Course (MOOC) platform that offers innovative training and learning materials in advanced textile materials. This platform is intended to enhance technicians, graduates, engineers, managers, and mentors’ knowledge of advanced textiles, particularly in smart, digital, and green manufacturing. The project involved learners – students and employees – in various activities such as online courses, hackathons, a mobility program, and bootcamp to achieve this goal. Additionally, a new ADDTEX hub was established to facilitate industry upskilling.

The ADDTEX Erasmus+ project offered online interactive courses and a Summer School bootcamp to provide a holistic learning experience for participants, including trainees, teachers, and experts. The project employs various e-learning tools and methods, catering to both asynchronous and synchronous formats. The goal of the ADDTEX mobility (bootcamp) was to enhance students’ and young researchers’ green, digital, managerial, and communication skills in the creative industries, particularly in producing smart textiles. Students gained skills to develop smart prototypes addressing sustainability, safety, and societal needs. Furthermore, the on-site Summer School, held in Prato, Italy, offered a unique opportunity for participants to engage in transnational collaboration, contributing to developing prototypes and business plans. The culminating presentations of these prototypes provide students with invaluable feedback from specialised professionals in the textile industry. The asynchronous learning format within the project serves as a platform for students and young researchers to immerse themselves in the intricate facets of green and digital transitions and smart textiles within the context of the European Union.

On the other hand, synchronous e-learning, mainly through the hackathons format, facilitates direct interaction with companies and industry clusters, enabling students to address and resolve real-world challenges proposed by the industry. In addition, the ADDTEX MOOC is designed to deliver engaging lesson content, incorporating a myriad of multimedia elements such as videos, graphics, animations, and comprehensive explanations provided by educators. This approach ensures that participants are thoroughly engaged and empowered throughout their learning journey within the project.

COURSE DEVELOPMENT

In the framework of the ADDTEX project, INCDTP was involved in the development of courses from smart and digital transition categories. The smart transition courses for Managers and Mentors contain seven lessons, from which INCDTP developed 1 lesson related to Innovations linked to smart, intelligent textiles. From smart transition courses, INCDTP developed the module “Innovations linked to smart (figure 1), intelligent textiles” for different levels (e.g. Managers and Mentors, Engineers and Professionals, respectively Technicians and Graduates). To assess the knowledge gained from the digital materials, students completed quizzes consisting of a maximum of five questions within 15 minutes. Upon finishing the online lessons and demonstrating their knowledge through the assessment, the ADDTEX MOOC platform automatically generates a certificate confirming the successful completion of the course (figure 2).

The learning module developed by INCDTP for Managers and Mentors is elaborated to provide a comprehensive understanding of cutting-edge innovations in smart textiles. These innovations encompass a wide array of applications, including but not limited to health monitoring, rehabilitation, protective equipment for various industries, military applications, augmented human capabilities, and sophisticated devices such as supercapacitors and harvesting devices. Furthermore, the module also contains the intricate integration of advanced software and hardware, equipping participants with a thorough understanding of the technological landscape in this domain. Smart textiles for health state monitoring refer to developing advanced fabric-based materials with embedded sensors to monitor various biomedical parameters continuously. These textiles are knitted garments, and the integrated sensors can track vital signs such as heart rate, body temperature, and movement, providing real-time data for health monitoring purposes. This innovative technology has the potential to revolutionise healthcare by allowing for non-invasive, continuous monitoring of an individual’s health status, leading to early detection of health issues and more personalised medical interventions. (figure 3).

In the context of rehabilitation, textile-based systems integrating actuators have proven to be instrumental in facilitating the recovery of impaired body functions. These systems encompass a variety of innovative technologies, each designed to address specific rehabilitation needs. These technologies include smart gloves [5] equipped with advanced sensor and actuator technology, allowing for precise and targeted rehabilitation of hand and finger movements. Arm exoskeletons, integrating textiles with rigid mechanical

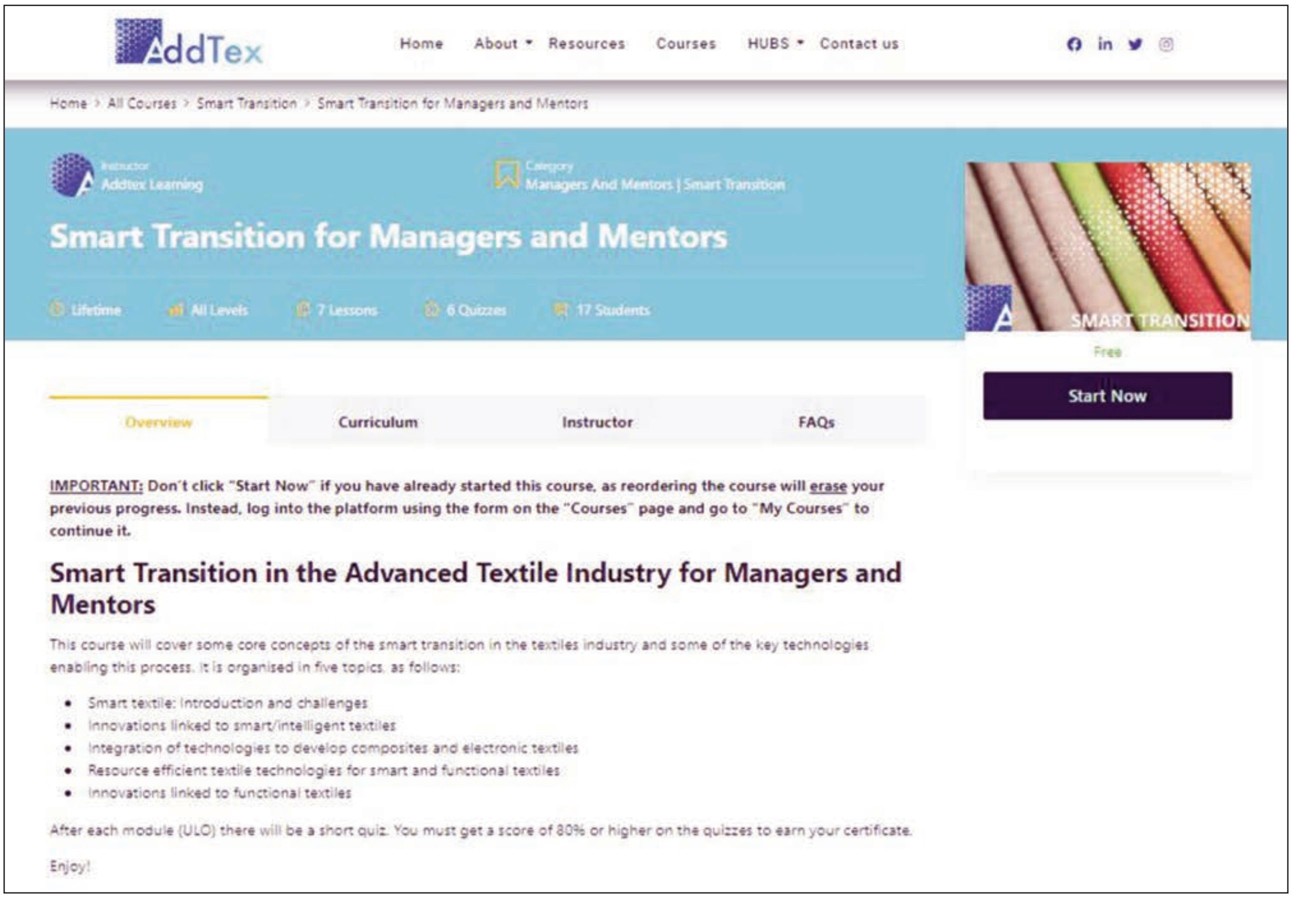

Fig. 1. Smart transition for Managers and Mentors

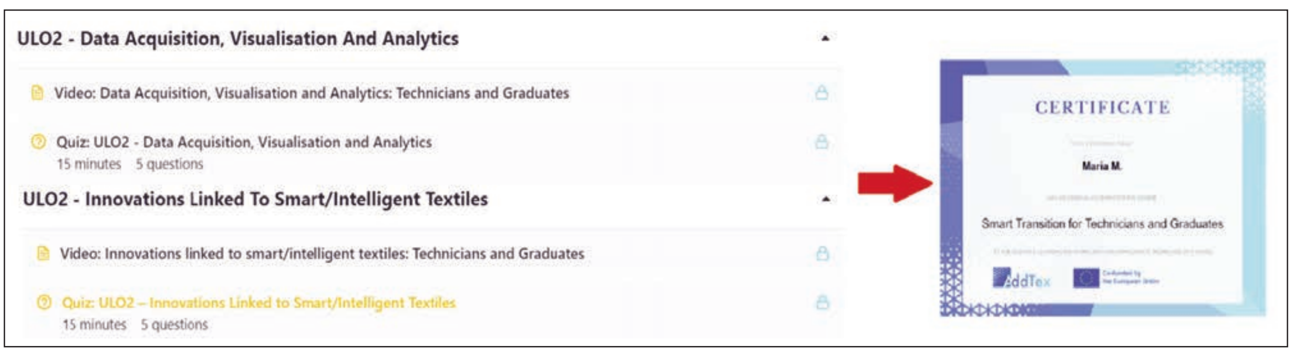

Fig. 2. Testing and certification of course completion

Fig. 3. Smart shirt with integrated ECG for heart monitoring, oximetry, respiration and temperature [4]

and electronic components [6], offer comprehensive support for upper limb rehabilitation, providing assistance and resistance as needed. Furthermore, the ExHand exoskeleton actuator [7] explicitly targets hand and finger movements, offering a tailored approach to rehabilitating fine motor skills. These advanced textile-based systems underscore the evolving landscape of rehabilitation technology, offering promising solutions for individuals seeking to regain lost functions (figure 4).

Smart textiles for personal protection (figure 5) are a groundbreaking innovation integrating advanced technology into protective uniforms. These textiles are designed with sophisticated sensors continuously monitoring vital signs such as pulse, temperature, and humidity. Additionally, they are equipped with GPS technology to track the wearer's location and

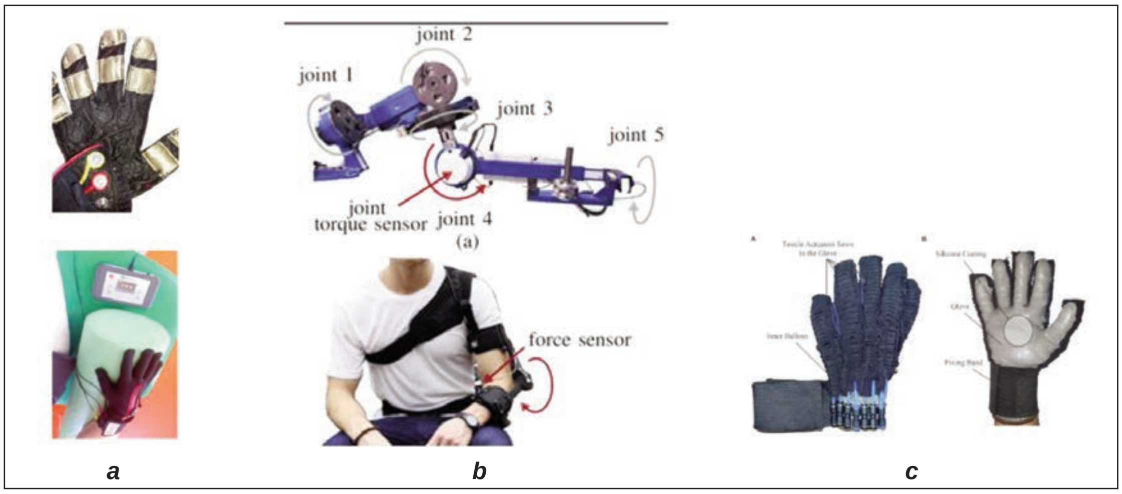

Fig. 4. Graphical representation: *a* – histogram; *b* – box plot graph of the reflection variable (colour variant M1)

Fig. 5. Smart textile for protection [8]

movement. Moreover, the textiles can detect toxic and combustible gases, providing advanced protection. In case of exposure to a hazardous environment, such as a fire, these textiles are equipped with alert systems that promptly notify the wearer and relevant authorities, ensuring swift and effective response to potential dangers. This advanced technology makes these textiles suitable for high-risk applications such as firemen's personal protection equipment [8].

The smart textile for military applications comprises intelligent uniforms seamlessly integrated with state-of-the-art sensors. These sensors are embedded within CORDURA® fabric, comprising 60% cotton and 40% nylon 6,6. The integration of these smart textiles has undergone rigorous testing by soldiers to assess their effectiveness and practicality, as detailed in the referenced study [9]. This development marks a significant leap forward in the evolution of military attire, with the potential to revolutionise the capabilities and safety of military personnel. The collaboration between the U.S. Army and the Massachusetts Institute of Technology (MIT) has yielded groundbreaking advancements in smart clothing fibres (figure 6, *b*), creating a revolutionary technology capable of transforming standard uniforms into wearable autonomous computing systems. These innovative smart uniforms offer many cutting-edge features, including the ability to self-power, provide digital camouflage, and monitor (figure 6, *a*) a wide range of biomedical parameters [10–13]. Researchers at the prestigious Institute for Soldier Nanotechnologies at the Massachusetts Institute of Technology (MIT) have significantly advanced in developing fibre prototypes. These innovative prototypes are constructed using polymer fibres intricately embedded with hundreds of tiny silicon microchips (figure 6, *b*). Upon electrification, these microchips demonstrate a remarkable capability to sustain a digital connection spanning impressive distances of tens of meters. This breakthrough in nanotechnology holds promising implications for various applications, particularly in advanced communication and connectivity technologies [10].

Smart textiles used for augmented humans (Human 2.0) serve a significant purpose in several domains, including medical rehabilitation, enhancement of soldiers' performance, and augmentation of human capabilities through soft exoskeletons [11]. This necessitates the integration of various technologies such as textiles, robotics, software (AI, data analytics), and hardware (electronic components). An example of this integration is the use of force sensors based on QTSS (Quantum Technology Supersensor) ink printed on fabric to develop wearable prosthetic sockets for amputees [12].

A recent study introduced a new type of flexible supercapacitor. These supercapacitors have a CNT-textile anode and a MnO2/graphene textile cathode. They operate at a potential of 1.5 V and have an energy density of 12.5 Wh/kg [14]. The study also mentioned that a polyester-based textile structure can be coated with graphene nanosheets and MnO2. The study highlighted that these supercapacitors are well-suited for energy storage in flexible electronics [15]. The seamless integration of software and hardware components enables the development of a sophisticated and versatile smart monitoring

a *b*

Fig. 6. Smart textiles for military: *a* – Smart uniform used by soldiers in training activity [13]; *b* – knitted sleeve from polymeric fibres containing hundreds of tiny silicon microchips [10]

platform that leverages textile support or tiny sensor-based fibres, knit, woven, or nonwoven structures. As an illustration, the innovative garment integrates ECG leads through screen printing on a knitted structure, serving as the soft component. This garment should also contain a robust hardware unit, which serves as the complex component, facilitating communication and efficient data storage for subsequent in-depth analysis. By harnessing the power of AI technologies such as expert systems, neural networks, fuzzy logic, and genetic algorithms [16], it becomes possible to create an intelligent garment that is not only capable of real-time monitoring but also facilitates predictive sensor data analysis, thereby enhancing overall functionality and utility.

CONCLUSIONS

Smart and intelligent textiles refer to integrating advanced electronic components into textile products, eventually also software components based on artificial intelligence (AI), to improve the quality of life for wearers. These textiles are designed to collect data from various sensors integrated into the fabric and then use AI algorithms to analyse and interpret this data. The potential benefits of such technology include enhanced comfort, performance, and even health monitoring for the wearer.

Despite the potential advantages, the current landscape shows that many of these prototypes are still in the validation stage within laboratory settings, designated explicitly as Technology Readiness Level 4 (TRL 4). This level indicates that while the concepts have been demonstrated in a lab environment, they have not yet advanced to a stage where they are ready for widespread commercialisation. The maturity and refinement required for these innovations to be truly groundbreaking and market-ready have not yet been achieved. This highlights the ongoing challenges in translating promising technological concepts into practical, consumer-ready products within the smart textiles industry.

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Determinants of economic performance in the clothing industry – an EU data panel analysis

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ABSTRACT – REZUMAT

Determinants of economic performance in the clothing industry – an EU data panel analysis

In a global economy, textile and clothing companies operate in a highly competitive international market, where numerous firms compete for consumer demand, characterised by frequent changes, depending on fashion. Therefore, increasing economic performance is essential to survive in such an environment. This piece of research has the objective to analyse the factors that determine performance expressed in the form of companies' turnover, at sector level in the European Union region, trying to answer the question of which are the drivers influencing the turnover in the textile and clothing industry and how strong their influence is. In pursuing this, multiple linear regressions have been performed between turnover and its determinants. The findings show that turnover is strongly influenced by the number of employees, imports and exports and less influenced by consumers' expenditure. These results may serve to underpin the macro policy decisions regarding the textile, clothing and footwear industry.

Keywords: *textile and clothing industry, economic performance, productivity, competitiveness, turnover*

Determinanți ai performanței economice a industriei textile și de îmbrăcăminte – analiză de tip panel a datelor din Uniunea Europeană

Într-o economie globală, companiile din industria textilă și de îmbrăcăminte operează pe o piață internațională extrem de competitivă, în care numeroase firme concurează pentru cererea consumatorilor, caracterizată prin schimbări frecvente, în funcție de modă. Prin urmare, creșterea performanței economice este esențială pentru a supraviețui într-un astfel de mediu. Această cercetare are ca obiectiv analiza factorilor care determină performanța exprimată sub forma cifrei de afaceri a companiilor, la nivel de sector în Uniunea Europeană, încercând să răspundă la întrebarea care sunt factorii care influențează cifra de afaceri în industria textilă și de îmbrăcăminte și cât de puternică este influența lor. În acest scop, au fost efectuate regresii liniare multiple între cifra de afaceri și factorii determinanți ai acesteia. Rezultatele arată că cifra de afaceri este puternic influențată de numărul de angajați, importuri și exporturi și mai puțin influențată de cheltuielile consumatorilor. Aceste rezultate pot servi la fundamentarea deciziilor macroeconomice din industria textilă, de îmbrăcăminte și de încălțăminte.

Cuvinte-cheie: *industrie textilă și de îmbrăcăminte, performanță economică, productivitate, competitivitate, cifră de afaceri*

INTRODUCTION

Worldwide, population growth demands larger quantities of food, clothes and services. This is the reason why the textile industry has intensively developed, and, due to globalisation, operates on international competitive markets, where companies can survive only by increasing economic performance.

The textile and clothing industry in the European Union encompasses 197,000 companies, 1.3 million employees, and 170 billion euros turnover [1]. The average labour productivity in member states reached 40.2 thousand euros of value added per employee in 2023, while ten years ago it used to be 27 thousand euros. This increase in productivity is driven both by improved techniques and by reducing the number of workers and improving their skills. Women represent more than 70% of all workers in the industry. Consumption of clothing per person differs depending on the country. In Luxembourg, one person spent 1,500 euros to buy clothes, while in Hungary, one person spent 200 euros in 2022. On average, one person spent 630 euros on clothing [2]. Italy is the largest player in the textile and clothing industry in the European Union, accounting for 36% of turnover and 24% of employment [2]. Other important contributors are Germany, France, Spain, Portugal, Poland and Romania. By subsector, besides Italy, Germany plays a significant role in technical and industrial textile, interior textile and man-made fibres, yarns, fabrics; France in leather clothes and accessories; Spain, Portugal and Romania in footwear.

Given the complexity of the textile value chain, the European Union is proposing a complex strategy for the textile and clothing industry. The strategy focuses on strengthening industrial competitiveness and accelerating innovation in this branch. The aim is to stimulate the EU market for sustainable and circular textiles, including textile reuse [3].

As seen, the textile industry is an important pillar of the European Union economy, being one of the fourteen industrial sectors that the Commission has identified as strategic in the recovery from the COVID-19 pandemic [4]. Given the importance of the textile industry, it becomes relevant to analyse the competitiveness and productivity of this branch and the drivers behind its performance.

Usually, financial indicators are utilised to measure the economic performance [5]; as such, for this piece of research, turnover will be used as an expression of performance. Thus, the objectives of the paper are to explore the drivers of turnover of the textile and clothing industry and to rank them based on their influence. The research question is: Which are the determinants influencing the turnover in the textile and clothing industry, and how strong is their influence?

A possible answer to this question and, thus, the hypothesis tested in this piece of research, is that consumer demand, exports, and imports influence the turnover (sales revenue) of companies. The assumption is based on the basic economic theory of market equilibrium [6], when supply equals demand, and supply is made up of domestic production, plus imports, minus exports. As such, we expect a positive influence of imports and demand and a negative influence of exports on turnover.

In achieving the objectives of the research and answering the above question, multiple linear regressions have been performed between turnover and its influencing factors. The results of the study will facilitate the development of macroeconomic policy actions regarding the textiles and clothing industry.

The paper is structured as follows: after the introduction, the literature review explores the main results of research related to economic performance in the textile and clothing industry and the drivers behind it. Then, the methodology used in this study is presented, including the variables of the regression and tests made for their validation. The results are then discussed, the drivers influencing the performance are ranked, and the conclusions are drawn.

LITERATURE REVIEW

The growing and intense competition in the textile and clothing market calls for exploring businesses' performance and their drivers. A large body of literature analysed the performance of this sector, and many researchers studied the factors influencing it.

Performance is defined as the relationship between output (turnover, production of goods) and input (consumed resources, such as labour, capital, money, energy, etc.) [7]. Some studies focused on productivity, as a form of performance, and analysed the textile and clothing industry productivity in individual countries, in different world regions. In Asia, the world leader of the clothing industry, some authors [8, 9] found that productivity increased in China and Taiwan, with growth driven mainly by technical improvements. Productivity growth rates have been found for Malaysia, 7% [10], and India, 3.5% [11].

In the United States of America, Datta and Christoffersen [12] found productivity growth of 2.1%, the main driver being technical change. In Europe, Milašius and Mikučionienė [13] argued that investments in the textile and clothing industry determine the long-term productivity growth, which indicates the concerns of producers to industrial development. One report of the European Commission on EU Textile Ecosystem and its Competitiveness [14] shows that this branch registered rapid productivity growth of 10%, since the value added was growing faster than employment. Moreover, the specialists argued that the value growth added may be explained by increasingly efficient production processes, which lowered production costs.

Overall, in those regarding productivity, both labour and technical, [15] argued that labour productivity, measured by value added per employee, is higher in developed countries compared to developing countries and higher in the textile industry compared to the clothing industry, in almost all regions and countries; and Kapelko and Oude Lansink [16] demonstrated a relatively small overall productivity increase for both textile and clothing firms due to positive technical change.

But performance can be expressed as competitiveness, as well, which can be assessed in different ways, including turnover, number of companies, number of employees, export and imports, as argued by Girneata and Dobrin [17]. The authors analysed the competitiveness of the European textile and clothing industry in the larger context of globalisation, using indicators such as household consumption, turnover, investment, employment, number of firms and EU balance trade for both textile and clothing. The results of the study showed that the competitiveness of the textile and clothing industry fell significantly in the period under analysis, 2007–2013, causing restructuring and downsizing.

Some authors [5] argued that performance can be measured exclusively based on financial information because performance management systems have been designed and operated predominantly by the accounting and financial functions within the company [18]. As such, turnover, as a financial result, has been studied for assessing the performance of the textile and clothing industry, but imports, exports, and consumption as drivers for turnover have been less explored. This is the reason why this piece of research fills in the gap and is original. The economic performance is assessed using turnover as the financial result of companies, and number of employees, expenditure of consumers for purchasing clothes and footwear, and exports and imports' values as its drivers, as explained in methodology.

METHODOLOGY

The research aimed to analyse the main influences on the turnover in the clothing and footwear sector at the macroeconomic level. For this, data were selected from the European statistical database Eurostat, regarding the net value of turnover, for the 27 Member States in the period 2019–2022, this period being established according to the availability of data.

The independent variables, for the 27 Member States and the same period, consumption, expressed as expenditure, the number of employees in this industry, the value of imports and the value of exports have been selected (table 1).

Considering the 27 Member States and the 4 years taken into analysis, a panel model with a number of 108 observations results, however, for Estonia in 2019 and 2020, no data have been identified regarding Turnover and Number of Employees, thus these 2 records were removed so as not to affect the model, therefore a final model with a number of 106 observations has resulted.

The analysis of descriptive statistics for the variables used in the econometric model (table 2) highlights significant differences in terms of centrality and variability of the data. The turnover variable (T-over) has a mean of approximately 5,295 million euros, but the median is considerably lower, standing at 1,191 million euros. This difference highlights the presence of very large values (outliers) that raise the mean. A similar situation is observed in the case of the export value and import value variables, where the mean is higher than the median, indicating a positively skewed distribution. In the case of the number of employees, the mean is 12,537, but the median is much lower, at 6,034, reflecting a significant variation in the number of employees between the different countries. In contrast, the expenditure (PPS) variable has a mean of 731.5 euros/inhabitant and a median of 696.5 euros/inhabitant, suggesting a relatively symmetrical distribution.

Another important aspect is the analysis of skewness and kurtosis, which allows the evaluation of the shape of the data distribution. All variables present positive skewness coefficients, which indicates a tendency of skewness to the right, characterised by the presence of very high values. The most pronounced asymmetry is observed in the case of the import variable, with a coefficient of 2.245, suggesting the presence of extreme values that deviate significantly from the normal distribution. Also, the turnover variable

Table 1

NAMING AND CODING OF VARIABLES

Variable	Codification	Unit of measurement	Explanation
Net turnover	T-over	Millions of euros	It measures the value of turnover for enterprises whose objective is the wholesale of clothing and footwear.
Expenditure	PPS	Nominal expenditure per inhabitant (in euros)	It measures the value of expenditure per inhabitant, in euros, for the purchase of clothing and footwear.
Import Value	Imp_Val	Millions of euros	It measures the value of imports for each Member State *i* in year *t*, at the global level as a partner.
Export Value	Exp_Val	Millions of euros	It measures the value of exports for each Member State *i* in year *t*, at the global level as a partner.
Number of employees	Employee	Persons	It measures the number of people working in enterprises whose objective is the wholesale of clothing and footwear.

Note: Logarithm (Ln_Variable) for each variable that registered a distribution different from the normal one. The logarithm of the data set has been applied, using the natural logarithm.

Table 2

DESCRIPTIVE STATISTICS FOR THE ANALYZED VARIABLES

	T-over	EXP_val	IMP_val	Emplyee	PPS
Mean	5295.228	5079.623	7037.473	12537.68	731.5094
Standard Error	767.7818	677.7892	976.5481	1571.174	31.68366
Median	1190.72	1567.839	2344.013	6034.5	696.5
Standard Deviation	7904.797	6978.267	10054.18	16176.23	326.2032
Sample Variance	62485819	48696215	1.01E+08	2.62E+08	106408.5
Kurtosis	0.685525	2.116689	5.233824	1.17515	0.723824
Skewness	1.464382	1.714796	2.244813	1.523086	0.744562
Range	26159.8	28410.9	50256.47	62782	1598
Minimum	39.8	12.15908	127.7565	107	178
Maximum	26199.6	28423.06	50384.22	62889	1776
Sum	561294.2	538440	745972.2	1328994	77540
Count	106	106	106	106	106

has an asymmetry coefficient of 1.464, which indicates that there is a concentration of small values in contrast to a few very high values. Regarding flattening, the import variable records a kurtosis coefficient of 5.234, typical of a leptokurtic distribution, with a sharp peak and thick tails. The rest of the variables have kurtosis values less than 3, characteristic of platokurtic distributions, which suggests a lower concentration of values around the mean.

The observation of the extreme values and the range indicates notable differences between the minimum and maximum values for each variable. For example, for the turnover variable, the minimum value is 39.8 million euros, and the maximum value reaches 26,199.6 million euros, resulting in a range of 26,159.8 million euros. Similarly, the value of exports varies between 12.16 million euros and 28,423.06 million euros, and the value of imports between 127.76 million euros and 50,384.22 million euros. In the case of the number of employees, the range of variation is extremely large, 62,782 people, from a minimum of 107 to a maximum of 62,889. For the expenditure variable, the difference between the minimum and maximum is 1,598 euros/inhabitant, suggesting significant variations in expenditure between the countries analysed.

Descriptive analysis of the variables in the model indicates high variability and the presence of outliers that significantly influence the mean. The positive skewness of the distributions suggests that large values are predominant, and the kurtosis coefficients indicate, in some cases, sharp peaks and thick tails of the distributions.

To obtain more robust results and to reduce the influence of extreme values, it is recommended to apply a logarithm to variables that present asymmetric distributions. This approach will contribute to normalising the distributions and improving the accuracy of the econometric model.

The equation of the multiple linear regression model was set to be in the following form, in which the variable is measured by country *i* and year *t*:

$$LnTover_{it} = LnPPS_{it} + LnIMP\_Val_{it} + LnEXP\_Val_{it} + LnEmplyee_{it} + \varepsilon \quad (1)$$

RESULTS AND DISCUSSIONS

Following the process of applying the logarithm to the variables, the first step was to determine possible correlations between the variables, especially those related to turnover and its determinants.

The correlation coefficients between the logarithmic variables and turnover (table 3) highlight the existence of significant and strong relationships between turnover and the variables number of employees, export value and import value. The relationship between the logarithmic number of employees and logarithmic turnover is extremely strong and positive, with a correlation coefficient of 0.9338. This result suggests that as the number of employees increases, turnover shows a significant upward trend. The p-value is 0.0000, indicating that this relationship is statistically significant at any conventional level (1%, 5%, 10%).

Another significant relationship is between the logarithmic value of exports and the logarithmic turnover, with a correlation coefficient of 0.8537. This indicates a positive and strong correlation, suggesting that exports contribute significantly to the increase in turnover. The high level of correlation confirms that export activity is an essential pillar of financial success in the wholesale clothing and footwear sector. The p-value of 0.0000 attests to the robustness of this relationship, indicating that there is an extremely

Table 3

CORRELATIONS BETWEEN VARIABLES

Covariance Analysis: Ordinary
Date: 03/23/25 Time: 13:05
Sample: 1 106
Included observations: 106

Correlation Probability	LN_EMPLY...	LN_EXP_VAL	LN_IMP_VAL	LN_PPS_N	LN_T_OVER
LN_EMPLYEE	1.000000 -----				
LN_EXP_VAL	0.900849 0.0000	1.000000 -----			
LN_IMP_VAL	0.893070 0.0000	0.923003 0.0000	1.000000 -----		
LN_PPS_N	-0.110039 0.2615	-0.043736 0.6562	0.144734 0.1388	1.000000 -----	
LN_T_OVER	0.933847 0.0000	0.853735 0.0000	0.921138 0.0000	0.143153 0.1432	1.000000 -----

low probability that this correlation would occur by chance.
Also, the logarithmic value of imports is positively and strongly correlated with turnover, the correlation coefficient being 0.9211. This suggests that an increase in imports has a positive impact on turnover, which may reflect an intense supply activity with products intended for marketing. The fact that the p-value is also 0.0000 confirms the statistical significance of the relationship, indicating that imports are a significant factor in increasing the income of enterprises in the analysed sector.
The stationarity test indicates that the logarithmic series is stationary at the individual level, according to the Im, Pesaran and Shin W-stat, ADF – Fisher Chi-square and PP – Fisher Chi-square tests, all having a p-value of 0.0000, which allows the rejection of the unit root hypothesis. Although the Levin, Lin & Chu t-test suggests the presence of a unit root (p-value 0.9854), the overall results validate the stationarity of the series. Therefore, the model is valid, and we can continue with the regression analysis.
The linear regression model applied for the dependent variable – logarithm of turnover – highlights statistically significant results and a high degree of explanatory power. The coefficient of determination R2 is 0.9423, which indicates that approximately 94.23% of the variation in turnover (logarithm) is explained by the independent variables included in the model (number of employees, value of exports, value of imports and expenditure). The adjusted R2 coefficient, with a value of 0.9401, confirms the stability of the model even after adjusting for the number of variables.
The overall significance test of the model, reflected by the F-statistic value (412.36) and the associated probability (p-value 0.0000), shows that the model is significant overall, rejecting the null hypothesis that all coefficients are equal to zero. This indicates that at least one of the independent variables has a significant impact on turnover.
Analysing the regression coefficients, it can be noticed that the employee variable has a positive and statistically significant coefficient (0.9706), with a p-value of 0.0000. This result indicates a positive relationship between the number of employees and turnover, suggesting that a 1% increase in the number of employees would lead, on average, to an

Table 4

RESULTS OF THE REGRESSION MODEL BETWEEN TURNOVER AND ITS DRIVERS

Dependent Variable: LN_T_OVER
Method: Least Squares
Date: 03/23/25 Time: 13:08
Sample: 1 106
Included observations: 106

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_EMPLYEE	0.970657	0.075886	12.79093	0.0000
LN_EXP_VAL	-0.190743	0.071769	-2.657722	0.0091
LN_IMP_VAL	0.434961	0.109542	3.970712	0.0001
LN_PPS_N	0.719106	0.120780	5.953851	0.0000
C	-7.794858	0.763295	-10.21212	0.0000

R-squared	0.942301	Mean dependent var	7.085617
Adjusted R-squared	0.940016	S.D. dependent var	1.924977
S.E. of regression	0.471458	Akaike info criterion	1.380050
Sum squared resid	22.44958	Schwarz criterion	1.505684
Log likelihood	-68.14263	Hannan-Quinn criter.	1.430970
F-statistic	412.3664	Durbin-Watson stat	1.530990
Prob(F-statistic)	0.000000		

Estimation Command:
=========================
LS LN_T_OVER LN_EMPLYEE LN_EXP_VAL LN_IMP_VAL LN_PPS_N C

Estimation Equation:
=========================
LN_T_OVER = C(1)*LN_EMPLYEE + C(2)*LN_EXP_VAL + C(3)*LN_IMP_VAL + C(4)*LN_PPS_N + C(5)

Substituted Coefficients:
=========================
LN_T_OVER = 0.970657129219*LN_EMPLYEE - 0.1907427595*LN_EXP_VAL + 0.434961317854*LN_IMP_VAL + 0.719106196124*LN_PPS_N - 7.79485778377

increase of approximately 0.97% in turnover, all other variables remaining constant.

The analysis of the export variable reveals a negative coefficient of –0.1907, indicating that a 1% increase in exports leads to a 0.19% reduction in the sector's turnover. The associated p-value of 0.0091 confirms that this negative influence is statistically significant. This result may suggest that not all exports directly generate substantial revenues within the wholesale clothing and footwear sector. It is possible that some exported products yield lower profit margins or that export activities incur additional costs, which ultimately reduce profitability.

In contrast, the import variable demonstrates a positive coefficient of 0.4349, indicating that a 1% increase in imports results in a 0.43% increase in turnover. The statistical significance of this relationship, supported by a p-value of 0.0002, highlights the positive contribution of imports to turnover. This finding may imply that the supply of imported clothing and footwear is advantageous for the sector, reflecting a robust volume of trade in imported products and their positive impact on business revenue.

Furthermore, the expenditure variable also exhibits a positive coefficient of 0.7191, accompanied by an extremely low p-value of 0.0000, indicating a highly significant positive influence on turnover. This result suggests that in countries with higher nominal expenditure per inhabitant, the turnover of enterprises operating in the wholesale clothing and footwear sector is correspondingly higher. Consequently, increased consumer spending capacity directly contributes to stronger business performance within the sector.

The regression model is robust and well specified, highlighting that the number of employees, the value of imports and expenditure have a positive and significant impact on turnover, while the value of exports exerts a negative effect. The model provides a pertinent explanation of the economic relationships between the variables and can serve as a basis for formulating economic policies that support growth in the wholesale clothing and footwear sector.

The interpretation of the coefficients shows that the number of employees and the value of imports are the factors with the greatest positive impact on turnover, while the value of exports has a negative effect. Expenditure also contributes positively to income growth. One person spent on average, 731.50 euros to buy clothes and footwear, which is in line with statistics showing that the average expenditure for clothes is 630 euros [2].

These results suggest that development strategies should focus on expanding the labour force and efficiently sourcing through imports, while monitoring the negative impact of higher exports.

The finding that an increase in the number of employees leads to a significant increase in turnover is supported by the literature on human resource efficiency in the trade and textile sector. According to studies [19], human capital is a key factor in economic value creation, and increasing the workforce can increase production capacity and operational efficiency.

The negative impact of exports on turnover in the clothing and footwear sector, highlighted by the regression analysis, is explained by the way value is created in the global textile supply chain. Many EU countries with high export volumes-such as Romania, Bulgaria or Portugal-act as manufacturing hubs, under outsourcing models with low profit margins [20, 21]. Thus, although export volumes are high, turnover remains limited due to low value added per unit. In addition, exports are often realised at wholesale prices in a B2B context, as opposed to domestic sales that may occur at higher retail prices or through vertically integrated channels [22]. Additional costs of exporting-logistics, compliance, foreign market risks-can further reduce margins [23]. Therefore, reliance on exports without integration of higher value-added functions (branding, design, direct retailing) can lead to poor financial performance.

The positive effect of imports can be explained by the theory of comparative advantage, but also by modern observations on global trade and globalisation. Especially in clothing retailing, studies [24] show that firms that import products from low-cost markets can achieve higher margins and better competitiveness. This is a common reality in the EU, where many local brands import clothes from Asia or North Africa, maintaining low costs and diversity in their offer.

The positive association between household spending and turnover is well documented in the consumer literature. According to Engel's model and subsequent studies [25], as incomes rise, the share of spending on clothing remains relatively stable, but in absolute terms it increases. Also, in markets with higher purchasing power, such as the European Union, there is a more pronounced trend towards fashion consumption and clothing diversity.

CONCLUSIONS

The paper explored the drivers of economic performance in the clothing and footwear industry, using regression models for analysing the relationships between turnover and its factors of influence: employees, purchases, exports and imports.

The results of the regression model highlight the importance of factors for increasing turnover in the clothing and footwear retail trade sector. On the one hand, the number of employees, imports and exports, in this particular order, prove to be essential variables, with a significant influence on turnover. The results show that 1% increase in the number of employees would lead, on average, to an increase of approximately 0.97% in turnover; a 1% increase in exports leads to a 0.19% reduction in the sector's turnover; a 1% increase in imports leads to a growth of turnover by 0.43%. On the other hand, consumption, expressed in terms of purchases, does not have the same relevance, which suggests that the dynamic of the domestic market does not influence the direct income of enterprises in this sector.

Moreover, part of the hypothesis established at the beginning of the research is validated, with turnover being positively influenced by imports and negatively by exports. Regarding demand, expressed as consumers' expenditure, it can be stated that it positively influences turnover, as assumed, but to a lesser extent.

Based on these findings, sectoral policymakers are recommended to support strategies that encourage the expansion of workforce capacity and facilitate efficient access to imported goods, both of which have a strong positive impact on turnover. At the same time, policies should aim to reduce the structural dependence on low-margin export models by stimulating value-added activities such as branding, design, or retail integration. These shifts could enhance the sector's profitability and long-term resilience within the EU.

The research has its limitations, consisting of the fact that the analysed period is short. This restriction may be overcome in the following years, by future research, as new statistical data appear. Moreover, the value of the Durbin-Watson statistic (1.3196) indicates a possible residual positive autocorrelation, but this aspect requires further checks to confirm whether there is a problem of autocorrelation of errors.

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Assessing the preparedness of the textile sector for implementing Industry 4.0: An organisational culture perspective

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ABSTRACT – REZUMAT

Assessing the preparedness of the textile sector for implementing Industry 4.0: An organisational culture perspective

Current research highlights the importance of an appropriate organisational culture (OC) for successfully implementing Industry 4.0 (I4.0), suggesting that overlooking OC may impede organisations from fully leveraging and maintaining the benefits of I4.0. Although there is an agreement on the characteristics of suitable OC for I4.0, methodologies to evaluate organisational readiness from an OC perspective are needed. Our study aims to assess the preparedness of organisations for implementing I4.0. Through an extensive literature review, we identified the suitable OC for I4.0, gauged the currently prevailing primary perceived OC, and evaluated the preparedness of the selected sector for implementing I4.0. Utilising data collected from Pakistan's textile sector (PTS), the research employs a cross-sectional survey utilising the Competing Values Framework (CVF). After an extensive literature review, the study found that an OC with dominant adhocracy culture profile traits is well-suited for implementing I4.0. However, the data from 162 textile organisations reveal that the perceived primary/dominant OC in PTS is the clan culture profile, with the control culture profile being the least prevalent. The results indicate that the current prevailing OC characteristics, as perceived by the respondents, are not suitable for I4.0 implementation, indicating that the selected sector is not ready to implement I4.0 from an OC perspective. This study is unique in its systematic approach, adapting the CVF to evaluate perceived OC for I4.0 readiness in a developing economy using qualitative and quantitative methods. The approach may be applied to different sectors and countries.

Keywords: *Competing Values Framework, digitalisation, innovation, efficiency, supply chain management*

Evaluarea pregătirii sectorului textil pentru implementarea Industriei 4.0: O perspectivă a culturii organizaționale

Cercetările actuale subliniază importanța unei culturi organizaționale (CO) adecvate pentru implementarea cu succes a Industriei 4.0 (I4.0), sugerând că neglijarea unei culturi organizaționale poate împiedica organizațiile să valorifice pe deplin și să mențină beneficiile I4.0. Deși există un consens cu privire la caracteristicile unei culturi organizaționale adecvate pentru I4.0, sunt necesare metodologii pentru a evalua pregătirea organizațională dintr-o perspectivă a culturii organizaționale. Studiul nostru își propune să evalueze gradul de pregătire al organizațiilor pentru implementarea I4.0. Printr-o analiză extinsă a literaturii de specialitate, am identificat o cultură organizațională adecvată pentru I4.0, am evaluat cultura organizațională primară percepută în prezent și am evaluat gradul de pregătire al sectorului selectat pentru implementarea I4.0. Utilizând datele colectate din sectorul textil din Pakistan (PTS), cercetarea utilizează un sondaj transversal care vizează cadrul de valori concurențiale (CVF). După o analiză extinsă a literaturii de specialitate, studiul a constatat că o cultură organizațională cu trăsături dominante ale profilului cultural adhocratic este potrivită pentru implementarea I4.0. Cu toate acestea, datele de la 162 de organizații textile relevă faptul că principala cultură organizațională percepută în sectorul textil din Pakistan este profilul culturii clanului, profilul culturii de control fiind cel mai puțin prevalent. Rezultatele indică faptul că trăsăturile culturii organizaționale predominante actuale, așa cum sunt percepute de respondenți, nu sunt potrivite pentru implementarea I4.0, ceea ce indică faptul că sectorul selectat nu este pregătit să implementeze I4.0 din perspectiva culturii organizaționale. Acest studiu este unic prin abordarea sa sistematică, adaptând cadrul de valori concurențiale pentru a evalua cultura organizațională percepută pentru pregătirea I4.0 într-o economie în curs de dezvoltare, folosind metode calitative și cantitative. Abordarea poate fi aplicată diferitelor sectoare și țări.

Cuvinte-cheie*: cadrul de valori concurențiale, digitalizare, inovare, eficiență, gestionarea lanțului de aprovizionare*

INTRODUCTION

It has been established that implementing Industry 4.0 (I4.0) fosters real-time connectivity and collaboration among stakeholders, including personnel, equipment, and products [1]. This integration spans production processes, distribution, and post-sales services, enhancing productivity, efficiency, and financial performance while promoting sustainability in manufacturing facilities [2–5]. When it comes to implementing I4.0, extensive scholarly investigations consistently emphasise the important role of OC in facilitating and driving the implementation of I4.0

[6–8]. Moreover, studies have explored I4.0 maturity models, which help organisations gauge their readiness and progress in adopting I4.0 technologies. These models consider cultural aspects an integral component of readiness assessments for I4.0 [9,10]. Identifying the dominant organisational culture effectively reveals the significant compatibility between individuals and organisations. Moreover, it is an effective tool for investigating and solving disputes and misunderstandings within the workforce, ultimately differentiating employees of one organisation from their counterparts and facilitating greater success [11] and competitive advantage [11, 12]. The OC plays a significant role in successful technology adoption, promoting innovation, enabling smoother mergers, and improving employee job satisfaction, organisational success, and team effectiveness [13]. Moreover, it shapes individual behaviour, influences decision-making processes, and steers leaders and members toward achieving organisational objectives. It is instrumental in sustaining and enhancing the organisation's mission, performance, and the competence of its members [12]. The effectiveness of an OC cannot be definitively classified as good or bad. It depends on how well it aligns with the organisation's mission, purposes, and strategies, and if established, it can serve as an asset in achieving its goals; otherwise, it is a liability [14]. The literature on I4.0 reveals that most studies focus on technical aspects and neglect the importance of managerial approaches and OC, which play a crucial role in successfully implementing this concept [2]. Identifying OC characteristics that align with the technological and operational demands of I4.0 is crucial [2]. The intertwined relationship between social and technological dimensions is essential in organisational development and change processes [7]. I4.0 is a pivotal example recognised widely as a 'socio-technical system', inherently acknowledging the synchronous optimisation of social and technical aspects [15]. The authors have conducted a comprehensive review of the existing literature and have found that the investigation into I4.0 implementation concerning the role of OC within PTS remains notably deficient. The literature reveals a consensus on the ideal culture for implementing I4.0 [2, 8, 16–21]. However, how organisations should assess their readiness for implementing I4.0 from an OC perspective needs attention. Failure to consider the suitable OC for implementing I4.0 may impede the implementation of I4.0.

This study aims to investigate the perceived prevailing characteristics of OC, determine the primary (most dominant) perceived OC, and assess organisational readiness to adopt I4.0 from the OC perspective. The study utilises empirical data collected from PTS as a case study. The textile sector is a key contributor to Pakistan's economy. The sector's exports account for approximately 7 to 62% of Pakistan's national exports, contributing nearly 8.5% to the GDP and employing around 19 million people, almost 40% of the country's workforce [22, 23]. Implementing I4.0 may boost the economy and create new opportunities for those employed in this sector. This research contributes to the existing body of literature by incorporating data from PTS through a mixed-methods approach. Our study provides a structured method for determining the prevailing perceived organisational culture and evaluating organisational readiness for deploying I4.0 from an OC's perspective. The insights from the study may be instrumental in devising strategies to align the OC for implementing I4.0.

The study is organised into six main sections: Section 2 begins with a literature review. Section 3 explains the methodology and data collection process, and Section 4 presents the findings. Section 5 provides a discussion, and Section 6 summarises the findings and the study's limitations.

LITERATURE REVIEW

Industry 4.0

The Industrial Revolution (IR) was an era of substantial technological and economic development that began in Europe in the eighteenth century and revolutionised the production and distribution of products. It led to the shift from manual *labour* to machine-based production, resulting in the emergence of new technologies, industries, and economic systems. The IR significantly changed working conditions, *urbanisation*, and the economy, tremendously impacting society. Four industrial revolutions, each building upon the preceding one and delivering technological and manufacturing process breakthroughs, are presented in figure 1 [2, 24–26].

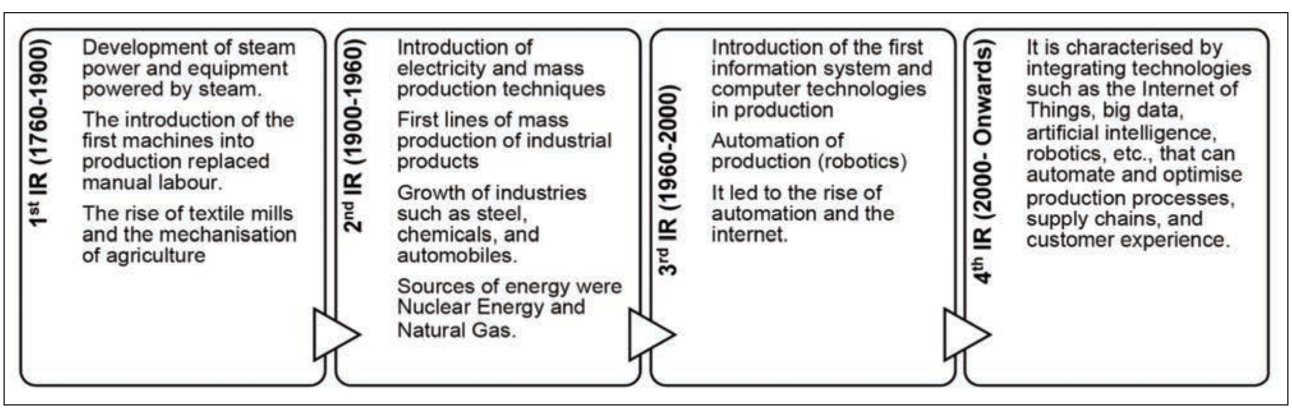

Fig. 1. Industrial Revolutions [2, 24–26]

The term "Industry 4.0 (I4.0)" was coined from German' Industrie 4.0,' an initiative of the German Federal Government in 2011 [24]. I4.0 enables autonomous data collection, analysis, and interaction between products, processes, suppliers, and customers through the Internet using cutting-edge technologies [27]. I4.0 includes various technologies such as additive manufacturing or 3D printing, cloud computing, cyber-physical systems manufacturing execution system, big data, sensors, RFID, e-value chain, autonomous robots, augmented reality, simulations or an analysis of virtual models, and cyber security, etc.; however, there is a disagreement over the specific types of technologies that make up I4.0 [5, 27–33]. For the past few years, the business and research communities have paid close attention to the initiative of I4.0 [5]. It is rising to the top of the industrial sector's priorities [34].

Organisational culture

"On Studying Organisational Cultures", a 1979 publication in US academic literature, coined the term "Organisation Culture (OC)" [35, 36]. Several interpretations of OC have emerged over time due to its various definitions [37]. The academic literature has documented over a hundred different dimensions of an OC[38]. Hence, defining and interpreting OC is challenging [36]. During the 1980s and 1990s, an increasing emphasis was observed on studying OC and developing its measurement tools [11]. Some of the frequently referenced definitions of OC are:

"The culture is a socially constructed attribute of organisations that acts as the social glue holding an organisation together [39]."

"The group culture is a pattern of shared basic assumptions learned by a group as it solved its problems of external adaptation and internal integration, which has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel about those problems [40, 41]."

"Culture is related to an organisation' shared language, beliefs, symbols, and values, and a measure of culture's strength is the extent to which all the organisation's members understand these things [42]."

"Culture is the collective programming of the mind, which distinguishes the members of one category of people from another [43]."

The Competing Values Framework (CVF)

The CVF developed by Cameron et al. (1999) was used to meet the research objectives. The CVF has been empirically driven and extensively used in quantitative studies to diagnose and change OC [39, 44–48]. Moreover, this framework helps to identify the dominant perceived OC and subcultures in organisations [49, 50]. The CVF classifies OC into four categories, as illustrated in figure 2 and summarised below [51].

The Clan Culture Profile (CCP): The upper left quadrant of the CVF corresponds to the characteristics typical of a Clan Culture within an organisation, distinguished by its internal orientation and flexibility. The foundational values of this culture prioritise employee involvement initiatives, teamwork, and a commitment to the holistic growth and welfare of employees. They also perceive customers as integral partners in the organisational process. This culture prioritises empowering employees, thus fostering a high level of engagement and promoting organisational loyalty. Leadership within this framework predominantly assumes a guiding and mentoring role, where harmony and collaboration are highly esteemed. Organisational success is measured by the degree of collaboration, participatory engagement, and stakeholder consensus. *Control Culture Profile (CoCP)* is characterised by an internal focus alongside control and stability (lower left quadrant). This culture values clear authority in decision-making, standardised processes, and accountability measures, fostering a formal and structured workplace. Organisations adopting this profile aim for efficiency and stability, employing hierarchical organisational structures and decision-making to achieve these objectives. Responsibilities are organised in a consistent setting to sustain consistency in process outputs. Long-term goals focus on maintaining stability, predictability, and efficiency, all supported by clear and established guidelines. *Adhocracy Culture Profile (ACP)* combines an external focus with flexibility (upper right quadrant). Work environments with this OC type emphasise adaptability, creativity, and innovation. Leaders are viewed as innovators and are willing to take risks. These organisations prioritise experimentation and innovation, fostering cohesion through a shared commitment to these values. Their long-term goals centre on growth and securing new resources, with success driven by developing unique products or services. This culture encourages individual creativity, autonomy, and decentralised decision-making. *Market Culture Profile (MCP)* combines an external focus with an emphasis on control and stability (lower right quadrant). The core values of organisations with stronger MCPs are competitiveness and productivity. Organisations with this culture perceive the external environment as competitive and challenging, viewing customers as discerning and focused on value. Leaders' main responsibility is to lead organisations toward productivity, results, and profits. The business success indicators are market penetration and market shares. Such organisations perceive an aggressive approach as improving productivity and profit [39]. Organisations with this OC are dedicated to understanding and meeting customers' needs. They foresee emerging market patterns and respond to these challenges proactively with agility and innovation [39, 52]. According to the CVF, a company can possess four unique organisational culture profiles simultaneously. However, one of these cultures may have a greater influence on the company's values, behaviours, and social interactions and can be regarded as the primary culture profile [53]. To assess organisations' preparedness from

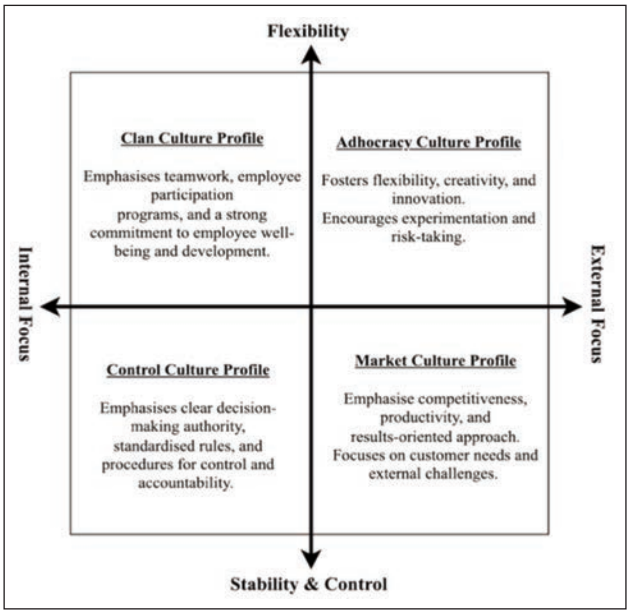

Fig. 2. The Competing Values Framework adapted from Cameron et al. [39]

an OC perspective, it is important to understand the prevailing (Primary) OC for implementing I4.0. The authors needed help finding a single study examining the characteristics of current OC within PTS. Consequently, this situation necessitates identifying the existing primary (most dominant) organisational culture profile. To achieve this, employing the CVF, our RQ1 is formulated as follows:

RQ1. Which OCP is perceived as the primary culture within the textile sector of Pakistan?

Based on the research question, we propose the following hypothesis:

$H_0$1: No significant difference exists in the prevalence of four types of OCPs.

Suitable OC for implementing Industry 4.0

Organisation Culture (OC) is a multifaceted and dynamic concept shaped by several factors, including national culture, styles of leadership, vision, employee behaviour, organisational structures, environment, rituals, hiring practices, narratives, external factors, values, communication, and reward systems, among others [14, 54–57]. OC significantly shapes individual behaviours, impacts decision-making processes, directs leaders and team members towards the attainment of organisational objectives, and plays an important role in sustaining and improving employee competence. It plays a critical role in integrating an organisation's vision, mission, and performance, determining whether it serves as an asset or a liability to its objectives [12, 14]. Additionally, demographic diversity may significantly impact cultural perspectives within a workplace, leading to the emergence of subcultures [58]. By studying thousands of organisations through the lens of the CVF, researchers have also concluded that more than 80% of them have one or more clear dominant organisational culture profiles. Moreover, they found that organisations that don't have a dominant OCP either lack clarity about their OC or balance all four types of OCPs (Hierarchy, market, clan, and adhocracy) equally. Each category of the OC in CVF has unique characteristics [39]. With this in mind, the literature review in this section, through the lens of CVF, aims to identify the characteristics of OC most suitable for implementing I4.0. A systematic literature review (SLR) concluded that specific OC characteristics, such as continuous learning for innovation adaptation, knowledge sharing and transfer, and entrepreneurship traits of risk-taking and flexibility, creativity, and innovation, align with I4.0 [16]. Another SLR revealed that organisational agility, the capacity for rapid adaptation to a changing external environment, is critical for the early adoption and successful implementation of I4.0 [8]. Another study has highlighted the importance of aligning OC with the principles and requirements of I4.0, advocating for an OC that promotes innovation, adaptability, and a willingness to embrace technological change [17]. In a study, authors concluded that 13 organisations implementing I4.0 have observed that they require an entrepreneurial mindset, openness, a desire to learn, and a willingness to embrace change [21].

Furthermore, another study concludes that a culture that promotes continuous learning is vital for adapting to new technologies and fostering innovation within the I4.0 framework [18]. Adopting I4.0 requires constant innovation and education, not only to enhance individual skills but also to evolve OC. So, the innovative culture (defined by Wallach) is more suitable for implementing I4.0[2]. Encouraging employees to innovate their processes and explore new technologies helps organisations adapt to the rapidly evolving landscape of I4.0. Ongoing education keeps employees updated on the latest technological advancements and best practices, which helps organisations make informed decisions about technology adoption. Moreover, the literature suggests that the characteristics of Innovative Culture defined by E. Wallach closely resemble those of the Adhocracy/ Developmental Culture Profile proposed by Cameron and Quinn [39]. Subsequently, we conclude after a comprehensive review of existing literature that the characteristics of a prerequisite OC conducive to successfully implementing I4.0 are focused on promoting innovation, entrepreneurial risk-taking, adaptability, agility, continuous learning, knowledge-sharing, willingness to accept change, openness to new ideas, and the encouragement of employee-driven process development [2, 8, 16–21]. These OC characteristics are closely related to the Adhocracy Culture Profile (ACP); hence, it can be argued that organisations implementing I4.0 should focus more on developing an ACP while considering OC characteristics from other cultural profiles to meet their specific needs. Our argument is further strengthened by an SLR that has concluded the unanimous agreement in the existing literature about the characteristics of OC required for implementing I4.0. The SLR concludes that ACP, characterised by a tendency to accept change, creativity, ambiguity, and adaptability, is suitable for implementing I4 [16]. Given that the dominant culture profile for implementing I4.0 is ACP, the following research question is formulated to assess the preparedness of PTS from an OC perspective:

RQ2: Does the perceived OC in the textile sector of Pakistan align with the dominant OC profile required to implement Industry 4.0 successfully?

RESEARCH METHODOLOGY AND DATA COLLECTION

The research objectives drove the research methodology. A structured questionnaire-based survey following a cross-sectional approach was conducted to achieve the objectives.

Development of questionnaire

To measure the construct of "Organisational Culture", we used an already validated questionnaire designed by Naor et al. (2014), which aligns well with the study's objectives [60]. This questionnaire is grounded in the CVF, a widely recognised model for assessing perceived organisational cultural profiles, with proven face and empirical validity. This model is useful in diagnosing and transforming OC [39]. The CVF facilitates an in-depth examination of OC from unitarist and pluralist viewpoints. It helps to identify the dominant cultures and reveals concealed subcultures [49]. This model covers most of OC's dimensions [46]. It has gained popularity and has been used in several modern quantitative studies [47–51]. A five-point Likert scale was used, with 1 indicating strong disagreement and 5 indicating strong agreement.

Target population and sampling strategy

Organisations were included in the study based on their active membership in reputable industry bodies, such as the All-Pakistan Textile Mills Association and the Chambers of Commerce of major cities. To ensure random sampling and avoid convenience sampling, we created a list of all 512 eligible organisations [23]. An Excel-based random number generator was then used to assign random numbers to these organisations, giving each an equal chance of selection. Data collection involved multiple follow-ups, including emails and phone calls, to ensure that even less responsive organisations were included, contributing to a more balanced and representative sample. The target participants were managerial-level employees from departments likely to be directly involved in I4.0 implementation, ensuring they could understand and accurately complete the questionnaire. We opted for a single respondent per organisation to streamline data collection while maintaining the credibility and representativeness of the responses within the constraints of available resources.

Pilot study

A pilot study was carried out by collecting data from thirty textile units to evaluate the reliability of the construct dimensions. The internal consistency of items was assessed using Cronbach's Alpha (CA), a widely recognised test [61, 62]. The α values met the accepted threshold, confirming the reliability of the construct dimensions. The standard deviation ($s = 0.57$) was also estimated to calculate the sample size using equation 1.

Sample size (n)

We used equation 1 for sample size calculation as the construct's dimensions are measured using a Likert scale, which may be considered a continuous variable, and the N is also finite [63, 64].

$$n = \frac{(Z^2)(N)(óp^2)}{[(N-1)(e^2) + (Z^2)(óp^2)]} \approx 110 \qquad (1)$$

where N (Population Size) = 514; e (acceptable error) = 0.03 for continuous data, óp = StDev, z = 1.96 at α of 5%.

Data collection and sample descriptive statistics

The survey questionnaire was distributed via email. 162 textile units in Pakistan participated in the research. Process improvement/industrial engineers account for 43.83%, QA/QC comprises 24.69%, others constitute 15.43%, production contributes 12.96%, and product development makes up 3.09%. The age distribution reveals that 74.69% of participants are aged 20 to 35, with 5.56% above 45 and 19.75% between 36 to 45. Regarding experience, 38.27% have 1–5 years of experience, 30.25% have 6–10 years, 14.20% have 11–15 years, and 17.28% have over 15 years. Gender distribution shows 91.98% male and 8.02% female participants. Job roles vary, with 5.56% as first-level supervisors, 66.05% in middle management, and 28.40% in top management. Organisation sizes range from 85.80% having over 500 employees, 9.26% with 250 to 500 employees, to 4.94% having less than 250 employees. Data on business models indicate that 56.79% follow B2B, 28.40% are exclusively B2C, and 14.81% engage in both. Ownership distribution reveals that 58.02% are family-owned, and 41.98% are corporate-owned. Regarding textile sector categories, Composite Textile Companies (13.58%), Yarn Manufacturing Units (8.02%), Garment Manufacturing Units (39.51%), Chemical Treatments and Coloration Units (3.09%), Apparel (34.57%), Technical Textiles Manufacturing (4.94%), and Accessories and Gear Items (21.60%) are covered, offering a comprehensive overview. The research encompasses demographic and organisational characteristics within the textile sector.

Validity and reliability of the constructs

It is important to ensure that the instrument accurately assesses the variables as intended while preserving precision. It is ensured by evaluating the validity and reliability indicators of the constructs [61, 62]. The questionnaire used for measuring OC already demonstrates a strong psychometric quality, so face validity is not required. Still, the consistency of items of the four dimensions of the construct OC has been evaluated using Cronbach's alpha (CA) values. An acceptable value for research purposes is 0.70 or above [61]. The associated CA values (table 1) have reached or surpassed the required level.

Procedure used to evaluate the organisational preparedness

The following steps were taken to achieve the study's objectives.

Step 1: Identification of the primary perceived *OCP*

To determine the primary perceived OC, four types of OC profiles were compared using the descriptive statistics, Friedman Test, followed by Wilcoxon Signed Ranked Tests for pairwise comparisons [64,65]. Mohelska and Sokolova employed a comparable methodology to determine the prevailing OC in the Czech Republic [2].

Step 2: Evaluation of the Preparedness for Implementing Industry 4.0

The primary perceived OC and the most suitable organisational culture identified through the literature review were compared qualitatively.

RESEARCH FINDINGS

Identification of the most dominant (Primary) perceived OCP

Descriptive statistics of the perceived OCPs are presented in table 1. The CCP has the highest average (3.62) and median scores (3.50), whereas the CoCP received the lowest average (3.20) and median (3.00) scores. The MCP stands as the second most prevalent perceived OCP. The ACP has an average score of 3.39 and a median of 3.20, respectively. Consequently, in PTS, the order of prevalence of organisational culture profiles based on descriptive statistics (average and median scores) may be ranked as CCP > MCP > ACP > CoCP. Statistics

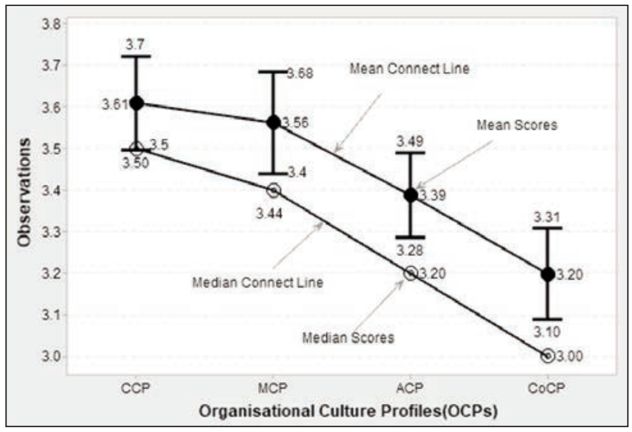

Fig. 3. The interval plot (95% CI of Average) shows the hierarchy of perceived dominance of OCPs

reveal that CCP is perceived as the most prevalent perceived OCP, while CoCP is the least prevalent.

In figure 3, the CCP is the most dominant, and CoCP is the least prevailing. It is important to note that overlapping CIs can occur even with significant differences in distributions, particularly with non-normal data.

Data normality tests

Table 2 presents the results of normality tests for four types of perceived OCPs using the Kolmogorov-Smirnov and Shapiro-Wilk tests, the most commonly used in the research [65]. The p-values for both tests are less than 0.01 for all four types of *perceived* OCPs, suggesting a deviation from normal distribution.

Friedman Test for verification of H01

The non-normality of the data implies that parametric statistical tests, which assume normality, are inappropriate for analysing OCPs. Consequently, to test the dominance hierarchy obtained from descriptive statistics, the Friedman Test, the results of which are presented in table 3, followed by Wilcoxon Signed

Table 1

DESCRIPTIVE STATISTICS OF PARTICIPANTS' PERCEPTION OF FOUR TYPES OF PERCEIVED OCPS AND CRONBACH'S ALPHA

OCPs	N	Average	StDev	95% CI of Average	Median	CA
CCP	162	3.62	0.73	(3.50, 3.72)	3.50	0.83
MCP	162	3.56	0.79	(3.45, 3.67)	3.40	0.88
ACP	162	3.39	0.66	(3.28, 3.50)	3.20	0.78
CoCP	162	3.20	0.71	(3.09, 3.31)	3.00	0.70

Table 2

RESULTS OF NORMALITY TESTS FOR FOUR TYPES OF PERCEIVED OCPS

OCPs	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CCP	0.18	162	0.00	0.92	162	0.00
MCP	0.23	162	0.00	0.88	162	0.00
ACP	0.22	162	0.00	0.90	162	0.00
CoCP	0.17	162	0.00	0.95	162	0.00

Ranked Tests for pairwise comparisons, the results of which are summarised in table 4, are employed [64, 65]. We reject the null hypothesis ($H_0$1) (P<0.01), implying that at least one OCP significantly differs from others (table 3). However, this test fails to identify which group has the highest or lowest statistically significant median scores.

Table 3

FRIEDMAN TEST RESULTS INDICATE THAT THE PREVALENCE OF PERCEIVED OCPS DIFFERS SIGNIFICANTLY

OCPs	Mean Rank	Chi-Square	DF	P-Value
CCP	2.84	27.88	3	0.00
MCP	2.59			
ACP	2.38			
CoCP	2.19			

Wilcoxon Signed Ranked Tests for pairwise comparison of perceived OCPs

To identify the primary perceived OCP, we developed null hypotheses ($H_0$2–$H_0$7) based on median scores, used Wilcoxon Signed Ranked Tests and made pairwise comparisons of the perceived OCPs. The results of Wilcoxon Signed Ranked Tests, presented in table 4, revealed that perceived CCP has a significantly higher prevalence than ACP (p<0.01). Although CCP (median = 3.62) tends to be more prevalent than MCP (Median = 3.56), the difference is not statistically significant (p = 0.07). The MCP exhibits a significantly higher prevalence than ACP (p<0.01). The MCP also surpasses CoCP significantly (p<0.01). Finally, the ACP is significantly more prevalent than the CoCP (p<0.05). The findings from the pairwise comparisons show that the CCP has been perceived as the primary OC and revealed a significant difference in median scores compared to ACP and CoCP. The MCP is the second most prevalent OCP compared based on median scores. Conversely, CoCP is the least dominant OCP within PTS. The dominance hierarchy, ranking Organisational Culture Profiles from the most to the least dominant, is presented in figure 3.

DISCUSSION

The findings reveal that the Clan Culture Profile (CCP) is the primary *perceived* OC within PTS (RQ1). At the same time, Adhocracy Culture Profile (ACP) is identified as the most suitable organisational culture Profile for implementing Industry 4.0 (RQ2). This prevalence of the *perceived* CCP can be attributed to several factors. Firstly, the labour-intensive processes in the textile sector require close coordination and cooperation among workers, which a clan culture emphasising group cohesion and shared values can facilitate [23]. Effective communication and task execution are essential in such environments, making CCP a natural fit. Secondly, Hofstede's research on employee values, undertaken by IBM in the late 1960s, indicated that Pakistani society prioritises "collectivism". This cultural trait prioritises cooperation, communal values, and the welfare of the community or family over personal interests [66, 67]. National cultural traits significantly influence organisational culture, and in Pakistan, collectivism likely contributes to the dominance of the CCP [11, 68].

Furthermore, the PTS is well known for its team-oriented work culture, in which the leaders leave or join the organisation with the entire team, highlighting the group cohesion prevalent in CCP. However, the dominance of CCP poses challenges for implementing I4.0, which requires a culture that values innovation, experimentation, risk-taking, and openness to change – traits not typically associated with CCP. Consequently, from an OC perspective, PTS is not well-equipped for I4.0 implementation. As this is the first study in the selected sector, further research using different OC frameworks is needed to compare and validate these findings.

Table 4

PAIRWISE COMPARISONS OF PERCEIVED OCPS USING WILCOXON SIGNED RANKED TESTS

Null Hypotheses	Z-score	P-Values	Significant?	Pairwise comparison
$H_0$2: The prevalence of CCP is not significantly different from ACP.	– 4.11	0.00	Yes	CCP>ACP
$H_0$3: The prevalence of CCP is not significantly different from CoCP.	– 4.89	0.00	Yes	CCP>CoCP
$H_0$4: The prevalence of CCP is not significantly different from MCP.	–1.85	0.07	No	CCP = MCP
$H_0$5: The prevalence of MCP is not significantly different from ACP.	–3.10	0.00	Yes	MCP>ACP
$H_0$6: The prevalence of MCP is not significantly different from CoCP.	–3.80	0.00	Yes	MCP>CoCP
$H_0$7: The prevalence of ACP is not significantly different from CoCP.	–2.77	0.01	Yes	ACP>CoCP

CONCLUSION

To successfully implement Industry 4.0, an adhocracy culture profile (ACP) should ideally be the dominant organisational culture. However, the clan culture profile (CCP) is currently perceived as the most prevailing OC in PTS, while the control culture profile (CoCP) is the least prevalent. This indicates that Pakistan's textile industry is not yet well-prepared for Industry 4.0 implementation from an organisational culture perspective.

Future research

Future research may incorporate the perceptions of OCPs across various demographics, such as gender, education, departments, organisation size, and experience, to gain a deeper understanding of subcultures within organisations and assess the consistency in opinions across different groups. Additionally, collecting more responses from the same organisations could further enhance findings and present more accurate perceptions of OC.

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How do textile enterprises use digital technology to realize green innovation? A multicase comparative study

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ABSTRACT – REZUMAT

How do textile enterprises use digital technology to realize green innovation? A multicase comparative study

The application of digital technology in textile enterprises can promote their search for knowledge, and its crucial meaning lies in injecting new evolutionary power into the green innovation of enterprises. This research delves into strategies for fostering knowledge search in enhancing textile enterprises' digital technology capabilities, ultimately refining and establishing a framework that catalyses green innovation. Employing the grounded theory approach, this research outlines the dimensions and critical attributes of digital technology, knowledge search, and green innovation practices in textile enterprises. Furthermore, this research constructs a theoretical frame enabling textile enterprises to harness digital technology for knowledge exploration and advancing green innovation. The findings reveal that textile enterprises use digital technology to help multiagent interaction, forming the dynamic support of green incremental and radical innovation. Knowledge search is critical for textile enterprises to realize green innovation using digital technology. Therefore, this study unveils a new path of development for nd green innovation in textile enterprises under the backdrop of the construction of ecological civilization.

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

Cum utilizează întreprinderile textile tehnologia digitală pentru a realiza inovarea ecologică? Un studiu comparativ multicaz

Aplicarea tehnologiei digitale în întreprinderile textile poate promova căutarea de cunoștințe, iar semnificația sa esențială constă în injectarea unei noi puteri evolutive în inovarea ecologică a întreprinderilor. Această cercetare analizează strategiile de încurajare a căutării de cunoștințe în cadrul consolidării capacităților tehnologice digitale ale întreprinderilor textile, rafinând și stabilind în cele din urmă un cadru care catalizează inovarea ecologică. Utilizând abordarea teoriei fundamentate, această cercetare subliniază dimensiunile și atributele critice ale tehnologiei digitale, căutarea de cunoștințe și practicile de inovare ecologică în întreprinderile textile. În plus, această cercetare construiește un cadru teoretic care permite întreprinderilor textile să utilizeze tehnologia digitală pentru explorarea cunoștințelor și avansarea inovării ecologice. Rezultatele arată că întreprinderile textile utilizează tehnologia digitală pentru a contribui la interacțiunea multiagent, formând suportul dinamic al inovării ecologice incrementale și radicale. Căutarea cunoștințelor este esențială pentru ca întreprinderile textile să realizeze inovarea ecologică utilizând tehnologia digitală. Prin urmare, acest studiu dezvăluie o nouă cale de dezvoltare pentru inovarea ecologică în întreprinderile textile, care este de mare importanță pentru tehnologia digitală, producția inteligentă și inovarea ecologică în contextul construirii civilizației ecologice.

Cuvinte-cheie*: întreprinderi textile, tehnologie digital, căutare de cunoștințe, inovare ecologică*

INTRODUCTION

Data has emerged as a fundamental strategic asset with advances in digital technology and data analytics. The embedded and integrated nature of digital technology has opened new horizons for the search for knowledge and green innovation in textile enterprises [1]. The strategic emphasis on promoting digital technology in textile enterprises is crucial to integrating the digital economy with the real economy [2]. From a resource-based perspective, digital technology enables enterprises to integrate and collaborate with knowledge, reducing the costs associated with information inquiry, production, transportation, tracking, and verification. This is achieved through integrating digital resources [3, 4]. Knowledge search theory suggests that knowledge search serves as the primary medium for knowledge circulation, improving the competitiveness of textile enterprises in a dynamic external environment and effectively promoting green innovation [5, 6].

In the context of green innovation, digital platforms, and information technology facilitate the dissemination and integration of knowledge, increasing the flow of knowledge search and promoting green innovation [7, 8]. According to knowledge search theory, knowledge search is the primary medium of knowledge circulation. Therefore, knowledge search can improve the competitiveness of textile enterprises in an external dynamic environment, thus effectively promoting green innovation of textile enterprises [6]. In green innovation, digital platforms and information technology are used to increase the flow of knowledge search, thus promoting green innovation [8]. In the context of green innovation and evolution, there are certain particularities. For the local situation, under the influence of digital technology and knowledge search, the evolution of green innovation performance should be analysed in depth with specific cases. Regarding research methodologies, the prevailing trend leans towards single-case studies, with a notable absence of multicase studies, which could offer a more comprehensive and nuanced understanding.

Can the application of digital technology form a new way to influence the green innovation of textile enterprises based on knowledge search? Drawing from a range of theories encompassing technological innovation, digital empowerment, the resource-based view, and dynamic capabilities, this research reviews pertinent literature on digital technology, knowledge search, and green innovation. Focusing on the widespread adoption and penetration of digital technology in textile enterprises, it contributes to broadening the theoretical landscape of green innovation within the textile industry. This research examines four Chinese textile enterprises across subsectors to explore how digital technology drives green innovation in the knowledge-information era. Analysis of digital technology applications, knowledge search, and green innovation cases reveals strengths in digital construction, production planning, intelligence boosting, and scene utilization. Additionally, fundamental practices and knowledge acquisition routes for green innovation with digital technology are examined. Focusing on both practical demands and theoretical shortcomings, the mechanisms supporting green innovation in textile enterprises, enabled by digital technology, undergo refinement. This refinement strives to elevate and strengthen their green innovation performance amidst the digital era.

The marginal contributions of this research are as follows:

- First, based on the perspective of knowledge search and modern organization theory, the case study objects are comprehensively described and systematically deconstructed, and the process and influence mechanism of digital technology that empowers green innovation of textile enterprises are analysed.
- Second, employing grounded theory's coding technique, multicase studies were conducted across four textile enterprises. This research deepened the understanding of digital technology theory and examined the mechanisms by which digital technology fosters green innovation in textile enterprises. This endeavour enriches and broadens theoretical research on digitalization and organizational dynamics, offering valuable insights to guide green innovation practices in the textile industry.
- Third, it formulates effective control policies and provides policy suggestions and implementation paths for the government to transform the business model of textile enterprises, digital intelligence, and green development.

LITERATURE REVIEW

Green innovation is a collective behaviour that impacts the entire life cycle of enterprises, including reducing unit energy consumption, developing clean energy, recycling waste, and designing green products [9]. Research interprets the meaning of green innovation from many perspectives, including enterprise value [10, 11], strategic decisions [12, 13], resource access [14], internal and external learning [7], and R&D capacity [15]. In addition, scholars also believe that green innovation can coordinate enterprises' economic and ecological effects, emphasize the orientation of the green market, meet the green needs of stakeholders, and be more conducive to winning green competitive advantages and sustainable development of enterprises [16, 17].

Green innovation research combines evolution, quantification, influencing factors, and performance [18]. Scholars define green innovation based on process and results [19, 20], measuring it through market share, benefits, energy conservation, pollution prevention, waste recycling, non-toxic design, and green products [21, 22]. The quantity and quality of green patents are key indicators. Efficiency measures use Super-SBM, GML, DEA, and SFA models [23, 24]. Green innovation is also classified as breakthrough and incremental [25, 27]. Driving factors for green innovation include political, market, stakeholder, technical, and other factors. Market factors reflect consumer demand for green products [28]. The pressure on stakeholders extends to the green innovation process [29]. Technical factors encompass green patents, professionals, and inter-organizational learning [30]. Realization paths range from value chains to asymmetric innovation [31–33]. Green innovation results measure economic, social, and environmental performance, competitive advantage, and organizational performance [34–36].

Digital platforms help improve enterprises' innovation management ability and teams' core competitiveness [37]. In the context of carbon neutrality, textile enterprises strengthen the tracking of digital technology innovation trends, actively organize green and advanced technology reserves, and improve the decision making of green development and R&D investment [38]. Non-competitiveness makes the same set of data infinitely copied to multiple agents for simultaneous use, overcomes the total limitation of traditional production factors, exerts the multiplier effect of the elements of the data, and fully releases the value of digital technology [39]. The boundaries between industries and departments tend to blur and the level of innovation of the corporate output improves. This is conducive to textile enterprises that use digital technologies and platforms to form information exchange and team cohesion [40, 41].

Knowledge search is a collective learning behaviour that crosses organizational boundaries and emerges based on members' shared values and communication modes when organizations explore knowledge, such as market and technology, to acquire heterogeneous knowledge and improve technology, creativity, and cohesion [42]. Knowledge search is a process that goes from initial knowledge mastery to knowledge accumulation and innovative application [43]. Based on innovation search theory and knowledge supermodel theory, the communication between big data and information makes the organization gradually change into indoctrination-acceptance learning to supplement inertia, which reserves sufficient knowledge materials and data for green innovation and forms original incentives. How can research organizations communicate research knowledge to decision makers more effectively? Searches across knowledge boundaries significantly impact corporate innovation performance, and exploratory searches try to eliminate organizational conventions and knowledge bases and expand the width and depth of search [5]. Research on the use of knowledge in Canadian social science research found that knowledge is essential for enterprises to obtain a sustainable competitive advantage [44, 45]. Based on search theory and organizational learning theory, knowledge research affects the capability of enterprises to differentiate themselves through technology knowledge acquisition and dissemination [45]. From the perspective of dynamic capabilities, the resources obtained from the search for knowledge can be transformed into capabilities to promote the behaviour and performance of green innovation [46]. Knowledge search is essential for enterprises to overcome the double constraints of resource and technology shortages. However, its internal mechanism has yet to be explored and analysed [47, 48].

Existing research has made rich achievements, focusing on the connotation of knowledge search, digital technology, and green innovation, and it rarely studies the internal mechanism of green innovation in textile enterprises. Textile enterprises focus on the production, processing, and sales of textiles. It is a traditional industry with a long history and a broad market demand. Compared to other industries, textile enterprises pay more attention to selecting raw materials, improving the production process, and the quality control of products. The textile industry dramatically impacts the environment in the production process, including water consumption, wastewater discharge, and chemical use. The industrial chain of textile enterprises is relatively long, covering many links from raw material procurement, spinning, weaving, printing, dyeing, garment production, and sales. This long industrial chain requires textile companies to coordinate multiple links in green innovation to achieve overall greening. Therefore, textile enterprises face more significant challenges and opportunities in green innovation and need to reduce environmental impact and achieve sustainable development through technological innovation. At the same time, the textile industry is greatly affected by market changes. Consumer demand, fashion trends, policy environment, and other factors may impact the production and sales of textile enterprises. Therefore, textile enterprises must have a keen understanding of the market and the ability to respond quickly to market changes. The path of green innovation in textile enterprises has not been revealed, and there is a particular theoretical "gap", which is the key to realizing textile enterprises from "survival" to "strength". Therefore, based on grounded theory and through multicase analysis, this research discusses how textile enterprises use digital technology to realize prospective research and reactive search from the perspective of knowledge search to realize green incremental innovation and radical innovation of textile enterprises.

RESEARCH METHODOLOGY

A multi-case study is employed to delve into the impact of knowledge search on green innovation within textile enterprises, offering a comprehensive and nuanced understanding of the subject matter. The multi-case study is more suitable for expounding the particularity of actual activities and behaviours of internal organization and management, highlighting the organizational situation and green innovation process, and revealing the relationship between digital technology empowerment and green innovation. Selecting representative enterprises as case study objects, sorting out various enterprise data and interview data through information acquisition, and adopting data reduction displays to obtain structured and coded case data. At the same time, the characteristics and performance of case enterprises in each research variable are clarified. Through the analysis and comparison between cases, the universal laws of different enterprises in the relationship between research variables and the crisis development stage are found, the matching relationship is refined, and the mediating role of knowledge search is summarized.

Case selection

The criteria for selecting textile enterprises for research are multi-faceted, prioritizing those operational for over three years, successfully navigating initial risks, and embarking on a phase of green innovation. The availability of case data enhances the validity of the study. The empowerment of digital technology drives green innovation in these enterprises through "digital technology and digital platform", optimizing organizational structure and strategy. Accurate identification of enterprise needs helps to focus green innovation efforts. Enterprises dynamically adjust their development and strategic goals to discover their unique green innovation paths. Selected enterprises must represent the future trends of China's textile industry. Four enterprises in Hangzhou's Linping, Suzhou's Wujiang, Shaoxing's Keqiao, and Nantong's Tongzhou districts were chosen, with Hangzhou's Linping District pioneering a "counting wisdom and Linping" journey, textile fabrics being a key industry there.

This study targeted four distinct textile enterprises located in Linping (Hangzhou), Wujiang (Suzhou), Keqiao (Shaoxing), and Tongzhou (Nantong) districts, chosen for their variation in digital technology adoption, size, personnel composition, capital base, business operations, and strategic goals. This heterogeneity allowed for a nuanced exploration of the impact of knowledge search on green innovation within the textile industry. This diversity enables a comprehensive, objective examination of digital technology, knowledge search, and green innovation. Furthermore, these enterprises boast strong governance, green innovation achievements, and high recognition. The study analysed their public data and reports to gain insights. The selected cases, renowned textile enterprises, exhibit strong typicality, guiding China and global textile development. Their digital technology is advanced, green innovation achievements are significant, and industrial development logic is precise. The selected textile enterprises should have a certain representativeness and can reflect common phenomena and trends in the industry. This helps to extend the research results to a broader range of textile enterprises and provide a reference for green innovation in the entire industry. Priority should be given to companies that have already practiced or achieved specific results in green innovation to further study the path, mechanism, and effect of green innovation. These companies can provide rich case and data support for research.

The enterprises in Wujiang District, Suzhou, focus on the R&D of core component technology, which ensures seamless data integration, long-term intelligent management, and garment production transformation, leading the domestic textile industry. The enterprises showcase strong prospects and research value. They implement strategic layouts, integrating digital technology and green innovation, which is essential for this study. The enterprises have actively pursued digital technology, knowledge search, and green innovation, facilitating data collection. Their clear digital strategies, knowledge search patterns, and green innovation layouts offer rich case study material. We visited Tongzhou District textile enterprises, and their digital and green achievements provided valuable data to explore the evolution of textile firms in these areas.

Linping has more than 7,600 clothing enterprises, and 80% of Hangzhou women's clothing is produced in Linping. Shengze Town, Wujiang District, Suzhou City, is called "Ancient Silk Town" and "Famous Textile City". It is a crucial textile base, export base, and trading center in China, where information release and textile index are produced and is committed to building a "fashion capital". The unique advantage of the "printing and dyeing + market" in Shaoxing Ke Qiao has led to the vigorous development of the textile industry in the Keqiao District and accelerated the transformation and upgrading of the traditional textile industry. Nantong is known as the "Textile City". The textile industry is Nantong's most recognizable and symbolic pillar, enriching the people industry. Nantong Tongzhou Bay makes every effort to build a green and low carbon textile park, and garment enterprises gradually transform to focus on high-end knitted fabrics and forward-looking technologies to achieve green development.

Based on the endowment factor and the development stage of the enterprises, the effective mode, typical path, and coping strategy of digital technology that empowers textile companies to green innovation are refined, and its development effect is analysed to further use digital technology to achieve green innovation breakthrough. This study selects four textile enterprises as samples to collect and analyze public data and company reports.

Data collection

First, access to official websites and media reports can help form a comprehensive understanding of textile enterprises and their development trajectories, news events, operating results, digital transformation initiatives, and other related information.

Subsequently, data on corporate characteristics, digital technology utilization, green innovation practices, and emerging trends were collected and collated from various sources, including but not limited to the company's official website, news articles, academic publications, industry analysis reports, and publicly available materials, such as annual or quarterly reports, corporate social responsibility reports, and interim financial statements.

Second, collect public documents, including authoritative media's news reports on enterprises. Search for keywords such as digital technology, green innovation, and knowledge search in paper databases such as Cnki.net, Weipu, and WOS, and collect relevant literature. Information from the official website information of the enterprise, "China Enterprise Innovation and Development Report". Collect relevant public news reports, news commentary materials, and enterprise development published on the public platform of WeChat, pay special attention to news reports on digital technology, information management, and green innovation, and collect 89 related reports with about 30,000 words.

The 'Textile Enterprise Knowledge Search and Green Innovation' research team comprises one associate professor, one professor, and five graduate students. The team members conduct on-the-spot investigations on the enterprise's production facilities, management platforms, and technical departments and directly observe and record critical information. These visits are designed to collect first-hand knowledge about digital technology advancements, knowledge-sharing practices, and green innovation initiatives and to adjust based on previously collected insights. The team developed an interview outline, visited the enterprise for on-site observation, and conducted in-depth interviews, mainly for researchers tasked with supervising digital technology initiatives. The interviewees were interviewed for about an hour to form a 30,000-word investigation report.

Complement and cross-validate with other data. Ensure the reliability and objectivity of the research data. Finally, a 105,000-word database is constructed, which provides detailed data support for the case study. Ensure the credibility of evidence with multiangle data sources. Based on the research questions based on data analysis, the proposition is presented, and relevant evidence is collected to verify the proposition to ensure the validity of the research. Through step-by-step coding, mining data categories, identifying category attributes, and exploring category relations, theoretical construction is carried out through inductive analysis, and theoretical research models are formed. Descriptive statistical results of various types of data are shown in table 1.

Specifically, corporate official website data and information on corporate websites include annual reports (quarterly reports), corporate social responsibility reports, corporate interim reports, etc. Open literature includes authoritative media news reports on enterprises and the publication of research papers. The on-site investigation and interview data provide detailed data support for the case study. The essential information is shown in table 2.

The current situation of green innovation, knowledge search, digital technology, and enterprise platform applications has been resolved through open channels and enterprise investigations. This research compiles digital technology's internal and action mechanisms to empower green innovation in textile enterprises.

Table 1

DESCRIPTION		
Serial number	**Data type**	**Data description**
1	Corporate official website data and information	About 45,000 words
2	Open literature	89 articles, about 30,000 words
3	On-site investigation and interview data	30,000 words

Table 2

BASIC INFORMATION OF CASE ENTERPRISE				
Enterprise name	**CS Enterprise**	**XS Enterprise**	**QF Enterprise**	**JT Enterprise**
Establishment time	2002	1999	1996	Year 2000
Belonging region	Linping District, Hangzhou City, Zhejiang Province	Wujiang District, Suzhou City, Jiangsu Province	Keqiao District, Shaoxing City, Zhejiang Province	Tongzhou District, Nantong City, Jiangsu Province
Personnel size (number)	100–199 persons	300–399 people	Less than 50 people	200–299 persons
Registered capital	RMB 100 million	$7.2 million	102.8978 million yuan	93 million yuan

RESULTS AND DISCUSSION

Data coding and analysis

This study's primary focus is examining the application of digital technology, knowledge exploration, and green innovation in textile enterprises. With this backdrop, this research delves into the influence mechanism of how textile enterprises leverage digital technology to facilitate green innovation, using the green innovation process of selected case enterprises as the primary narrative thread. This exploration includes case enterprise selection, digital technology application, knowledge search behaviours, and the resultant green innovation performance. The study completes the coding process by meticulously navigating through three stages: labelling, conceptualization, and categorization. This involves extracting relevant phenomena from textile enterprise data, assigning conceptual frameworks, and extracting categorical insights.

Open decoding

Open decoding means that, based on fully understanding the discourse meaning of written data, the content of text data is broken up. The text data is then disassembled into different nodes by encoding meaningful units [49, 50]. This study follows the step-by-step coding technology of programmed grounded theory and completes data processing.

First, the team members independently coded and recorded accordingly. Second, a comparative analysis is carried out. In the coding process, new concepts and categories are compared and revised repeatedly. The team members ask experts (Professors from Harbin Engineering University, Hebei University and Zhejiang Sci-Tech University) for verification when there is disagreement. Finally, the encoded data are compared with the relevant literature, re-encoded to help solve the previous questions, and finally achieve theoretical saturation. Before open coding, researchers set the corresponding numbers for each data to avoid confusion between the text data of interviewees in the data analysis process [50]. Then, the words, sentences, and paragraphs in the text materials are carefully read and thought repeatedly, taking "digital technology, knowledge search, and green innovation of textile enterprises" as the core of the question, constantly looking for and comparing the recurring meaning units, setting them as different nodes and setting codes to form the basic analysis units in the process of data analysis.

In the open coding phase, the researchers brainstormed the data to open up all potential possibilities in the data at the beginning of the analysis. By splitting the relevant data word by word and grasping the overall coherent meaning of the context of the words and sentences, the initial data are subdivided into micro-analysis units related to the research topic and relatively independent meaning, which are marked with labels and expressed as "aaXXX + phenomenon name", forming an open coding label set as the primary material for spindle coding. Based on the open decoding process, this research explores the mechanism of digital technology empowerment in green innovation. After careful analysis, 56 concepts are retained and abstracted into 33 initial categories, such as "using computer technology to design textile product patterns and colours", "using digital technology to realize product visualization", "imitation production equipment creation and production scheme replication", and "textile enterprises create production platforms for joint manufacturing". The corresponding relationship between concepts and categories in open decoding is shown in table 3.

Table 3

SOME EXAMPLES OF THE 'LABELLING' PROCESS

Data	Level 1: Open Coding: Labelling
A In traditional textile pattern design, digital technology is used to achieve colour without limit. Under computer digital technology, as long as the designer can think of the colour, it can be expressed through digital technology, but also the use of digital technology to expand the textile pattern in the three-dimensional space form, such as the matching textile pattern simulation in three-dimensional space, the actual effect of a comprehensive test, to more quickly determine the colour matching, fabric and so on. Designers are utilizing software such as Adobe Illustrator, CorelDRAW, and Adobe Photoshop for pattern design. After completing the first draft, the computer can be passed to the enterprise and consumers for visual inspection. At the same time, in the context of digital technology, designers can achieve remote control and product style adjustment. From a practical point of view, the application of digital technology in modern textile pattern design, on the one hand, created a new textile pattern design style, on the other hand, to achieve the transformation of human art design. ...	aa001 Using computer technology to design patterns and colours of textile products aa002 Using digital technology to realize product visualization aa003 Acquisition of new knowledge aa004 Explore the needs of emerging markets aa005 Enterprises actively supply more environmentally friendly textile products to meet the needs of consumers for green environmental protection products
B Based on traditional manufacturing, the intelligent production plan now incorporates more intelligent new technologies, business data, process flow data, and equipment data, allowing for batch replication and real-time production schedule tracking. Digitization, intelligence, and information transmission in production management enable departments to analyse and provide feedback on production capacity data. The input values include the order number and delivery cycle. B In recent years, enterprises have conducted thorough market research, examining domestic and foreign textile trends, consumer preference shifts, and competitor strategies. Analysis reveals a growing demand for eco-friendly, functional, and personalized customized products. Recognizing this opportunity, enterprises have realigned their product structures, bolstered R&D and production of eco-friendly materials and functional fabrics, and enhanced personalized customization services. Market demand has fuelled increased investment in R&D for new fibre materials like graphene and bio-based fibres, as well as intelligent production technology. Technological innovation has led to the development of higher-value, market-competitive products. To market these products, enterprises leverage social media, e-commerce platforms, and other diverse channels, fostering stronger consumer interaction and staying attuned to market feedback and evolving demands. B Given the limitation of production capacity, equipment upgrading and process improvement was carried out. Automated production lines and intelligent warehousing and logistics systems were introduced to improve production efficiency and product quality. Strengthen cooperation with supply chain partners, realize resource and risk sharing, and enhance the efficiency and competitiveness of the entire industrial chain. Actively explore cross-border integration with other industries, such as deep integration with information technology, biotechnology, and other fields. Through cross-border cooperation, new application fields and market space can be expanded. ...	bb001 Imitation production equipment creation and production plan replication bb002 Textile enterprises build production platforms for joint manufacturing bb003 Identify and grasp market opportunities bb004 Break down the limitations and barriers to knowledge and production capacity bb005Improve the existing knowledge level according to current needs bb006Expand the knowledge reserve of textile enterprises according to market demand bb007 Enterprises provide environmentally friendly textile products with improved production processes in the existing market bb008 Enterprises provide greener and more environmentally friendly textile products. bb009 Style design of textile green products bb010 Colour matching of textile green products bb011 Fabric Design of Green Textile Products

Table 3 (continuation)

C Consumers understand and purchase textiles through online platforms and experience purchase or pick-up services in offline physical stores. Enterprises can establish official websites or open flagship stores on mainstream e-commerce platforms to display information, pictures, and prices of various textiles for consumers to browse and purchase. We use social media platforms such as Weibo, WeChat, and TikTok to carry out brand and product promotion to attract the attention of potential customers. Provide convenient online booking and payment functions so consumers can complete the purchase process anytime and anywhere. C Through establishing a perfect order processing system, enterprises have realized the capture and processing of order data from multiple data sources such as e-commerce platforms and ERP systems. Through data analysis and application, the enterprise can adjust the production plan promptly, optimize inventory management, and provide customers with more accurate logistics and distribution services. This not only improves the enterprise's operation efficiency and market competitiveness but also wins wide customer acclaim. C With the rapid development of science and technology, textile technology is constantly upgrading. Textile enterprises keep up with the pace of the times and actively enter the field of emerging textile technology. Enterprises increase investment in research and development of new materials, processes, and technologies and continuously launch high-performance textiles with independent intellectual property rights. At the same time, enterprises also cooperate with scientific research institutions, universities, and other units to jointly overcome technical problems and promote the innovation and development of textile technology. This forward-looking technology layout and muscular R&D strength allow enterprises to remain leading in the fierce market competition. ...	cc001 Adopt online to offline to provide services for consumers cc002 Grasping platform order data for processing cc003 Enter the new textile technology field cc004 Explore new channels of the textile industry and market cc005 Dare to bear the high cost of searching for new textile knowledge cc006 Dare to bear the maladjustment and risks that may be brought about by the application of new textile technology cc007 Enterprises actively explore more fashionable and popular green textile products; cc008Enterprises actively apply new fabrics to improve the quality of green products cc008 Enterprises actively apply new fabrics to improve the quality of green products
D The enterprise introduces the Internet of Things technology to realize real-time monitoring and data analysis of production equipment. Through the intelligent scheduling and scheduling system, the enterprise can automatically adjust the production plan, optimize the production process, and improve production efficiency by more than 20%. At the same time, by accurately controlling the production process and parameters, the company has also successfully reduced the product failure rate and improved product quality and customer satisfaction. D Fully implements the precise control strategy of information flow and logistics. It includes formulating clear information management policies; establishing standards and processes for information collection, processing, distribution, and confidentiality; establishing an information management platform to realize centralized management, classified storage, efficient retrieval and sharing of information resources; and promoting inter-departmental collaboration. At the same time, effective information communication channels should be built, and internal mail, instant messaging, regular meetings, and video conferences should be used to ensure a smooth flow of information and encourage employee communication and collaboration. In addition, advanced information technologies such as ERP and WMS are introduced to achieve comprehensive resource management and accurate inventory control. Big data analysis is used to provide strong support for decision-making. In terms of logistics, set up a special logistics management department to achieve process reengineering and professional management; improve the logistics system, reduce costs, and improve efficiency by rationally planning routes, reducing inventory and turnover links; introducing automated warehousing equipment and logistics tracking system to improve storage, pickup and transportation efficiency and service quality; and according to the actual selection of the appropriate logistics model, such as outsourcing or alliance, to reduce costs and enhance flexibility. At the same time, a risk management plan should be developed to deal with potential risks. D Textile enterprises know that knowledge is constantly developing and updating. Therefore, enterprises continue improving and perfecting reserve knowledge through continuous knowledge search and learning. Enterprises use advanced technologies such as big data and artificial intelligence to screen and analyse massive amounts of information and discover new knowledge points and technical trends. At the same time, enterprises also pay attention to maintaining close contact with experts and scholars inside and outside the industry and keep abreast of industry trends and technological progress. This continuous knowledge search and improvement mechanism keeps enterprises' knowledge reserves always keeping pace with the times and provides strong support for the innovation and development of enterprises. ...	dd001 Efficient Internet of Things Link Intelligent Scheduling and Scheduling dd002 Realize accurate management and control of information flow and logistics dd003 Enterprises complete the improvement of reserved knowledge through knowledge search dd004 Enterprises improve and extend the reserved knowledge in different scenarios, processes, and links through knowledge search dd005 Enterprises vigorously search for environmental protection management information; dd006 Enterprises actively explore the information of emerging textile technologies and complete the knowledge search for improving production processes or processes such as printing and dyeing; dd007 Access to relevant policy information; dd008 Enterprises agree that textile products should meet the needs of green environmental protection dd009Realize the greening of the whole production process

Spindle decoding

The principal axis coding refines the relationship between concepts based on the results of open coding. Among them, principal axis coding refers to the in-depth classification, synthesis, and organization of text data by researchers using the most important or frequent open coding, finding the code numbers with semantic relations, and associating them with each other [49, 50]. Through this coding paradigm, concepts and categories are linked; that is, by using the conditions of a phenomenon, the actions and results taken against the situation are comprehensively considered to master the phenomenon's essence. Principal axis coding aims to cluster the initial categories refined by open coding again, discover and establish the potential relationships among the initial categories, abstract and form a higher-level principal category, and prepare for the next step of finding story clues.

Further carry out principal axis and selective coding around the text data, classify, refine, and comprehensively adjust again, merge code numbers with similar meanings, and sort out the correlation between code numbers. Research team classifies 33 code numbers into 14 more refined ones using similar, heterogeneous, horizontal, and vertical comparisons. Clustering analysis is carried out on relatively independent open decoding results, and the principal axis decoding is obtained to analyze the conceptual hierarchy relationship of each category. Open decoding is formed into the initial category for integration. Finally, 14 main categories are abstracted and summarized, and the results of spindle coding are shown in table 4.

Table 4

MAIN CATEGORY, SUBCATEGORY, AND INITIAL CATEGORY

Main category	Subcategory	Initial category
A01 Digital product design technology	AA01 Textile colour design AA02 Textile pattern simulation AA03 Intelligent visual inspection of finished products	aa001 Using computer technology to design patterns and colours of textile products aa002 Using digital technology to realize product visualization
A02 Digital manufacturing technology	AA04 Transformation of production equipment AA05 Replication of production plan AA06 Production platform building	bb001 Imitation production equipment creation and production plan replication bb002 Textile enterprises build production platforms for joint manufacturing
A03 Digital sales service technology	AA07 Online to offline AA08 Order collection and processing AA09 Supply chain link AA10 Logistics service	cc001 Adopt online to offline to provide services for consumers cc002 Grasping platform order data for processing dd001 Efficient Internet of Things Link Intelligent Scheduling and Scheduling dd002 Realize accurate management and control of information flow and logistics
A04 Exploring new knowledge and market opportunities	AA11 Acquisition of new knowledge AA12 Demand exploration AA13 Opportunity identification AA14 Break through barriers	aa003 Acquisition of new knowledge aa004 Explore the needs of emerging markets bb003 Identify and grasp market opportunities bb004 Break down the limitations and barriers to knowledge and production capacity
A05 Channel excavation	AA15 Perception of new technology AA16 Exploration of market channel	cc003 Enter the new textile technology field cc004 Explore new channels of the textile industry and market
A06 Risk-taking	AA17 Knowledge search cost bearing AA18 Risk of new knowledge application	cc005 Dare to bear the high cost of searching for new textile knowledge cc006 Dare to bear the maladjustment and risks that may be brought about by the application of new textile technology
A07 Knowledge absorption and reserve	AA19 Improve the level of knowledge AA20 Expand knowledge reserves	bb005 Improve the existing knowledge level according to current needs bb006 Expand the knowledge reserve of textile enterprises according to market demand
A08 Knowledge expansion and extension	AA21 Reserve knowledge expansion AA22 Extension of reserve knowledge	dd003 Enterprises complete the improvement of reserved knowledge through knowledge search dd004 Enterprises improve and extend the reserved knowledge in different scenarios, processes, and links through knowledge search

Table 4 (continuation)

Main category	Subcategory	Initial category
A09 Information Acquisition	AA23 Management information acquisition AA24 Access to technical information AA25 Access to relevant policy information	dd005 Enterprises vigorously search for environmental protection management information dd006 Enterprises actively explore the information of emerging textile technologies and complete the knowledge search for improving production processes or processes such as printing and dyeing dd007 Access to relevant policy information
A10 Green product improvement	AA26 Improvement of the production process of green products AA27 Environmental protection of green products is improved	bb007 Enterprises provide environmentally friendly textile products with improved production processes in the existing market bb008 Enterprises provide greener and more environmentally friendly textile products
A11 Improve the quality of green products	AA28 Style improvement of textile green products AA29 Fabric upgrade of textile green products	cc007 Enterprises actively explore more fashionable and popular green textile products cc008 Enterprises actively apply new fabrics to improve the quality of green products
A12 Green product design	AA30 Enterprises actively try to learn fashionable, advanced, and environmentally friendly green textile products through learning and training	bb009 Style design of textile green products bb010 Color matching of textile green products bb011 Fabric Design of Green Textile Products
A13 Green product supply	AA31 Improve the supply of green textile products AA32 Meet the demand for green products	aa005 Enterprises actively supply more environmentally friendly textile products to meet the needs of consumers for green environmental protection products
A14 Green product demand perception	AA33 Textile products should meet the green demand	dd008 Enterprises agree that textile products should meet the needs of green environmental protection dd009 Realize the greening of the whole production process

Selective coding

Selective coding further integrates and refines existing categories more abstractly, generates and explores the main categories around the topic, and thus establishes the relationship between categories [49–50]. Researchers set up three new nodes around the theme of “Digital Technology and Green Innovation” in the above 14 codes, namely, “Digital Technology”, “Knowledge Search”, and “Green Innovation”.

Research team analyse 14 main categories. “Digital product design technology, digital processing and manufacturing technology; Digital sales and service technology” is the digital background on which green innovation depends, and products, manufacturing, and service are the core categories of digital technology in textile enterprises. It can be summarized as “digital technology”. “New knowledge and market opportunity exploration”, “channel mining”, and “risktaking” can be summarized as “prospective research”; “Knowledge absorption and storage”, “knowledge expansion and extension”, and “information acquisition” can be summarized as “reactive search”; prospective research and reflective search together constitute knowledge search; “incremental innovation” and “radical innovation” are the two-dimensional effects of green innovation, and finally 14 main categories are summarized and abstracted into three core categories.

Furthermore, analyse the 14 main categories formed by selective coding. Among them, ‘A01 Digital product design technology’, ‘A02 Digital manufacturing technology’, and ‘A03 Digital sales service technology’ are the digital background of green innovation and the core digital technology category in textile enterprises. The three are summarized as ‘A1 Digital technology’. ‘A04 Exploring new knowledge and market opportunities’, ‘A05 Channel excavation’, and ‘A06 Risk-taking’. can be summarized as ‘A2 Prospective research’; ‘A07 Knowledge absorption and reserve’, ‘A08 Knowledge expansion and extension’, and ‘A09 Information Acquisition’ can be summarized as ‘A3 Reactive search’. Prospective research and Reactive search constitute the ‘knowledge search’; ‘A10 Green product improvement’ and ‘A11 Improve the quality of green products’ can be summarized as A4’ Incremental innovation’, ‘A12 Green product design’, ‘A13 Green product supply’, and ‘A14 Green product demand perception’ can be summarized as ‘A5 Radical innovation’, ‘Incremental innovation’ and ‘Radical innovation’ are two dimensions of green innovation.

With the support of digital technology, sampled enterprises realize information exchange through element links, thus forming the driving force and way of organizational system innovation. Establish trust relationships through multi-agent interaction to realize organizational strategic innovation through collaborative governance. Team cohesion is formed through situational interaction, common development goals are triggered, and organizational structure innovation is promoted through the in-depth development of organizational integration. The storyline around this core category is as follows: first, textile enterprises realize deep digital technology by building digital networks, building digital platforms, upgrading digital technology and data management, and realizing multi-agent new knowledge and market opportunity exploration, channel mining, knowledge management, and information acquisition through digital technology. Under the joint action of digital technology and knowledge search, the trust mechanism and the learning mechanism are used extensively to adjust the learning behaviour of organizational subjects and promote the realization of green innovation goals.

Clustering analysis is carried out on the relatively independent open decoding results, and the principal-axis decoding is obtained to analyse the conceptual hierarchy relationship of each category. Open decoding is formed into the initial category for integration. Finally, five main categories are abstracted and summarized, and the results of principal axis decoding are shown in table 5.

In green innovation, textile enterprises should improve their keen grasp and adjustment ability of technical and policy environments, apply digital technology to green innovation, realize value process reshaping and knowledge search, and drive green innovation. Figure 1 summarizes the mechanism of influence of textile companies using digital technology to realize knowledge search and improve green innovation.

The remaining quarter of the data is used to test the saturation of grounded theory. After analyzing the materials, no new definition and type are found, so the model constructed by grounded theory has passed the theoretical saturation test.

Table 5

MAIN CATEGORIES FORMED BY SELECTIVE CODING

Category	Concept
A1 Digital technology	A01 Digital product design technology; A02 Digital manufacturing technology; A03 Digital sales service technology
A2 Prospective research	A04 Exploring new knowledge and market opportunities; A05 Channel excavation; A06 Risk-taking
A3 Reactive search	A07 Knowledge absorption and reserve; A08 Knowledge expansion and extension; A09 Information Acquisition
A4 Incremental innovation	A10 Green product improvement; A11 Improve the quality of green products
A5 Radical innovation	A12 Green product design; A13 Green product supply; A14 Green product demand perception

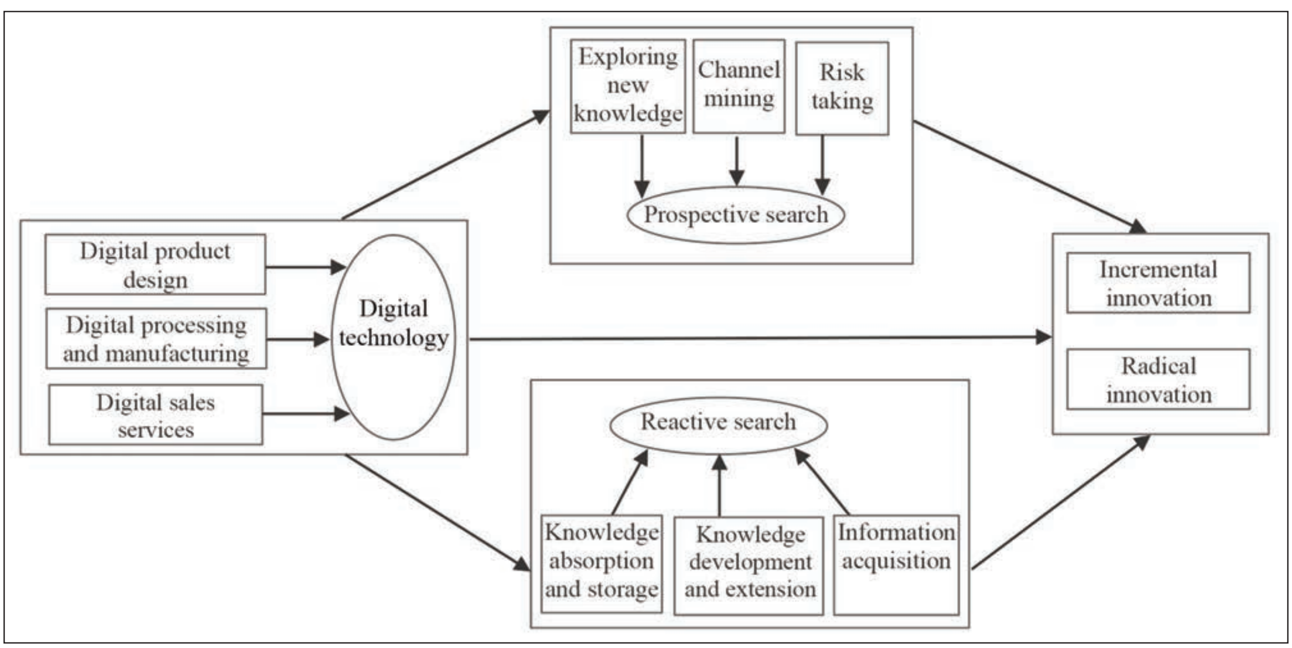

Fig. 1. The influence mechanism

The findings align with those of Matarazzo et al. [38], emphasizing that textile enterprises must follow digital trends, invest in digital reserves, and improve green development. We highlight R&D in the design, processing, and sales/service of digital products, enhancing the digital framework. From a resource-based perspective and industrial upgrading theories, we demonstrate that digital technology advances green R&D. Enterprises use big data to digitize consumer patterns, analyse demand-side data, predict fashion trends, and accurately capture marketing dynamics. With the deepening of digital technology in the design of green products and the innovation of textile enterprises, textile enterprises can use digital technology and platforms to continuously strengthen the green performance of products, thus improving the performance of green incremental innovation.

This research extends radical innovation concepts, complementing Brem et al. [25] and Agostini and Nosella [26]. This research explores the digital processes of textile enterprises to gain new knowledge and market opportunities and mine information to enhance risk-taking. This research also complements Abbas and Sagsan [8] on knowledge management for sustainable performance.

Supplementing Nambisan et al. [2], this research emphasizes the positive impact of digital technology on green innovation, enriching knowledge-level insights. Like Urbinati et al. [39], this research discusses the impact of digital technology on green innovation, highlighting the pivotal role of knowledge search. This further complements the research results of Kauffman and Weber [41] from the organizational level. This research improves knowledge search ability by applying digital technology in different fields. For example, this research found that increasing the efficient supply of textile products and services with a low carbon promotes the concept of textile products consumption with a low carbon life and establishing a traceability certification system for recycling textile materials, thus reducing the waste of textile resources and reducing carbon emissions.

Cross-border technical and market knowledge searches improve innovation performance and breakthroughs, supporting green innovation through creativity in knowledge. This research expands on Phelps et al. [51], clarifying knowledge management as an active organizational search behavior under digital technology. Digital platforms facilitate knowledge sharing, encouraging exchange and precise green innovation demand identification.

Digital technology integrates with multilevel factors, improving knowledge search, market access, and green innovation, according to Agostini and Nosella [26]. This expands Chang et al. [27] and Agostini and Nosella's [26] work, promoting data openness and interconnectedness. Digital technology decomposes organizational processes, facilitating structural reconstruction.

CONCLUSIONS

Using grounded decoding analysis from a multi-case study approach, we selected four textile enterprises as representative samples. Through interviews and factor analysis, this research applied grounded theory to qualitatively investigate the intersection of digital technology, knowledge search, and the construction of green innovation. This deliberate exploration delves into the green innovation process within enterprises amidst the backdrop of emerging technologies. This research constructs a theoretical framework on the application of digital technology in textile enterprises, examines its evolutionary process and pivotal mechanisms that influence green innovation, and consolidates the empowerment mechanism of digital technology for green innovation in textile enterprises from a knowledge search perspective. Key findings reveal that digital technology enhances information exchange capabilities through the interconnection of elements and knowledge exchange in knowledge search, thus dynamically supporting organizational system innovation. Second, this research reveals multi-agent interaction in knowledge search, fostering trust between internal and external organizational members and encouraging strategic innovation. Thirdly, this research reveals that digital technology enhances team cohesion by facilitating scenario-based interactions within knowledge search. This collaborative approach fosters the integration of diverse perspectives and promotes further development, ultimately acting as a catalyst for organizational structural innovation.

This paper provides a comprehensive analysis of digital processes in textile enterprises, focusing on how they acquire new knowledge, explore market opportunities, and enhance risk-taking capabilities through digital technology. The practical implications of this research are significant for textile enterprises and the industry at large. Firstly, the findings underscore the importance of digital technology in transforming traditional textile pattern design processes, enabling designers to create limitless colour and pattern combinations and facilitating real-time visualization and adjustment. Secondly, the research emphasizes the role of digital manufacturing technology in optimizing production processes and enhancing product quality. By incorporating intelligent production plans, real-time monitoring, and data analysis, textile enterprises can significantly reduce product failure rates and increase production efficiency. Furthermore, the study underscores the significance of digital sales service technology in expanding market reach and improving customer experience. By leveraging online platforms and social media for brand promotion and order processing, textile enterprises can tap into new customer segments and streamline the purchasing process, fostering customer loyalty and driving sales growth. Additionally, the research highlights the importance of proactive knowledge seeking and risk-taking in exploring new knowledge and market opportunities. By staying abreast of industry trends and technological advancements, textile enterprises can identify and seize market opportunities, leading to incremental and radical innovations in green product design and supply. Finally, the practical implications of this research extend to policymakers and stakeholders in the textile industry. By understanding the transformative potential of digital technology, they can create supportive policies and infrastructures that facilitate the adoption and integration of digital processes in textile enterprises. This will drive sustainable growth and innovation in the industry, ultimately benefiting consumers and the environment.

In conclusion, this paper demonstrates the critical role of digital processes in shaping the future of textile enterprises. By embracing digital technology, textile enterprises can enhance design efficiency, optimize production processes, expand market reach, and foster innovation, ultimately driving sustainable growth and competitiveness in the industry. China's textile enterprises have witnessed significant advances in digital technology, yet this study focused solely on four cases. The applicability of the theoretical model to textile and other manufacturing enterprises remains to be determined. Future research should employ cross-case analysis to enhance sampling and empirical methods to refine the model. Additionally, qualitative and quantitative methods will be combined to assess the generality of the conclusions and compare the differences among various types of enterprises. Moreover, the regional focus of the current study limits its conclusions. Future stratified sampling and large-scale investigations will examine the variations in digital technologies across regions and organizational structures, revealing the underlying mechanisms.

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Dynamic thermo-physiological comfort of a recycled Denim nano-layered fabric

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ABSTRACT – REZUMAT

Dynamic thermo-physiological comfort of a recycled Denim nano-layered fabric

This study investigated the dynamic thermo-physiological comfort of a recycled Denim nano-layered fabric. The top layer of the Multilayered Denim fabric was recycled Denim. The semi-permeable nanomembrane was chosen due to its high-water vapour permeability and waterproof properties. A nonwoven fabric was added to the garment as an extra layer to provide shape and support and avoid direct contact with the skin. A double-faced adhesive grid was used to ensure bonding between the various layers.

The breathability of used fabrics was studied based on the air permeability, water vapour resistance, and relative permeability using the Permetest according to the ISO 11092 standard. To study the dynamic of the thermo-physiological comfort, the dynamic cooling heat flow during evaporation was visualised. Results showed adding a semi-permeable nanolayer decreased the air permeability by about 16% compared to a simple Denim fabric. Conversely, the water vapour permeability was enhanced to 48% when the nanolayer foil was added. It was found that a multilayered Denim fabric had a better cooling feeling at the skin's first contact stage and equilibrium compared to a simple fabric.

Keywords: *recycled denim, nanolayer, breathable, dynamic heat flow*

Confortul termofiziologic dinamic al unui material textil nano-stratificat din denim reciclat

Acest studiu a investigat confortul termofiziologic dinamic al unui material textil nano-stratificat din denim reciclat. Stratul superior al materialului textil denim multistrat a fost denimul reciclat. Nanomembrana semipermeabilă a fost aleasă datorită permeabilității ridicate la vapori de apă și proprietăților sale de impermeabilitate. Un material nețesut a fost adăugat la produsul de îmbrăcăminte ca un strat suplimentar pentru a oferi formă și suport și pentru a evita contactul direct cu pielea. A fost utilizată o grilă adezivă cu două fețe pentru a asigura aderența între diferitele straturi.

Respirabilitatea materialelor textile utilizate a fost studiată pe baza permeabilității la aer, a rezistenței la vapori de apă și a permeabilității relative utilizând Permetest, în conformitate cu standardul ISO 11092. Pentru a studia dinamica confortului termofiziologic, a fost vizualizat fluxul de căldură dinamic pentru răcire în timpul evaporării. Rezultatele au arătat că adăugarea unui nanostrat semipermeabil a redus permeabilitatea la aer cu aproximativ 16% în comparație cu o țesătură denim simplă. În schimb, permeabilitatea la vaporii de apă a crescut cu 48% la adăugarea foliei nanostratificate. S-a constatat că o materialul textil denim multistrat creează o senzație de răcire în prima etapă de contact și echilibru cu pielea, comparativ cu un material textil simplu.

Cuvinte-cheie: *denim reciclat, nanostrat, respirabil, flux termic dinamic*

INTRODUCTION

The Denim market has been a cornerstone of the fashion industry for decades, characterised by its enduring popularity and versatility [1–4]. Denim jeans, jackets, and other apparel have become a staple in wardrobes worldwide, driven by comfort, durability, and style [5, 6].

A growing emphasis on sustainability has led to increased demand for eco-friendly Denim products [7, 8]. Brands are responding by adopting sustainable practices, such as using organic cotton, reducing water consumption, and implementing ethical sourcing.

The rise of personalisation has fuelled a trend towards customised Denim. The fast-fashion industry has played a significant role in popularising Denim, offering affordable and trendy options to the mass market [9, 10].

Multilayered textile fabrics are those composed of multiple layers of fabric or non-fabric materials, often bonded or laminated together to achieve specific properties or functions [11, 12]. These layers can be made from various materials, including natural fibres (like cotton, wool, and silk), synthetic fibres (like polyester, nylon, and acrylic), or blends of these [13–15]. Multilayered fabrics were used to enhance fabric performance, like durability, insulation, waterproofing, windproofing and UV protection.

Common types of multilayered fabrics are laminated, bonded fabrics and composite fabrics. Multilayers can create unique textures, patterns, and visual effects. They can serve as carriers for coatings, laminates, or other treatments [16].

Breathability in textiles refers to their ability to allow air and moisture to pass through them [17]. It's a crucial factor in various applications, especially clothing and bedding, as it directly impacts comfort and overall well-being [18].

The breathability of a textile is a vital consideration for various applications. By understanding the factors that influence breathability, you can select fabrics that are best suited for your specific needs [18]. Breathable fabrics help to regulate body temperature by allowing moisture to evaporate, preventing discomfort and skin irritation [17]. Poorly breathable fabrics can trap moisture, creating a breeding ground for bacteria and fungi, which can lead to skin infections and other health problems. In athletic wear, breathable fabrics help to wick away sweat, improving performance and comfort. Breathable fabrics can help to prevent moisture buildup, which can contribute to fabric degradation and reduce the lifespan of the garment.

Waterproof breathable fabrics differ from conventional coated materials owing to distinct characteristics of waterproofness and breathability. These fabrics function similarly to human skin. Numerous breathable and waterproof fabrics have been developed to minimise wearer heat stress through efficient moisture vapour transfer while preventing external water penetration. Several factors influence the breathability of a textile, like fibre type, fabric structure and finishing process [19–21]. Natural fibres like cotton, linen, and wool generally have better breathability due to their porous structure. Synthetic fibres like polyester and nylon can vary widely in breathability [22]. Some, like microfibre, can be highly breathable. Plain weave fabrics tend to be more breathable than twill or satin weaves [18, 23]. Jersey knit fabrics are generally more breathable than rib knit or French terry. Heavier fabrics may be less breathable than lighter ones, as they have a denser structure [23]. Treatments like water repellents or finishes can affect breathability [24, 25]. Some treatments can reduce the fabric's ability to absorb moisture, which can also impact its breathability.

Thermal Evaporative Resistance (RET) is used to quantify breathability and water vapour transport via textiles [26, 27]. Water vapour resistance refers to a fabric's capacity to transfer moisture vapour through it [28]. The less resistance there is, the more breathable the cloth is. The ISO 11092 standard defines the test technique.

As a result, it is fundamental to study the kinetics of water vapour transport. Based on the review of the literature investigation described in this section, there is an absence of studies dealing with the thermo-physiological comfort using layered Denim materials.

In this study, a layered denim fabric was developed. The top layer was made of recycled denim fabric. The semi-permeable material was incorporated due to its exceptional water vapour permeability and waterproof properties. A nonwoven fabric is utilised as an additional layer within a garment to provide shape and support while avoiding direct contact with the nanolayer semi-permeable membrane. All layers were bonded using a double-face adhesive grid. The Breathability of designed fabrics was evaluated regarding air permeability, water vapour resistance, and relative permeability. The dynamic of the evaporative cooling heat flow was studied using Permetest, based on the ISO 11092 standard.

MATERIALS AND METHODS

Denim nanolayered fabric design

Figure 1 illustrates the different fabric components of each layer, with denim fabric considered the top layer. A semi-permeable membrane was used due to its reparability, high water vapour permeability and waterproofing.

Table 1 presents the different properties of the different layers used in this study.

A nonwoven interfacing fabric was selected as an extra layer in a garment to provide shape and support and avoid direct contact with the skin of the nanolayer semipermeable foil. A double-face adhesive grid was placed between two adjacent layers to ensure adherence.

Figure 2 illustrates the different sample layout designs. Fabric (A) is a Denim fabric considered as a reference sample. The (AC) layout was made with Denim fabric (A) as a top layer and a nonwoven interfacing. In the case of the (AB), the nonwoven interfacing was replaced by the Semi-permeable foil PU Nanolayer (B). The sample (ABC), three different

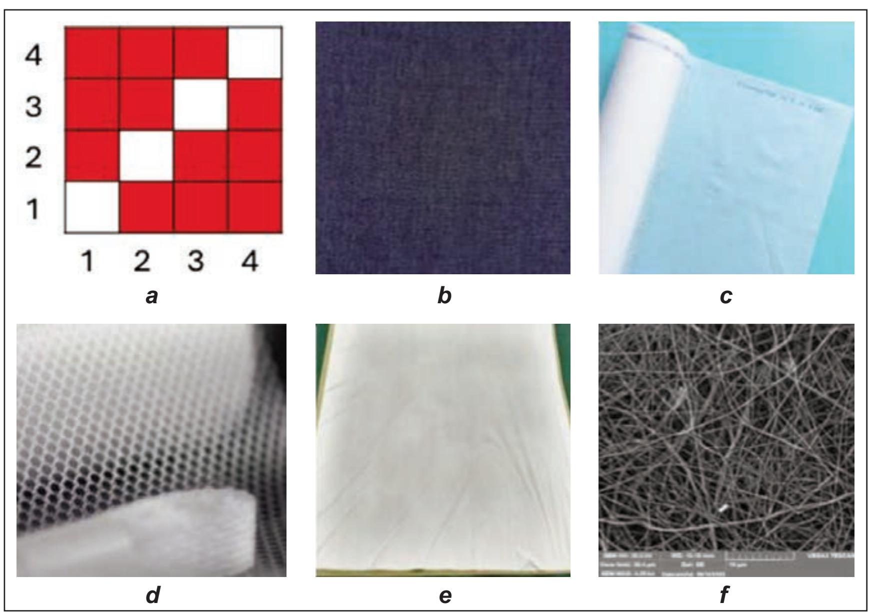

Fig. 1. Fabric Layers component: *a* – Denim fabric designs; *b* – Denim fabric; *c* – nonwoven interfacing; *d* – PA66 adhesive Monocomponent Cobweb; *e* – Semi-permeable foil PU Nanolayer; *f* – SEM image of PU Nanolayer foil

Table 1

LAYERS COMPOSITION PROPERTIES					
Layer	**Designation**	**Material**	**Mass per unit area (g/m²)**	**Fibre diameter (μm)**	**Thickness (mm)**
A	Recycled Denim fabric	100% recycled cotton	180±4	18.3±1.7	0.62±0.02
B	Semi permeable foil	PU	3.1	0.180	0.02±0.01
C	Nonwoven interfacing	85% PA66/15% recycled PET	35	-	0.12
	Double-face adhesive grid	PA66	6	-	0.01±0.005

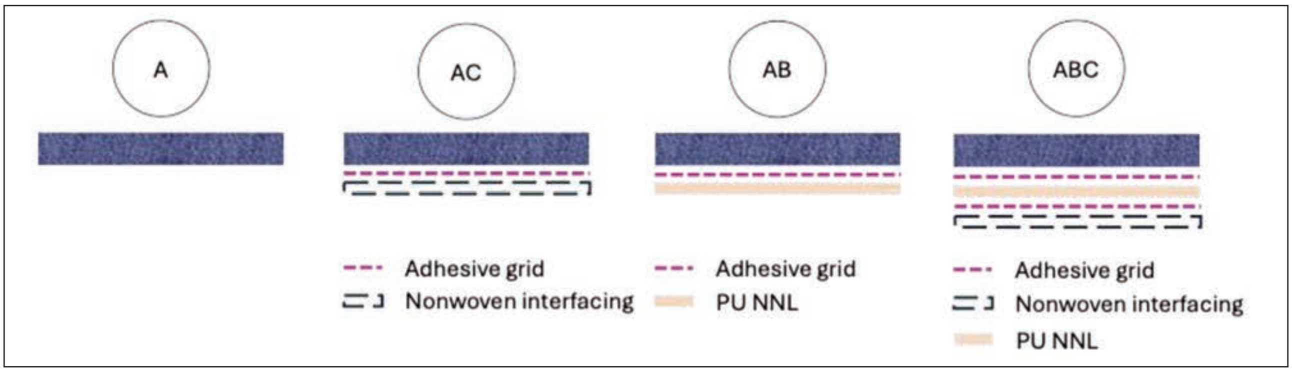

Fig. 2. Different layout layers of used samples

layers were composed of Denim (A), Semi-permeable foil PU Nanolayer (B) and nonwoven interfacing (C). The bonding process of all layers was carried out using a heat press machine at 115ºC, and the heat-pressing time was set to 30 seconds.

Air permeability

Air permeability measurements are made using the SDL Atlas Air permeability instrument according to EN ISO 9237 standard with 100 Pa air pressure.
Table 2 states the properties of the different layer configuration samples.

Table 2

DIFFERENT LAYERS CONFIGURATIONS PROPERTIES			
Sample	**Mass per unit area (g/m²)**	**Thickness (mm)**	**Air permeability (mm/s)**
A	180±4	0.62±0.02	465±10
AC	220±3	0.65±0.03	416±7
AB	189±1	0.62±0.04	402±3
ABC	228±5	0.66±0.04	389±5

Based on table 2, the thickness of the layered fabric is not the direct sum of each fabric's thickness. This is due to the bonding process where pressure was applied.

Thermo-physiological comfort

The relative water vapour permeability (%) and resistance (m^2Pa/W) values of different samples were tested using the Permetest instrument. In this instrument, the measuring head of the small Skin Model is covered by a resistant semi-permeable foil, which prevents the liquid water transport from the measuring system into the sample. A computer-evaluated sensing system quickly records cooling heat flow caused by water evaporation from the thin-porous layer. Regarding heat transfer, the Permetestent presents the model of real human skin. The instrument provides all kinds of measurements, like the ISO Standard 11092. The results are evaluated by the identical procedure as required in this standard and are treated statistically, displayed and recorded for future use [29].

Measurements conditions

After conditioning the fabrics for 24 hours under the standard atmospheric conditions of 20 ± 2 °C temperature and 65 ± 2 % relative humidity, all measurements were conducted.

RESULTS AND DISCUSSION

In this section, the effect of adding layers to a recycled Denim fabric on the thermo-physiological comfort was investigated. Then, the cooling heat flow during the evaporation of different layer configurations was studied.
Table 3 illustrates the water vapour relative permeability and resistance of the different designed fabrics.
Table 3 indicates that sample ABC is more competitive than the other samples. The relative water vapour permeability was increased to 47.63% when comparing Denim Fabric (A) to the layered sample (ABC). And the water vapour resistance was dropped to 34.37%.

Table 3

WATER VAPOUR RELATIVE PERMEABILITY AND RESISTANCE OF DESIGNED LAYERED FABRICS				
Water vapour	**Samples**			
	A (reference)	**AC**	**AB**	**ABC**
RWVP (%)	52.7±2.3	39.8±2.1	59.5±2.6	77.8±3.1
RET (m^2Pa/W)	6.4±0.3	7.1±0.4	5.6±0.2	4.2±0.1

Concerning the air permeability (table 2), it was decreased to 16.34% in the case of the sample (ABC) compared to sample (A), the Denim fabric. This is caused by the densities of dry air and water vapour. Humid air is less dense than dry air, and subsequently, we have more mobility in terms of water vapour particles compared to dry air particles. Also, during the drying process, the evaporation front drops from the outer surface to internal pores, as capillary transport of the liquid takes place in the inter-fibre spaces, governed by the concentration gradient of water between wet and dry surfaces. The evaporation of water in those holding regions involves the movement of condensed water before it is evaporated, which increases its evaporation duration [30]. The evaporation duration is reduced by increasing the contact surface between the liquid in the textile structure and the air in the external environment, which promotes water vapour evaporation.

The evaporative cooling heat flow kinetics under 1 m/s of air velocity are presented in figure 3.

Based on figure 3, the double adhesive grid and the nonwoven interfacing fabric have no significant effect on the water vapour diffusion. There were no noticeable changes between A and AC and between AB and ABC concerning the evaporative cooling heat flow.

Figure 3 suggests that displaying the cooling heat flow dynamics resulted in three phases. In the beginning, the maximum cooling heat flow was measured as the difference between the sample temperatures at 20±2°C and 65±2% relative humidity and the temperature at the top of the measuring heat, which was approximately 18±2°C due to evaporation from the semi-permeable foil. Throughout the second stage, also referred to as the transition phase, the cooling heat flow drops to a minimum before rising to an equilibrium value, marking the initiation of the third stage, the steady state phase.

At 0 seconds, the sample (ABC) had an evaporative cooling heat of 153.3±5.4 W, whereas the basic Denim sample (A) had 87.4±7.8 W. During evaporation on the Permetest device, samples initially maintained at room temperature (20±2°C) had warmer temperatures than those in the ventilation channel (18±2°C) resulting from evaporation from the semi-permeable membrane covering the top of the measuring heat. As a result, the last-mentioned was not heated since the fabric was hotter than the semi-permeable membrane top side that was placed on top of it.

In the second stage, to regulate the temperature between the fabric and the measuring top head, the heat flow fell to 39±1.3 W in the sample (ABC) versus 33.1±2.1 W in the basic Denim sample (A). In the final phase, the reducing heat flow increased until equilibrium was established. The increased flow is caused by evaporation from the semi-permeable membrane, which cools the fabric's top surface. The equilibrium cooling heat flow is defined as the continuous penetration of water vapour through a textile fabric. Figure 4 additionally demonstrates that the fabric (ABC) feels cooler than the simple Denim. In fact, at equilibrium, the evaporative cooling heat flow was 52.7±3.2 W in the case of the simple Denim Fabric compared to 61.7±2.4 W in the case of the sample (ABC). As a result, adding the PU membrane to a layered fabric leads to an enhancement of about 17% in cooling feeling. This is due to the inclusion of a semi-permeable PU membrane in the fabric, which improves water vapour permeability due to the higher number of pores distributed compared to the Denim fabric. The reference sample, made of 100% is significantly less cool than fabrics that have a semi-permeable PU barrier. Cotton fibre, as a natural cellulosic fibre, has excellent absorbency due to its multitude of hydrophilic –OH groups. The hydroxyl groups are univalent OH groups and polar. Consequently, they attract polar water molecules. As a result, the OH groups are responsible for the fibre's ability to absorb moisture [31, 32].

So, when textile fabrics formed of hydrophilic fibres absorb humidity, the fibres swell, resulting in a decrease in the fabric's porosity [33], and the phenomenon of water vapour condensation occurs.

Samples which include PU semi-permeable membranes are waterproof and hydrophobic foils that repel water vapour molecules and resist water vapour absorption.

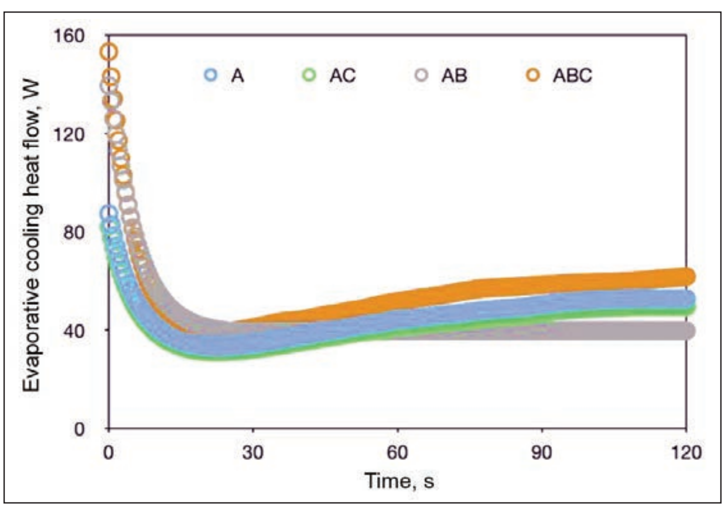

Fig. 3. Evaporative cooling heat flow kinetics of used samples

CONCLUSION

The dynamic thermo-physiological comfort of a recycled denim nano-layered fabric is highlighted in this study. A nonwoven fabric was added to the garment as an additional layer to give it shape, support and prevent nonmembrane direct skin contact. The top layer of the multilayered fabric was made of 100% cotton recycled denim, and a PU semi-permeable nanomembrane as a middle layer was selected because of its high-water vapour permeability and waterproof qualities. The different layers were bonded together using a double-faced adhesive grid.

Relative water vapour permeability (RWVP) and water vapour resistance (RET) were measured using the Permetest. The evaporative cooling heat flow was visualised using the same apparatus.

The use of a PU waterproof semi-permeable nanomembrane was noticed to significantly improve breathability. Comparing the simple Denim fabric to the layered sample with the PU membrane, the air permeability was decreased to 16.34%, the relative water vapour permeability was increased to 47.63% and the water vapour resistance was dropped to 34.37%.

When examining the dynamics of evaporative cooling heat flow, three stages were noticed. The difference between the sample temperatures at 20 ± 2 °C and 65 ± 2% relative humidity and the temperature at the top of the measuring heat, which was within 18 ± 2°C, caused by evaporative cooling from the semi-permeable membrane, was the initial phase of the maximum cooling heat flow. The cooling heat flow decreases to a minimal value during the second stage, referred to as the transition phase, and then rises to an equilibrium value, signifying a steady state phase. Based on the evaporative cooling heat flow kinetics, it was found that adding the PU nanomembrane to a layered fabric leads to an enhancement of about 17% in cooling feeling compared to a simple Denim fabric.

Future frameworks will be constructed on how external factors, such as temperature and relative humidity, affect the dynamics of the cooling heat flow of nano-layered Denim fabric.

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Impact of climate variability on Myanmar's agricultural, total exports, and textile industry: Asymmetric and dynamic multipliers

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ABSTRACT – REZUMAT

Impact of climate variability on Myanmar's agricultural, total exports, and textile industry: Asymmetric and dynamic multipliers

Climate change brings uncertainty and instability to ecosystems, economies, and global supply chains. It also significantly influences the total export value of countries that heavily rely on agriculture for economic growth. This study investigates the effects of climate variability on Myanmar's agricultural and total exports. This study uses the nonlinear autoregressive distributed lag (NARDL) approach for the annual data from 1990 to 2021. This study finds that rainfall negatively affects agricultural and total exports. Increasing rainfall leads to declining agricultural exports, whereas decreasing rainfall enhances total exports in the long run. Decreasing rainfall declines agricultural exports, while increasing rainfall diminishes total exports in the short run. Carbon emissions (CO_2) adversely affect agricultural and total exports in both runs. However, temperatures positively impact agricultural and total exports in both runs. In controlled variables, increased GDP has a positive impact on both agricultural and total exports. The textile and garment industry in Myanmar is perceived as an economic sector that is mainly export-oriented. Agricultural production contributes significantly to agricultural exports, which enhances total exports. This study offers new policy insights to adapt and mitigate climate change's influence on Myanmar's export sectors.

Keywords: *climate variability, textile field, garment industry, agricultural export, total export, NARDL, Myanmar, agricultural commodities*

Impactul variabilității climatice asupra agriculturii, exporturilor totale și industriei textile din Myanmar: Multiplicatori asimetrici și dinamici

Schimbările climatice aduc incertitudine și instabilitate ecosistemelor, economiilor și lanțurilor globale de aprovizionare. De asemenea, acestea influențează valoarea totală a exporturilor țărilor care se bazează în mare măsură pe agricultură pentru creșterea economică. Acest studiu investighează efectele variabilității climatice asupra exporturilor agricole și totale ale Myanmarului. Acest studiu empiric utilizează modelul Nonlinear Autoregressive Distributed Lag (NARDL) pentru datele anuale din perioada selectată 1990–2021. Această cercetare constată că precipitațiile afectează negativ exporturile agricole și totale. Creșterea precipitațiilor conduce la scăderea exporturilor agricole, în timp ce scăderea precipitațiilor sporește exporturile totale pe termen lung. Scăderea precipitațiilor scade exporturile agricole, în timp ce creșterea precipitațiilor diminuează exporturile totale pe termen scurt. Emisiile de carbon (CO_2) afectează negativ exporturile agricole și totale în ambele sensuri, respectiv pe termen scurt și pe termen lung. Cu toate acestea, temperaturile au un impact pozitiv asupra exporturilor agricole și totale în ambele cazuri. În variabilele controlate, creșterea PIB-ului are un impact pozitiv atât asupra exporturilor agricole, cât și asupra celor totale. Industria textilă și de îmbrăcăminte din Myanmar este percepută ca un sector economic orientat în principal spre export. Producția agricolă contribuie semnificativ la exporturile agricole, ceea ce sporește exporturile totale. Acest studiu oferă noi perspective politice pentru a adapta și a atenua influența schimbărilor climatice asupra sectoarelor bazate pe export din Myanmar.

Cuvinte cheie: *variabilitate climatică, domeniu textil, industrie de îmbrăcăminte, export agricol, export total, model NARDL, Myanmar, produse agricole*

INTRODUCTION

Climate change is triggering a new era of uncertainty and instability in ecosystems, economies, and global supply chains [1]. The changing climates include increasing variability, rising temperatures, shifting rainfall patterns, and a growing number of extreme climate occurrences [2]. It substantially impacts the agriculture sector, export and trade patterns, and economic activities of emerging and developing countries that heavily rely on commodity exports [3–5]. The nations are exposed to climate change when they depend on agriculture, natural resources, inadequate institutions, high poverty levels, and insufficient climate adaptation policies [6]. Climate change disrupts agricultural productivity through altered rainfall patterns and temperature extremes, leading to reduced crop yields. These effects negatively disturb the country's agricultural and total exports, where agriculture is vital to its export economy. Khan et al. [7] highlighted that climate variables' effects on a country's export sector have been substantial, primarily due to the increasing volatility in weather patterns. FAO [8] stated that it is crucial to prioritise strategies to safeguard business sectors against the consequences of climate change. Also, the United Nations enacted SDG 13, "climate action, to take urgent action to combat climate change and its impacts", aiming to address one of humanity's most pressing challenges. Therefore, understanding the impacts of climate variability on agri- and total exports in Myanmar goes beyond simple academic curiosity.

According to the Myanmar Garment Manufacturers Association, there has been a long-standing existence of the garment and textile industry in Myanmar, being one of the most prosperous and significant economic sectors. Moreover, the traditional garment and textile products are manufactured in authentic Myanmar artisan workshops by the Indigenous population, such as the following: Shan, Chin and Naga. Moreover, as a statistical approach, it is mentioned that over a decade, that is, between the years 1990 and 2001, "garment production increased from 2.5% of total exports in 1990 to 39.5% of exports in 2000", which means that it has become the most significant export industry in the state of Myanmar. In this regard, it is important to highlight the fact that Myanmar has one of a member state of the Association of Southeast Asian Nations, also known as ASEAN, since 23 July 1997. On the other hand, textiles represent the most important export products for the last period from ASEAN.

Currently, Myanmar faces difficulties because of the effects of the changing climate. Due to her susceptibility to floods and tropical cyclones, she is considered one of the most vulnerable countries to climate change globally [9]. This country has the highest vulnerability to economic impacts from climate change in the ASEAN regions [10]. In 2022, the country ranked second among 184 nations in the Global Climate Risk Index and eleventh among 191 nations in the INFORM Index for Risk Management. Floods, droughts, rising temperatures, heavy and sparse rainfall, and rising sea levels are the most significant threats in Myanmar [11]. Her most vulnerable sectors to climate change are agriculture, water resources, healthcare, forestry, coastal areas, and biodiversity [11]. Thus, the climate crisis could also impact Myanmar's agriculture and export dynamics regarding supply and demand. Climate change significantly squeezes the nation's export-dependent industries, which is particularly concerning for the country's economy [12].

Myanmar mainly exports agricultural commodities, minerals, and textiles for foreign income [13]. The textile and garment industry is one of the most important sectors in the emerging economy of Myanmar. The main export items are oil, gas, copper, wood, rice, pulses, seafood, clothing, and precious stones [13]. In 2022, the nation's export composition consisted primarily of mineral fuels, apparel and accessories, knit or crochet clothing, vegetables, cereals, fish, footwear, rubber articles, leather/animal gut articles, and fruits and nuts. These categories collectively accounted for 87.6% of Myanmar's global shipments [14]. This data highlights the economic importance of exports in the country. The agriculture sector, which accounts for 35.1 percent of Myanmar's total exports [15]. However, due to climate change, this sector may cause a loss in agricultural production, further affecting agri-export, which has a one-third share of total exports in Myanmar.

The climate crisis can potentially impact production activities and product supply chain disruptions [16]. The UNEP [17] stated that alterations in temperature and rainfall have reduced agricultural productivity, affecting food security and export volumes in Myanmar. The agricultural exports of Myanmar, such as rice, wheat, beans, and pulses, exhibit vulnerability to climate variations [18]. Severe rainfall for monsoon crops and drought for summer crops are Myanmar's most dangerous rainfall occurrences [19]. Hefty rainfall and severe weather can also disrupt transportation and extraction activities [16].

According to certain research studies [20], the industrial sector may experience indirect consequences because of climate change-induced disruptions in the supply chain. Hence, climate disruptions in export sectors can significantly influence a nation's foreign exchange reserves, balance of payments, and overall economic growth. The influence of climate factors on commerce and exports is a matter of great significance, not only for individual countries but also for the interconnected global society. Changing climates threaten production activities and supply chain stability, impacting the quality and quantity of exported products. So, this study explores the effects of climate variability on the export sectors and possible adaptation measures in Myanmar. It will provide insights into the path forward for the nation's climate-responsive exports.

Due to the high possible climate impacts on agriculture and export activities, we determined the link between climate variability and agri- and total exports in Myanmar using the nonlinear autoregressive distribution lag (NARDL). This method seizes the potential asymmetrical impacts of climate variables on the nation's exports, which need to be considered in the existing literature. The study first contributes to the current body of literature by exploring these asymmetrical impacts of temperature, rainfall, and CO_2 on agricultural and total exports in Myanmar. Second, we employ the NARDL method to enhance our understanding and application of knowledge in this field by using the data for 1990–2021. Third, as preliminary tests, we perform standard and structural break unit root tests [Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP)], BDS tests of nonlinearity, vector autoregressive (VAR) lag selection, the Wald test for long-run asymmetrical relation of variables, and bounds testing for cointegration. We also apply diagnostic analysis, stability checks, dynamic multiplier asymmetry, and the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) to verify the robustness of the study. Fourth, our findings can aid the government in creating policies to mitigate climate change impacts while encouraging economic development in Myanmar through export enhancement.

The rest of the sections are organised as follows: Section 2 presents a comprehensive analysis of the existing literature, providing a detailed overview of the current understanding of the relationship between climate variability and agri- and total exports, as well as the theoretical analysis. Section 3 outlines the data and methodology. Section 4 presents the results and discussions. Section 5 concludes with key findings and policy implications.

LITERATURE REVIEW

Empirical analysis

Based on prior literature, we analyse the interplay between climate variables and many countries' export performance, but the empirical literature on this issue is limited.

Vital et al. [21] indicated that rising temperature adversely impacts a nation's capacity to export agricultural commodities, leading to diminished crop productivity and output. It also significantly impacts export quality by affecting crop growth, pest incidence, water requirements, post-harvest conditions, and transportation logistics. So, unfavourable temperature changes have negatively affected the quality of exports and the availability of domestic intermediate goods [22]. Karlsson [23] analysed the restricted cubic spline (RCS) and found that an average temperature exceeding 25 degrees Celsius decreased about 0.22% in exports of the United States. In cold weather, each consecutive day with a temperature below –5 degrees Celsius reduced monthly exports by 0.21% compared to the reference temperature. Zhang and Li [24] applied a semi-parametric method and found a significant decrease in export quality as high-temperature days increased in China. Increasing temperatures intensify this negative impact, demonstrating that higher temperature significantly influences the export quality of newly entered goods, followed by departed goods. In contrast, goods under production are affected to a lesser extent. Jones et al. [25] investigated the correlation between temperature and exports, revealing that temperature has a detrimental effect on developing nations' economies. They determined that a 1-degree Celsius upsurge in temperature in a year causes an average reduction in export growth for developing nations, ranging from 2.0 to 5.7 percent. The temperature changes are more likely to affect exports and stable domestic spending than GDP [25].

Rainfall is a significant hydrological input for numerous countries, serving as a vital water resource upon which these nations strongly depend to foster economic development. Changes in rainfall patterns may impact crop productivity, leading to the exportation of agricultural goods. Olubunmi [26] stated that rainfall impacts productivity, exports, energy supply, transportation, agriculture, health, and work motivation. The maintenance of economies, production, crops, and export revenues in numerous nations heavily relies on the presence of constant rainfall. Jones et al. [25] indicated that minor rainfall impacts could stimulate increased exports from developing countries. Moreover, scholars argued that daily rainstorms may have a more detrimental impact on high-income nations than low-income ones. The manufacturing and service sectors, which form the foundation of developed economies, are more exposed to the effects of frequent heavy rainfall than the agricultural sector [27]. Heavy rainfall can also result in floods, which may cause the displacement of people and significant economic losses [28]. Bortz et al. [29] used the instrumental variable approach to study rainfall patterns, agricultural exports, and reserves in Argentina. The study showed that changes in rainfall adversely affected the economic development of nations that rely on exporting commodities. The link between the agriculture sector and rainfall suggests a causal relationship, implying that rainfall influences a country's exports through this mechanism. Bozzola [1] examined the influence of changing climates on the worldwide agri-food trade. Their findings revealed that a 5 mm rise in rainfall causes an average export value increase of 8.73% (1.77 billion USD).

Carbon dioxide (CO_2), one of the main components of GHGs, accounts for 76% of world emissions and causes pollution, leading to climate change [30, 31]. CO_2 arises from energy generation, specifically oil, coal, and gas combustion, for manufacturing resources and primary materials for the country's exports and economic growth [32]. The production and transportation of exchanged commodities and services released 8 billion metric tons of CO_2, about 25% of the total [33]. Increasing CO_2 has negatively impacted ecosystems, which are crucial for export sectors like agriculture and forestry [34]. Khan et al. [7] observed the link between CO_2 and Pakistan's agricultural export commerce. The authors indicated a negative correlation between CO_2 and agricultural exports, significantly influencing the country's economy. Accordingly, this negative association leads to a drop in the overall trade volume. Khan et al. [35] applied the common correlated effects mean group (CCEMG) to determine the effect of CO_2 on international trade for BRI countries. This study found that trade production has been significant because of the increase in CO_2 and the slowdown in countries' economic progress. [36] employed the vector autoregressive (VAR) to explore the link between CO_2 and economic factors in China. Among the economic factors, CO_2 has a causal, unidirectional link to export volume in China's eastern provinces.

Despite the insights provided by current literature, significant gaps still need to be addressed in assessing climatic variability's effects on agricultural and total exports. It requires understanding the nexus between temperature, rainfall, CO_2, and export performance to add to the present literature. More research is needed, particularly in Myanmar, grappling with significant challenges concerning climate change and its interactions. As the least developed nation, Myanmar requires this research endeavour to understand climate change's impacts and prepare for it. In contrast to the study into the effects of exports on environmental degradation, Myanmar is currently identifying the consequences of climate change and mitigating its effects. This research is vital in assessing the impact of climate change on Myanmar's export sectors and making policy recommendations to adapt and mitigate climate impacts that support sustainable economic growth. Expanding export-oriented activities that are resilient and adapted to changing climates will contribute to the country's economy. Lastly, the use of the advanced nonlinear model, NARDL, to investigate the effects of climate variability on agri- and total exports is still lacking, and this is the first such study in Myanmar.

Theoretical analysis

Climate variability, characterised by changes in temperature, rainfall patterns, and carbon emissions (CO_2), significantly impacts agricultural productivity. Given agriculture's central role in Myanmar's economy, it is crucial to understand how these climate factors influence agri- export and total exports. This theoretical analysis explores the climate variables' asymmetric effects on Myanmar's agri- and total export performance. Figure 1 illustrates the nexus between the studied variables.

Agriculture responses to temperature changes are often nonlinear [37]. Moderately increased temperature enhances crop growth, while extreme heat causes yield reductions due to heat stress and increased evapotranspiration [38]. Rainfall changes can lead to asymmetric impacts.

Drought conditions lead to water scarcity and reduced soil moisture, while heavy rains cause flooding, soil erosion, and nutrient leaching. Increased CO_2 boosts photosynthesis and water usage efficiency in certain crops, possibly leading to higher yields [39]. C3 plants, which are wheat, rice, soybeans, barley, oats, cotton, potatoes, tomatoes, and other broadleaf plants, generally respond positively to increased CO_2 levels.

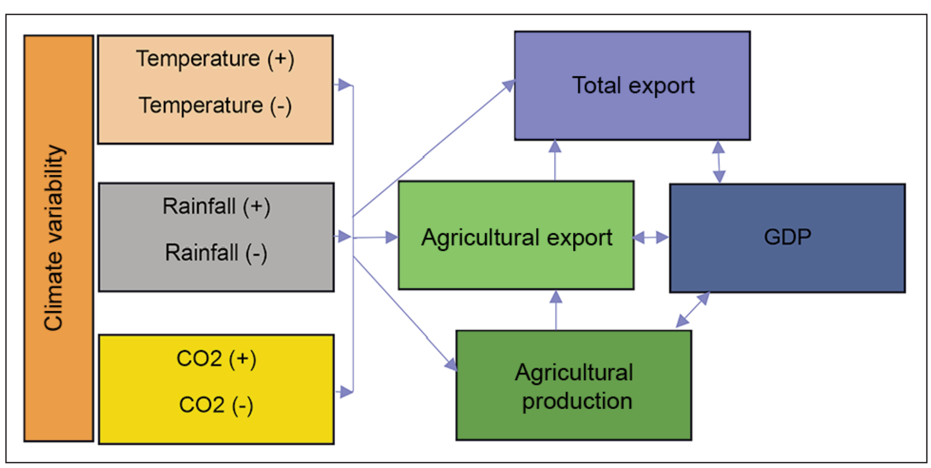

Fig. 1. Framework for the nexus between the studied variables

Besides, the CO_2 impact on crop yields is interlinked with temperature and rainfall changes. Higher CO_2 levels may partially mitigate the adverse effects of moderate heat stress on crop physiology, but may not offset the impacts of extreme heat or drought [40]. Therefore, climate variability directly influences agricultural productivity, leading to fluctuations in agricultural exports. Yuhuan and Thann [19] evidenced that climate variables have different impacts, indicating rainfall and CO_2 negatively affected agriculture in Myanmar, whereas temperature impacted agriculture favourably.

Regarding the export supply chain, climate-related disruptions such as extreme weather events (e.g., cyclones, floods) can impact the entire value chain [41]. These events can damage infrastructure, delay transportation, and increase costs, reducing the competitiveness of exports. Moreover, global climate patterns can influence international market prices and demand for agricultural products [42]. Myanmar's export performance is subject to these global dynamics, which can amplify the effects of local climate variability.

We also considered the role of GDP and agricultural production for the export sector in Myanmar. As robust export performance also fuels GDP growth by generating income and employment, a higher GDP can stabilise export performance [43]. As GDP rises, domestic consumption and export capacity can increase, influencing total export dynamics [44]. It also enhances the agricultural sector's resilience through increased investment in infrastructure, technology, and adaptation measures [37]. Improved agricultural productivity through better farming practices and technology adoption can mitigate the adverse effects of climate variability. Efficient production by allocating water, fertilisers, and labour resources can enhance crop resilience to climate stressors, stabilising agricultural output and exports. In developing countries, agricultural exports represent a significant portion of total exports [7]. In Myanmar, agricultural exports have a one-third share of total export revenue, highlighting the sector's importance to the national economy. The share of agricultural exports in total exports can be highly volatile, influenced by factors such as climate conditions, global commodity prices, and trade policies [45]. Fluctuations in agricultural production and global demand can lead to significant variations in the export value and its share in total exports. Hence, this study hypothesises that climate variability has a significant asymmetric impact on Myanmar's agricultural and total exports. Following this hypothesis, we employ a nonlinear econometric model (NARDL), which can capture the asymmetric effects of climate variability.

DATA AND METHODOLOGY

Data and sources

This study collected data from relevant sources, covering an annual time series in Myanmar from 1990 to 2021. To determine the impacts of climate variability on agricultural exports and total exports in Myanmar, we collected the total export value (current US$) and gross domestic product (current US$) from the World Development Indicators [46]. Agricultural gross production value (constant 2014–2016 thousand USD) from the Food and Agricultural Organization [47]. The agricultural export value index was gathered from the Department of Planning, Ministry of Agriculture, Livestock, and Irrigation, Myanmar, statically briefs and glance yearbooks from 1990 to 2021. The climate variables-annual mean temperature (degrees Celsius) and annual rainfall (mm)-were gathered from the World Bank climate change knowledge portal [11], while carbon dioxide (kilotons) was collected from the [48].

Econometric model

This study uses nonlinear autoregressive distributed lag (NARDL) to achieve the study's objective. The ARDL presented by Pesaran et al. [49] did not account for nonlinearity and asymmetrical relationships among variables. Shin et al. [50] created the NARDL, using both positive and negative partial sum decompositions of the explanatory variables to combine long- and short-run nonlinearities. It is an OLS function that uses bounds testing to make long-term inferences. Before the NARDL model's development, cointegration analysis commonly employed vector autoregressive (VAR) and vector error correction model (VECM). Later, Pesaran et al. [49] apply these conditions when the fundamental variables cointegrate at first different levels – I (1) in ARDL and assume symmetric behaviour. Likewise, NARDL can determine the cointegration at I (1) with asymmetric behaviour. We found that previous nonlinear models, such as the threshold error correction model (ECM) by Blake et al. [51] and the Markov-Switching ECM by Psaradakis et al. [52], need to be expanded. Therefore, we apply NARDL to capture the asymmetric behaviours of climate variables. In the study, we consider two response variables (agri-export and total export) to climate variability, so the two models are formulated.

For model (1), studying the asymmetric effects of climate variability on agricultural export in Myanmar, we considered three climate variables and two controlled variables. These controlled variables, agricultural production and GDP, were chosen for their significant influence on agricultural exports. Agricultural export is directly linked to agricultural production, making it a crucial control variable. Similarly, the country's economic growth encourages agricultural investment, boosting productivity and export capacity, making GDP another important controlled variable. Thus, we formulated the following model 1:

$$lnAEX_t = f(lnTEM_t, lnRF_t, lnCO2_t, lnLAGR_t, lnGDP_t) \quad (1)$$

For model 2, studying the asymmetric effects of climate variability on total export in Myanmar, we considered agricultural export and GDP as controlled variables along with the same climate variables. As a least developed country, Myanmar intensely relies on agricultural products such as pulses, rice, wheat, and other agri-products for export. Agricultural exports account for one-third of total exports in Myanmar. Hence, model 2 is formulated as follows:

$$lnTEX_t = f(lnTEM_t, lnRF_t, lnCO2_t, lnLAEX_t, lnGDP_t) \quad (2)$$

lnAEX and *lnTEX* are the natural logs of agri-export and total export, respectively. *lnTEM, lnRF*, and *lnCO2* are the natural logs of temperature, rainfall, and carbon emission, respectively. *lnAGR* and *lnGDP* represent the natural logs of agricultural gross production value and gross domestic products.

Before delving into a detailed explanation of the NARDL model, we underline the significance of the long-term asymmetry correlations, a key aspect of our research, as follows:

$$lnAEX_t = \beta_0 + \beta_1^+ lnTEM_t^+ + \beta_2^- lnTEM_t^- + \beta_3^+ lnRF_t^+ + \beta_4^- lnRF_t^- + \beta_5^+ lnCO2_t^+ + \beta_6^- lnCO2_t^- + \beta_7 lnAGR_t + \beta_8 lnGDP_t + \varepsilon_t \quad (3)$$

$$lnTEX_t = \alpha_0 + \alpha_1^+ lnTEM_t^+ + \alpha_2^- lnTEM_t^- + \alpha_3^+ lnRF_t^+ + \alpha_4^- lnRF_t^- + \alpha_5^+ lnCO2_t^+ + \alpha_6^- lnCO2_t^- + \alpha_7 lnAEX_t + \alpha_8 lnGDP_t + \varepsilon_t \quad (4)$$

$lnAEX_t$ and $lnTEX_t$ are k×1 vectors of *lnAEX* at time t, β (β_0, β_1^+, β_2^-, β_3^+, β_4^-, β_5^+, β_6^-, β_7, β_8) and *lnTEX* at time t, α (α_0, α_1^+, α_2^-, α_3^+, α_4^-, α_5^+, α_6^-, α_7, α_8) are the asymmetry of long-term behaviours. Climate variables (*lnTEM, lnRF* and *lnCO2*) can be divided as k×1 vector of regressors as follows:

$$lnTEM_t = lnTEM_0 + lnTEM_t^+ + lnTEM_t^- \quad (5.a)$$

$$lnRF_t = lnRF_0 + lnRF_t^+ + lnRF_t^- \quad (5.b)$$

$$lnCO2_t = lnCO2_0 + lnCO2_t^+ + lnCO2_t^- \quad (5.c)$$

$lnTEM_t^+$, $lnTEM_t^-$, $lnRF_t^+$, $lnRF_t^-$, $lnCO2_t^+$, $lnCO2_t^-$ are the partial sum decompositions of positive and negative changes in $lnTEM_t$, $lnRF_t$, and $lnCO2_t$

respectively. The following equations display partial separation of *lnTEM*, *lnRF* and *lnCO2*.

$$lnTEM_t^+ = \Sigma_{i=1}^t \Delta lnTEM_i^+ = \Sigma_{i=1}^t \max(\Delta lnTEM_i, 0) \quad (6.a)$$

$$lnTEM_t^- = \Sigma_{i=1}^t \Delta lnTEM_i^- = \Sigma_{i=1}^t \min(\Delta lnTEM_i, 0) \quad (6.b)$$

$$lnRF_t^+ = \Sigma_{i=1}^t \Delta lnRF_i^+ = \Sigma_{i=1}^t \max(\Delta lnRF_i, 0) \quad (6.c)$$

$$lnRF_t^- = \Sigma_{i=1}^t \Delta lnRF_i^- = \Sigma_{i=1}^t \min(\Delta lnRF_i, 0) \quad (6.d)$$

$$lnCO2_t^+ = \Sigma_{i=1}^t \Delta lnCO2_i^+ = \Sigma_{i=1}^t \max(\Delta lnCO2_i, 0) \quad (6.a)$$

$$lnCO2_t^- = \Sigma_{i=1}^t \Delta lnCO2_i^- = \Sigma_{i=1}^t \min(\Delta lnCO2_i, 0) \quad (6.b)$$

When the model utilises the above concept of cumulative positive and negative partial sums of climate variables, it describes an asymmetrical error-correcting form. The following equations 7 and 8 clearly illustrate:

$$\Delta AEX_t = \beta_0 + \partial lnAEX_{t-1} + \beta_1^+ lnTEM_{t-1}^+ + \beta_2^- lnTEM_{t-1}^- + \beta_3^+ lnRF_{t-1}^+ + \beta_4^- lnRF_{t-1}^- + \beta_5^+ lnCO2_{t-1}^+ + \beta_6^- lnCO2_{t-1}^- + \beta_7 lnAGR_{t-1} + \beta_8 lnGDP_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta lnAEX_{t-i} + \sum_{m=1}^{m=p} (\delta_1^+ \Delta lnTEM_{t-1}^+ + \delta_1^- \Delta lnTEM_{t-1}^-) + \sum_{m=1}^{m=p} (\sigma_1^+ \Delta lnRF_{t-1}^+ + \sigma_1^- \Delta lnRF_{t-1}^-) + \sum_{m=1}^{m=p} (\theta_1^+ \Delta lnCO2_{t-1}^+ + \theta_1^- \Delta lnCO2_{t-1}^-) + \sum_{m=1}^{p} \tau_1 \Delta lnAGR_{t-1} + \sum_{m=1}^{p} \tau_2 \Delta lnGDP_{t-1} + \varphi ECT_{-1} + \varepsilon_t \quad (7)$$

$$\Delta TEX_t = \alpha_0 + \partial lnTEX_{t-1} + \alpha_1^+ lnTEM_{t-1}^+ + \alpha_2^- lnTEM_{t-1}^- + \alpha_3^+ lnRF_{t-1}^+ + \alpha_4^- lnRF_{t-1}^- + \alpha_5^+ lnCO2_{t-1}^+ + \alpha_6^- lnCO2_{t-1}^- + \alpha_7 lnAEX_{t-1} + \alpha_8 lnGDP_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta lnTEX_{t-i} + \sum_{m=1}^{m=p} (\delta_1^+ \Delta lnTEM_{t-1}^+ + \delta_1^- \Delta lnTEM_{t-1}^-) + \sum_{m=1}^{m=p} (\sigma_1^+ \Delta lnRF_{t-1}^+ + \sigma_1^- \Delta lnRF_{t-1}^-) + \sum_{m=1}^{m=p} (\theta_1^+ \Delta lnCO2_{t-1}^+ + \theta_1^- \Delta lnCO2_{t-1}^-) + \sum_{m=1}^{p} \tau_1 \Delta lnAEX_{t-1} + \sum_{m=1}^{p} \tau_2 \Delta lnGDP_{t-1} + \varphi ECT_{-1} + \varepsilon_t \quad (8)$$

In the above equations, β_i and α_i are the long-run coefficients of *LnAEX* and *LnTEX*, whereas δ_i, σ_i, θ_i and τ_i are the short-run coefficients of variables. The null hypothesis states that there is no asymmetrical long-run relationship, stating $\partial = \beta^+ = \beta^- = 0$. We determine the null hypotheses by calculating the F-statistics and comparing them to the two crucial bounds (lower – I (0) and upper – I (1)). These bounds create a range encompassing all potential regressor classifications as I (0), I (1), or commonly cointegrated. We will accept the null hypothesis if the F-statistics are below the lower bound, indicating I (0). The outcome is considered inconclusive if the F-statistics are within the range of I (0) and I (1). If the F values exceed the I (1), we may reject the null hypothesis, indicating the presence of long-term cointegration. The error correction term, ECT (–1), denotes the rate of long-term balance adjustment after a short-term shock.

This study also employs the dynamic multiplier effects of climate variability. The long-term asymmetric coefficients are computed using the formulas; $L_{mi+} = \beta + \frac{\square}{\rho}$ and $L_{mi-} = \beta - \frac{\square}{\rho}$. When the independent factor changes, the long-run coefficient quantifies the relationship between components. The cumulative dynamic multiplier effect can model both long-term and short-term asymmetrical lines. The following equation calculates the percentage change in climate variability in agri-and total exports (X_t^+ and X_t^- on Y_t).

For the dynamic multiplier effects of climate variability on agricultural export:

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial lnAEX_{t+i}}{\partial lnTEM_t^+}, \quad m_h^- = \sum_{i=0}^{h} \frac{\partial lnAEX_{t+i}}{\partial lnTEM_t^-} \quad (9.a)$$

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial lnAEX_{t+i}}{\partial lnRF_t^+}, \quad m_h^- = \sum_{i=0}^{h} \frac{\partial lnAEX_{t+i}}{\partial lnRF_t^-} \quad (9.b)$$

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial lnAEX_{t+i}}{\partial lnCO2_t^+}, \quad m_h^- = \sum_{i=0}^{h} \frac{\partial lnAEX_{t+i}}{\partial lnCO2_t^-} \quad (9.c)$$

For the dynamic multiplier effects of climate variability on total export:

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial lnTEX_{t+i}}{\partial lnTEM_t^+}, \quad m_h^- = \sum_{i=0}^{h} \frac{\partial lnTEX_{t+i}}{\partial lnTEM_t^-} \quad (10.a)$$

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial lnTEX_{t+i}}{\partial lnRF_t^+}, \quad m_h^- = \sum_{i=0}^{h} \frac{\partial lnTEX_{t+i}}{\partial lnRF_t^-} \quad (10.b)$$

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial lnTEX_{t+i}}{\partial lnCO2_t^+}, \quad m_h^- = \sum_{i=0}^{h} \frac{\partial lnTEX_{t+i}}{\partial lnCO2_t^-} \quad (10.c)$$

where if $h \to \infty$, then $m_h^+ \to L_{mi+}$ and $m_h^- \to L_{mi-}$.

RESULTS AND DISCUSSION

Preliminary tests

For analysis, the first step is to present an overview of the data. For this purpose, table 1 shows the descriptive statistics and the correlation of the natural logs of variables. LnGDP has the highest mean value (23.90), whereas the LnTEM has the lowest mean value (3.17). The variables' standard deviations are lower than their respective mean values, indicating favourable performance across the variables. The skewness reveals that LnTEM has a distribution with extended right tails, indicating positive skewness, whereas the rest have distributions with extended left tails, indicating negative skewness. The kurtosis analysis shows that variables except LnRF have a platykurtic distribution, meaning their kurtosis values

Table 1

DESCRIPTIVE AND CORRELATION STATISTICS							
Variables	**LnTEX**	**LnAEX**	**LnTEM**	**LnRF**	**LnCO2**	**LnGDP**	**LnAGR**
Mean	21.94	3.38	3.17	7.62	11.55	23.90	16.76
Median	22.14	3.58	3.16	7.62	11.70	23.99	16.94
Max	23.61	5.05	3.19	7.76	12.18	25.05	17.24
Min	19.59	1.03	3.14	7.40	10.77	22.63	15.97
SD	1.27	1.27	0.01	0.07	0.39	0.83	0.42
Skew	–0.30	-0.30	0.11	–0.56	–0.49	–0.13	–0.45
Kur	1.67	1.68	2.72	3.79	2.22	1.51	1.72
Correlation							
LnTEX	1						
LnAEX	0.99	1					
LnTEM	0.55	0.55	1				
LnRF	0.02	0.02	–0.10	1			
LnCO2	0.81	0.81	0.46	0.15	1		
LnGDP	0.99	0.99	0.55	–0.01	0.79	1	
LnAGR	0.95	0.95	0.52	0.08	0.88	0.94	1

Note: ***, ** and * means 1%, 5% and 10% significant levels.

are less than three, and their tails are skewed positively. The correlation analysis shows that all regressors were positively related to the response variables at the 1% significant level.

After examining the data description and correlation, we employ ADF and PP unit root tests. In the time series analysis, it is necessary to determine whether variables are stationary at a level, I (0), or at the first-different level, I (1), before performing the estimation.

Table 2 shows that LnTEM and LnRF are stationary at the level, whereas the rest are stationary at the first-level difference in ADF, as confirmed by PP.

Additionally, we use the structural unit root test during the break year to verify the results using standard unit root tests (i.e., ADF and PP). Table 2 also confirms that variables (LnTEX, LnAEX, LnTEM, LnRF, LnCO2, and LnGDP) are stationary at the level. LnAGR is stationary at the first different level for 2010.

Table 2

UNIT ROOT ANALYSIS							
Standard unit root test	**LnTEX**	**LnAEX**	**LnTEM**	**LnRF**	**LnCO2**	**LnGDP**	**LnAGR**
ADF Level							
Intercept	–1.92	–1.93	–4.14***	–5.70***	–2.14	–2.52	–2.32
Intercept & Trend	–1.21	–1.20	–6.82***	–5.61***	–2.01	1.41	0.66
ADF 1st Difference							
Intercept	–4.59***	–4.64***			–3.91***	–5.80***	–3.64***
Intercept & Trend	–5.06***	–5.07***			–3.98**	–6.36***	–4.87***
PP Level							
Intercept	–2.65	–2.68	–4.14***	–8.60***	–1.99	–1.30	–2.04
Intercept & Trend	–0.89	–0.87	–10.71***	–8.93***	–1.40	0.39	0.63
PP 1st Difference							
Intercept	–4.49***	–4.49***			–3.23**	–5.76***	–3.70***
Intercept & Trend	–5.80***	–5.81***			–3.65**	–6.39***	–4.88***
Structural break unit root test							
At Level							
T-stat	–4.34*	–4.33*	–5.55***	–6.23***	–6.30***	–4.25*	–4.12
Break year	1999	1999	1997	2011	2003	1998	2003
At 1st Different							
T-stat							–5.43***
Break year							2010

Note: ***, ** and * means 1%, 5% and 10% significant levels.

Table 3

BDS TEST FOR NONLINEARITY							
Dimension	**LnTEX**	**LnAEX**	**LnTEM**	**LnRF**	**LnCO2**	**LnGDP**	**LnAGR**
2	0.19***	0.18***	–0.01	0.002**	0.17***	0.20***	0.20***
3	0.33***	0.22***	–0.04***	0.003***	0.28***	0.33***	0.34***
4	0.42***	0.23***	–0.06***	0.002***	0.36***	0.43***	0.43***
5	0.48***	0.22***	–0.03**	–1.69	0.41***	0.49***	0.49***
6	0.52***	0.21***	–0.02**	–1.88	0.44***	0.54***	0.53***

Note: ***, ** and * means 1%, 5% and 10% significant levels.

As this study intends to use nonlinear ARDL, it is necessary to determine whether nonlinearity exists among the variables. So, we check the BDS test that hypothesises that variables are independently and identically distributed. Table 3 displays that LnTEX, LnAEX, LnCO2, LnGDP, and LnAGR are significant at the 1% level for all dimensions, whereas LnTEM and LnRF are significant at the 1% level for four dimensions and three dimensions. These results reject the hypothesis at the 1% significant level, confirming that the variables are nonlinear.

Choosing the appropriate lag order is crucial for accurate model specification. Too few lags can cause model misspecification and omitted variable bias, while too many can lead to overfitting and inefficient parameter estimates. The correct lag length ensures the statistical significance of the included lags and enhances the model's predictive performance. Therefore, we use the vector autoregressive (VAR) lag selection criteria, including the Akaike information criterion (AIC), Schwarz criterion (SC), final prediction error (FPE), likelihood ratio (LR), and Hannan-Quinn (HQ). In table 4, all criteria indicated that Model 1 should have a lag of three while Model 2 should have a lag of one. Additionally, figure 2 shows the polynomial root graphs for the lag selection of two models, indicating that all spots existed within the circles. The VAR lag selection approach supports the suitable assessment of lag lengths for accurate model specification.

Table 4

VAR LAG ORDER SELECTION						
Lag	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**
Model 1: LnAEX (LnTEMLnRF LnCO2 LnGDPLnAGR)						
0	143.29	NA	3.11	–9.46	–9.18	–9.38
1	307.84	249.65	4.66	–18.33	–16.35	–17.71
2	361.99	59.75	1.90	–19.58	–15.90	–18.43
3	443.93	56.50*	2.49*	–22.75*	–17.37*	–21.07*
Model 2: LnTEX (LnTEMLnRF LnCO2 LnGDPLnAEX)						
0	267.88	NA	1.05	–17.45	–17.17	–17.36
1	406.10	211.94*	1.22*	–24.27*	–22.31*	–23.64*
2	441.52	40.14	1.74	–24.23	–20.59	–23.06

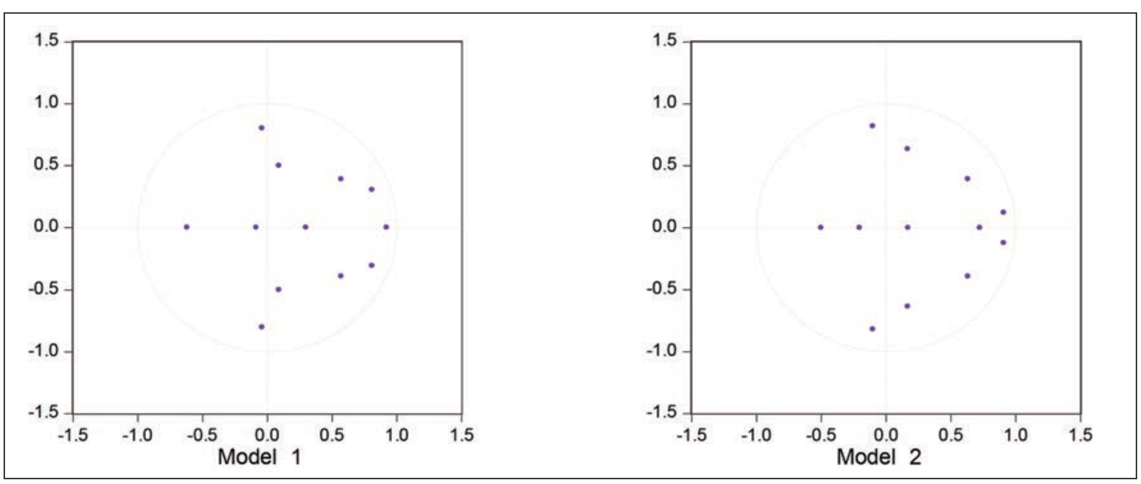

Fig. 2. AR Polynomial root graphs for lag selection

As the nonlinearity and lag selection are confirmed, the Wald test continues to check the long-term asymmetries of the climate variables on agri-export and total exports in Myanmar. The test hypothesises that climate variables have a symmetric relationship with export sectors. Table 5 shows that climate variables LnTEM, LnRF, and LnCO2 have an asymmetric association with agri- and total export at 1% and 5% significant levels, rejecting the null hypothesis. The result suggests that a nonlinear model better represents the relationship between climatic factors and exports in Myanmar.

Table 5

WALD TEST FOR LONG RUN SYMMETRIC RELATIONSHIP			
Variable	**LnAEX**	**LnTEX**	**H0: Long run symmetry ($\partial = \beta^+ = \beta^- = 0$)**
LnTEM	4.91***	3.36**	Rejected
LnRF	–4.10***	–3.41**	Rejected
LnCO2	–3.04***	–3.55**	Rejected

Note: ***, ** and * means 1%, 5% and 10% significant levels.

Once we confirm the asymmetrical relationship, we employ the bounds test for asymmetric cointegration of the variables over the long run. Table 6 shows that the F-statistic values of Model 1 for agricultural exports and Model 2 for total exports are 6.29 and 10.59, respectively, greater than the critical values of the lower and upper bounds at the 1% significant level. The result proves the evidence supporting the long-run correlation between the variables.

NARDL results in the long and short-run

After successfully passing the preliminary tests, we employ the NARDL model. Table 7 presents the model's findings for the impacts of climate variability on agricultural and total exports in Myanmar. Over the long term, increasing temperature (LnTEM+) shows a positive effect, while decreasing one (LnTEM–) indicates a negative impact on both agricultural export (LnAEX) and total export (LnTEX) at a 1% significant level. That is, a 1% increase in both LnTEM+ and LnTEM– leads to an increase in LnAEX by 13.40% and 10.57%, whereas a rise in LnTEX by 1.34% and 0.40%, respectively. Regarding coefficients, the temperature effect on agricultural export is greater than the total export. This result is similar to the previous findings [19,53], showing that temperature has favourable impacts on agriculture and enhanced export quantity. Undeniably, extreme hot and cold temperatures cause severe consequences for agriculture, exports, and a country's economy. However, temperature also has a crucial impact on agricultural productivity, particularly crops. Every crop variety has its temperature requirements for growth and development. In some regions, increasing temperature may benefit agricultural production [37]. Thus, it can be inferred that temperatures can extend the growing season and enhance crop growth, leading to higher yields and more produce available for export in Myanmar.

The increasing rainfall (LnRF+) negatively impacts agricultural export (LnAEX) at a 10% significant level, but decreasing rainfall (LnRF–) is not significant. Decreasing rainfall (LnRF–) negatively affects total export (LnTEX) at a 10% significant level, but increasing rainfall (LnRF+) is not significant. So, a 1% increase in LnRF+ declines in agri-export by 0.78%, while a 1% rise in LnRF– increases total export by 0.01%. As coefficients, the rainfall effect on agri-export is superior to the total export. This finding aligns with prior studies [2, 29], indicating that rainfall adversely affects the countries that rely on agricultural commodities for their economy. As a result, increasing rainfall may lead to heavy rain, which can negatively affect agricultural exports by causing waterlogging, damaging crops, reducing yield, and increasing the risk of crop diseases and pest infestations. In addition, excessive rainfall can disrupt harvest and transportation, leading to delays and quality degradation of export goods. So, decreasing rainfall did not reduce the total export growth in the study. According to Yuhuan and Thann [19], Myanmar faced difficulties with heavy rain, monsoon crop production and reduced yields, which can hinder exports.

Increasing carbon emission (LnCO2+) negatively impacts agri-export (LnAEX) and total export (LnTEX), whereas decreasing carbon emission (LnCO2–) positively affects both of them at 1% and 5% significant levels. It means that a 1% increase in LnCO2+ causes a loss to agri-export by 0.72% and total export by 0.04%, whereas a 1% rise in LnCO2– leads to reduce agri-export by 1.51% and total export

Table 6

BOUND TESTING FOR ASYMMETRIC COINTEGRATION				
Test statistic	**F-stat.**	**Sig.**	**I (0)**	**I (1)**
Model 1 LnAEX (LnTEM, LnRF, LnCO2, LnGDP, LnAGR)	6.29	10%	1.85	2.85
	-	5%	2.11	3.15
	-	1%	2.62	3.77
Model 2 LnTEX (LnTEM, LnRF, LnCO2, LnGDP, LnAEX)	10.59	10%	2.13	3.09
	-	5%	2.38	3.41
	-	1%	2.93	4.06

of about 0.13%. As coefficients, CO_2 affects agri-export more seriously than Myanmar's total exports. These findings are consistent with [2, 54], indicating that rising CO_2 contributes to climate change, which can cause extreme weather events, disrupt growing seasons, and negatively impact agricultural production. Thus, it may further damage the quality and quantity of Myanmar's agricultural and total export volumes. In controlled variables, economic growth (GDP) significantly affects both LnAEX and LnTEX at a 1% level, confirming that economic development strengthens the production of agriculture and export sectors in Myanmar. In the analysis, agricultural production positively impacts agri-export at a 1% significant level. So, this result is aligned with the fact that agriculture is the core sector of Myanmar's exports and economy. This study also finds the link between agri-export and total export. As expected, agri-export positively impacts total exports at a 1% significant level.

Over the short-term, an increasing and decreasing temperature impact in positive and negative manners at 1% and 5% significant levels. That is, a 1% increase in temperature will lead to an 11.39% and 0.58% increase in agri-and total export. In comparison, a 1% decrease in temperature leads to a rise of 3.54% and 0.36% in response variables, respectively. The short-term temperature effects are the same as the long-term temperature effects. Increasing rainfall negatively affects total export, while decreasing rainfall has a positive effect on agri- export at a 1% significant level. So, 1% increased rainfall reduces 0.01% in total exports, while 1% decreased rainfall results in a decline of 1.26% in agri-export. In the short term, decreased rainfall leads to drought or water scarcity, which can affect agri production and further quality and quantity reduction of agri-export in Myanmar. Increasing and decreasing CO_2 affect total exports negatively and positively at 1% significance, whereas their effects on agri-exports are constant. A 1% increase and decrease in CO_2 result in a decline of 0.01% and 0.05% in total exports. CO_2 may cause a reduction in total exports in both runs. In controlled variables, GDP has a 1% significant positive impact

Table 7

NARDL LONG AND SHORT RUN ANALYSIS

	Model 1: LnAEX		**Model 2: LnTEX**	
Long-Run Results	Coef.	t-stat	Coef.	t-stat
LnTEM (+)	13.40***	–1.26	1.34***	7.33
LnTEM (–)	–10.57***	2.16	–0.40**	–5.13
LnRF (+)	–0.78*	2.42	–0.01	–0.95
LnRF (–)	0.47	0.84	–0.01*	–2.87
LnCO2 (+)	–0.72**	–1.92	–0.04***	–5.93
LnCO2 (–)	1.51***	1.07	0.13***	7.34
LnGDP	1.42***	3.09	0.11***	7.41
LnAEX			0.97***	13.3
LnAGR	0.69**	–2.45		
Short Run Results				
DLnTEM (+)	11.39***	7.42	0.58***	17.82
DLnTEM (–)	–3.54**	–2.08	–0.36***	–16.97
DLnRF (+)	C	C	–0.01***	–6.22
DLnRF (–)	1.26***	6.75	C	C
DLnCO2 (+)	C	C	–0.01***	–7.39
DLnCO2(–)	C	C	0.05***	15.00
D(LnGDP)	0.97***	4.05	0.10***	16.57
D(LnAEX)			0.98**	10.41
D(LnAGR)	0.38*	1.84		
ECT (–)	–1.29***	–10.17	–1.59***	–20.58
Diagnosis Tests	**F-stat**	**p-value**	**F-stat**	**p-value**
BG Serial Correlation LM Test:	1.81	0.20	5.04	0.30
Heteroskedasticity Test: BPG	0.78	0.67	1.36	0.45
Heteroskedasticity Test: ARCH	1.26	0.27	2.05	0.13
Jarque-Bera normality test	0.11	0.94	0.09	0.95
Ramsey RESET Test	1.71	0.11	1.45	0.28

Note: ***, ** and * means 1%, 5% and 10% significant levels and C means holding as a constant in the models.

on agri- and total exports, showing a similar effect as long term. Agricultural production indicates a significant positive impact at the 10% level, meaning it plays a vital role in agri-export in Myanmar. When we look at agricultural exports, it has a positive effect on total exports at a 5% significant level. Hence, agri-export is also an essential sector of total exports in Myanmar.

Table 7 also displays several diagnostic tests, including the BG serial correlation LM test, the heteroskedasticity test (BPG and ARCH), the JB normality test, and the Ramsey RESET tests to model solidity. These tests show no apparent association issues with the model. We also apply the CUSUM and CUSUMSQ tests to ensure stable estimations. The calculated coefficients are stable when these test plots remain within the critical boundaries at a 5% significance level. Figure 3 illustrates that the lines did not go beyond the critical boundaries, implying no structural breaks or instabilities in the model. Therefore, the NARDL model successfully passes the stability and reliability tests for estimation.

Robust analysis

Dynamic multiplier effects analysis

Figure 4 exemplifies the results of the dynamic multiplier for the climate variables that impact Myanmar's agricultural and total exports. The dynamic multiplier results show a direct correlation between the multiplier effects of positive and negative temperature, rainfall, and carbon dioxide shocks. These curves depict the rate at which variables change following a one-unit adjustment in exports until they reach long-term equilibrium. Figures 4, *a1* and *b1* highlight the effects of temperature on agri-exports and total exports. An increase in temperature (black line) leads to a rise in agricultural and total exports. A decrease in temperature (black dotted line) also increases agricultural and total exports. In magnitude, temperature affects agricultural exports more significantly than total exports. In the 15th period, an increase and decrease in temperatures reach approximately 10% and 13% on the agri-export, while they only account for 1.4% and 0.4% points on the total export. As a result, increasing or decreasing temperatures positively impact agricultural and total exports. The impact of an increased temperature on agri-exports and total exports outweighs that of a decreased one.

Figures 4, *a2* and *b2* illustrate the effect of rainfall on agri-exports and total exports. An increased rainfall (black line) leads to decreased agri- and total exports. However, a decrease in rainfall (black dotted line) results in a decline in agri-export, but it increases total exports. Regarding impact size, rainfall affects agricultural exports more significantly than total exports. During the last period, the agri-export line decreased by 0.8% and 0.5 % due to increased

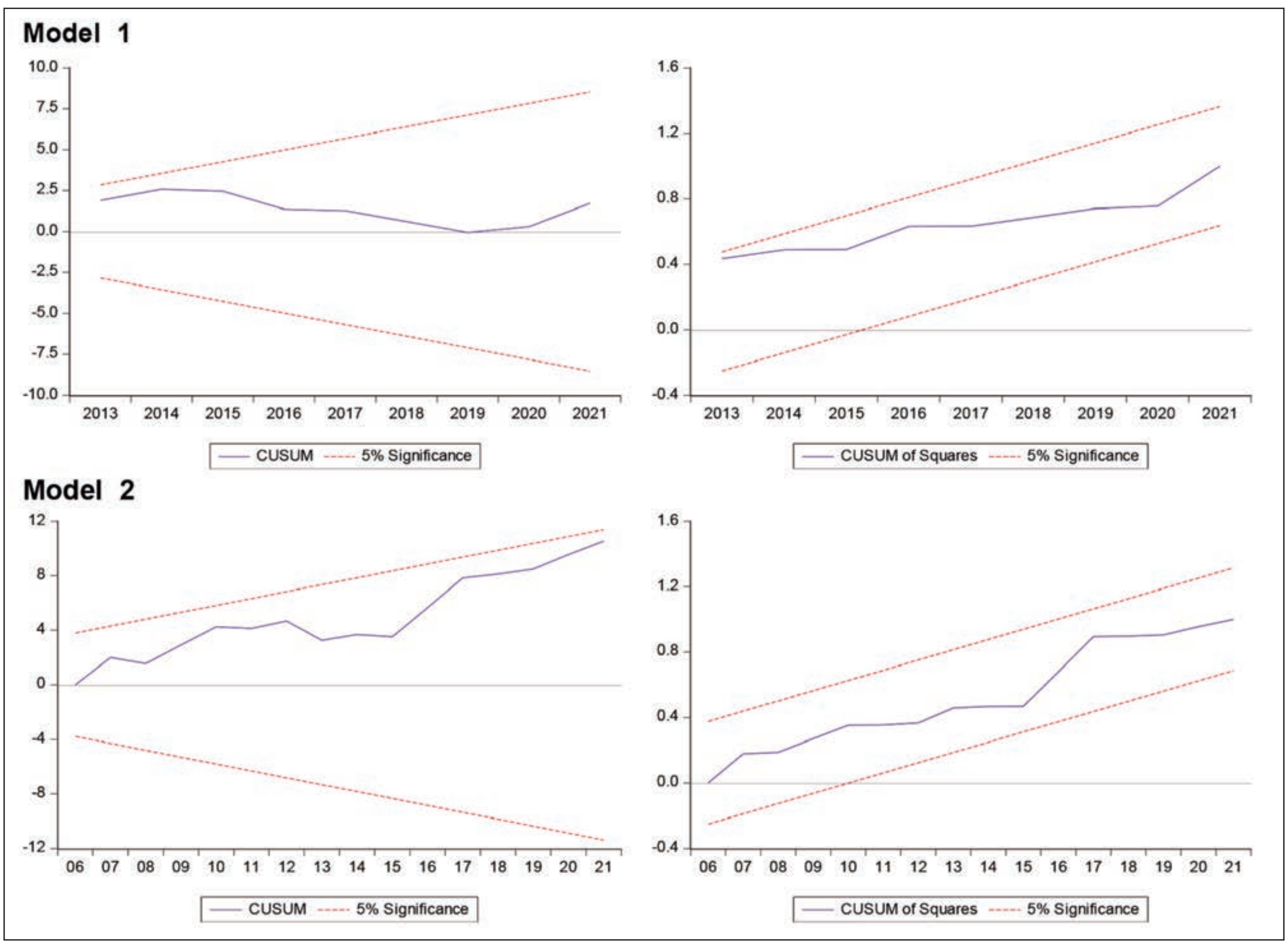

Fig. 3. Stability tests

and decreased rainfall, respectively, while the total export line shows a reduction of around 0.1%. Increased and decreased rainfall harms agriculture exports, whereas decreased rainfall positively impacts total exports. The positive effect of rainfall on Myanmar's agricultural and total export growth outweighs the negative impact.

Figures 4, *a3* and *b3* show the effects of carbon emission (CO_2) on agricultural and total exports. Increased carbon emissions (black line) lead to a drop in agri- and total exports. Decreased carbon emissions (black dotted line) also reduce agricultural and total exports. As a result of the magnitude of CO_2's impact on agricultural exports, it is superior to the total exports. In the last period, increased and decreased CO_2 reached 0.7% and 1.55 in the agri-export line, while they stood at 0.04% and 0.13% in the total export line. Increasing or decreasing CO_2 harms export sectors. Negative CO_2 has a more significant effect than positive ones. Finally, the multiplier effect confirms that climate variability effects on agricultural and total exports align with the long-term results of the NARDL model, as presented in table 8.

FMOLS and DOLS analysis

As the following robust analysis shows, this study utilises the FMOLS and DOLS procedures to verify the results of the NARDL model over a long period. They offer more precise estimates and a comprehensive understanding of the complex connections

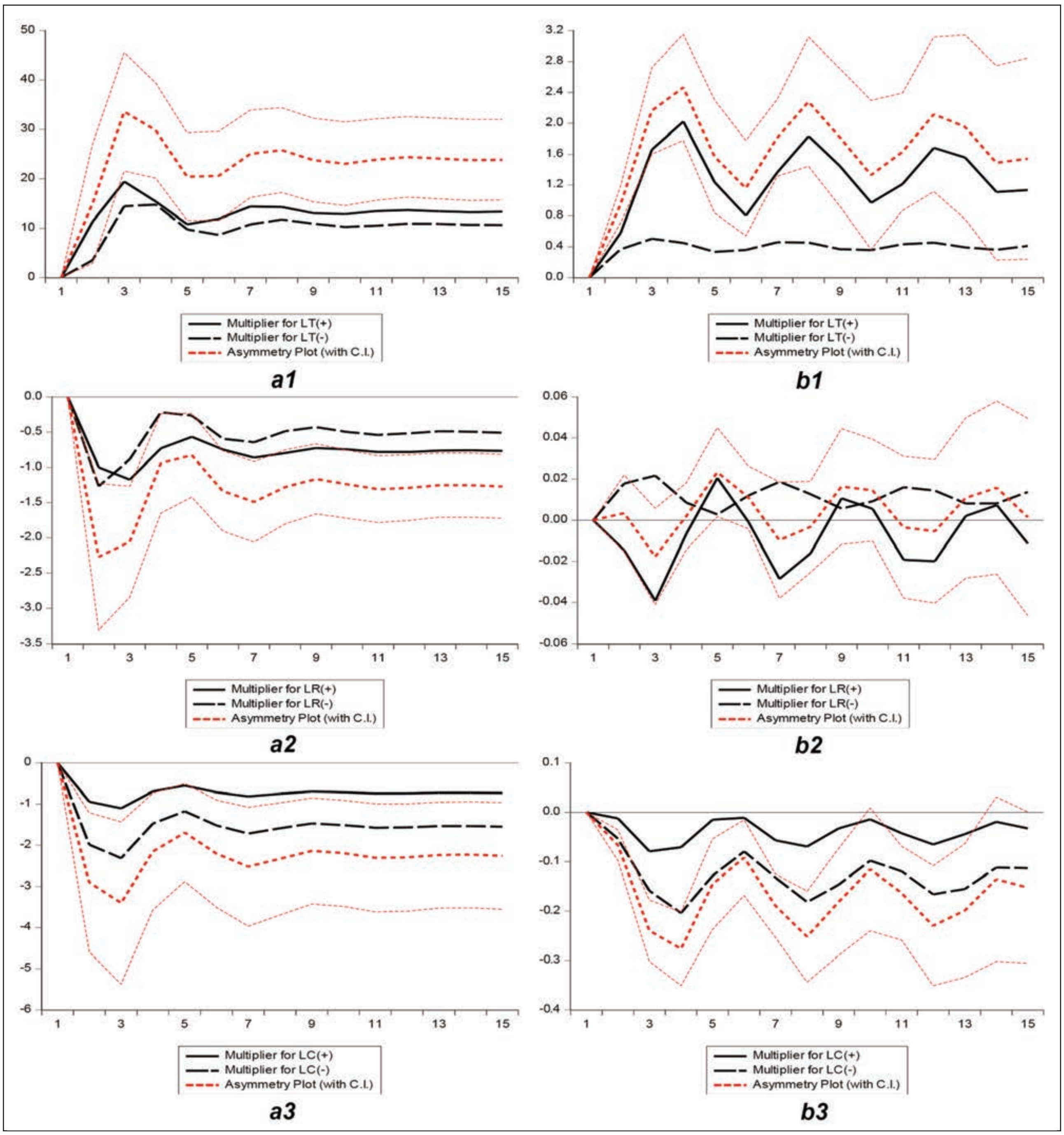

Fig. 4. Dynamic multiplier climate variables effects on agricultural and total exports

Table 8

ROBUSTNESS ANALYSIS								
Variables	Dependent variable: LnAEX				Dependent variable: LnTEX			
	FMOLS		DOLS		FMOLS		DOLS	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
LnTEM (+)	10.95***	5.28	11.39***	3.93	0.58***	22.17	0.58***	12.17
LnTEM (–)	–10.11***	–5.40	–10.11***	–3.84	–0.37***	–19.48	–0.36***	–11.40
LnRF (+)	–1.08***	–3.79	–1.01**	–2.54	–0.01**	–5.71	–0.01***	–3.06
LnRF (–)	1.28***	7.18	1.26***	4.92	–0.01***	–11.85	–0.01***	–6.64
LnCO2 (+)	–0.92***	–4.97	–0.93***	–3.50	–0.01**	–7.04	–0.01***	–3.60
LnCO2 (–)	1.94***	5.94	1.95***	4.18	0.05***	13.61	0.05***	7.84
LnGDP	0.96***	3.70	0.97**	2.65	0.10***	18.80	0.10***	10.23
LnAEX	-	-	-	-	0.98***	5.85	0.98***	3.22
LnAGR	1.30***	5.59	1.28***	4.07	-	-	-	-

Note: ***, ** and * means 1%, 5% and 10% significant levels.

among variables [55, 56]. They are unbiased and highly efficient, even amid endogeneity issues. Table 8 explains the estimation results using these two panels. The findings conclusively show that temperature has significant positive impacts on LnAEX (agri-export) and LnTEX (total exports), whereas CO_2 and rainfall have significant negative associations with LnAEX and LnTEX. Therefore, we can infer that the FMOLS and DOLS results resemble the NARDL results, confirming their reliability and validity.

In another train of thought, according to the World Bank report published in November 2023, the garment industry in Myanmar presents a series of particularities, including the significant share of approximately 85% of garment workers who are women, mostly young migrants from poor and rural areas of Myanmar. Moreover, 84% of companies in the garment sector have a positive perception, considering themselves competitive in the main markets [57–59]. Women are also an essential pillar of Myanmar's garment industry, holding the majority of positions as workers, managers (around 56%) or owners. Almost half of Myanmar's garment industry exports are destined for European Union markets, but a significant share is destined for US markets. The garment manufacturers in Myanmar are rather vulnerable and exposed to certain risk factors, including power supply issues, logistic enforcements, currency risk, and difficulties in obtaining licenses for certain production inputs.

Some researchers [60] have studied the natural outputs based on textile dyeing plants, aim to preserve traditional crafts passed down from generation to generation in Chin ethnic communities from Myanmar, but among the most important plant dye species used in the traditional textile industry are the following: "Chromolaenaodorata", "Lithocarpusfenestratus", "L. pachyphyllus". In this sense, agriculture is strongly connected to the traditional textile industry in Myanmar. Traditional textile dyeing is a very authentic traditional craft of Myanmar that contributes significantly to economic growth through the significant contribution of traditional export products.

CONCLUSION AND POLICY IMPLICATIONS

The study investigates the asymmetric impact of climate variability on Myanmar's agricultural and total exports using the NARDL approach for the 1990–2021 annual data. We apply the standard and structural break unit root test to determine the stationary nature of the variables. The results indicate that all variables exhibit mixed stationary behaviour at I(0) and I(1). The BDS test assesses the variables' nonlinearity and shows that they are not independently and identically distributed. The Wald test reveals the presence of asymmetry in the long run between climate variables and agri-and total exports in Myanmar. The diagnosis and stability tests confirm the accuracy and reliability of the model's estimates in the study. The robustness of the NARDL outcome, as confirmed by the dynamic multiplier asymmetry of climate variables and FMOLS and DOLS techniques, provides the reliability of the study.

Over the long and short run, temperatures positively impact agri- and total exports in Myanmar. Increasing temperatures favour export sectors more than decreasing temperatures. In contrast, rainfall negatively affects both agricultural and total exports. Specifically, an increase in rainfall leads to a decline in agricultural exports, while a decrease in rainfall results in an increase in total exports in the long run. Decreasing rainfall declines in agricultural exports, while increasing rainfall reduces total exports in the short run. Increasing rainfall impacts agricultural exports and overall exports more than decreasing ones. Carbon emissions adversely affect agricultural and total exports in both runs. Decreased carbon emissions affect export sectors more than increased ones. In controlled variables, GDP has a positive impact on both agriculture and total exports. Agricultural production contributes significantly to agricultural exports, and agri-exports increase total exports in Myanmar. To summarise, Myanmar's export sectors (agri and total) respond negatively to rainfall and carbon emissions, whereas they respond positively to temperature. The findings also highlight the significant and lasting impacts of climate variables, with the long-term effects proving to be more substantial than the short-term ones. Furthermore, it demonstrates that climate variables have a greater impact on agricultural exports than on total exports, underscoring the seriousness of its implications.

Myanmar's textile and garment industry is export-oriented and very important for the economic growth of this emerging country. Marsh and Lu [61] argued that in the past decade, the European Union fashion industry has had a particular interest in certain sources such as Cambodia and Myanmar, mainly for reasons related to Corporate Social Responsibility concerns. Because the textile and garment industry in Myanmar presents an increased attractiveness, it is understood that it attracts significant foreign direct investments, which contribute to sustainable development and increase the number of workers in this economic sector.

Based on the findings, the study suggests four crucial policy implications for Myanmar, each offering potential benefits. First, investing in irrigation infrastructure, efficient water management techniques, and climate-resilient crop varieties is essential to mitigate the adverse effects of unpredictable rainfall.

Implementing carbon reduction policies and promoting sustainable agricultural practices can help manage carbon emissions. Enhancing climate monitoring and forecasting systems and adopting greenhouse agriculture can stabilise agricultural output in response to temperature changes. Second, diversifying the export base and promoting value-added processing of agricultural products can reduce dependency on climate-sensitive exports, potentially leading to a more stable economy. Developing improved transportation, storage, and climate-resilient infrastructure will help withstand extreme weather events, ensuring trade continuity. Third, implementing training programs for farmers on climate-smart practices and conducting public awareness campaigns on the impacts of climate change are essential for building capacity and fostering sustainable development, potentially leading to a more resilient agricultural sector. Fourth, as climate variables have a greater impact on exports in the long run than in the short run, it is necessary to prioritise long-term climate adaptation and mitigation strategies, potentially leading to a more sustainable future. Moreover, the greater impact of climate variables on agricultural exports compared to total exports underscores the critical vulnerability of the agricultural sector. So, prioritising investment in climate-smart agricultural practices, including climate adaptation and mitigation practices, is required to safeguard agricultural productivity. By addressing these policy areas, Myanmar can better manage the negative impacts of rainfall and carbon emissions on its exports while leveraging the positive effects of temperature increases.

While this study offers valuable insights, it is essential to acknowledge its limitations. We considered temperature, rainfall, and carbon emissions to determine the impact of climate variability. However, we could not consider humidity, wind, and solar radiation as climate variables due to data limitations. Moreover, this study did not include extreme climate change events such as floods, droughts, cyclones, earthquakes, etc. Given the likelihood of climate escalation globally, further research across diverse regions and countries using varied climate and production datasets and methods will be necessary and beneficial. Therefore, this study recommends using panel data analysis like the CSARDL model for group regions like ASEAN and Asia to understand the regional climate change on their economies for further research in the future.

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Redefining fashion: eco-design and circular economy practices in Romania

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ABSTRACT – REZUMAT

Redefining fashion: eco-design and circular economy practices in Romania

This study examines best practices in eco-design within six Romanian textile companies, highlighting their commitment to environmental sustainability, circular economy principles, social responsibility, and education. These companies implement innovative solutions such as the use of durable and recycled materials, waste reduction strategies, eco-friendly dyeing processes, and ethical labour practices. Their approaches align with global trends in sustainable fashion, demonstrating how the industry can transition toward more responsible production and consumption models. By adopting similar strategies, fashion companies can greatly minimise their ecological footprint and promote a more sustainable and socially responsible future.

Keywords: *eco-design, good practices, environmental sustainability, circular economy, social responsibility, education*

Redefinirea modei: practici de eco-design și economie circulară în România

Acest studiu examinează cele mai bune practici în domeniul eco-design-ului în cadrul a șase companii textile românești, subliniind angajamentul lor față de sustenabilitatea mediului, principiile economiei circulare, responsabilitatea socială și educația. Aceste companii implementează soluții inovatoare, cum ar fi utilizarea de materiale durabile și reciclate, strategii de reducere a deșeurilor, procese de vopsire ecologice și practici de muncă etice. Abordările lor se aliniază cu tendințele globale în moda sustenabilă, demonstrând cum industria poate face tranziția către modele de producție și consum mai responsabile. Prin adoptarea unor strategii similare, companiile de modă își pot minimiza considerabil amprenta ecologică și pot promova un viitor mai sustenabil și mai responsabil din punct de vedere social.

Cuvinte-cheie: *eco-design, bune practici, sustenabilitate, economie circulară, responsabilitate socială, educație*

INTRODUCTION

The textile industry has increasingly recognised the necessity of transitioning from a linear economy to a circular economy model, which emphasises sustainability through the principles of reduce, reuse, and recycle. This shift is essential to mitigate the significant environmental impacts associated with textile production and consumption, such as resource exhaustion, environmental pollution, and waste generation. The concept of eco-design plays a pivotal role in this transition by integrating sustainability into the design process, thereby enhancing product life cycles and minimising waste [1, 2]. Eco-design in textiles involves creating products that are both visually appealing and eco-friendly throughout their life cycle. This includes considerations for material selection, production processes, and end-of-life management. For instance, the development of green textiles, which employ sustainable materials and processes, is a strategic goal within the circular economy framework [2]. Furthermore, the implementation of eco-design principles can lead to increased product durability and recyclability, which are crucial for reducing the overall environmental footprint of the textile industry [3, 4].

Recent studies highlight the increasing pressure on the textile industry to adopt eco-design principles to reduce its environmental impact. For instance, Schumacher et al. [5] conducted an assessment of the textile industry's circular economy landscape in the United States, identifying key challenges and opportunities for sustainable practices. Tripa et al. [6] emphasise that technical textiles exert significant ecological pressure, necessitating solutions that integrate sustainable materials and production processes. Another study suggests that customised clothing represents a viable strategy to address textile waste by minimising overproduction and unsold stock [7]. Additionally, Indrie et al. [8] propose an innovative algorithm for textile waste arrangement to optimise waste management in the industry. Spyridis et al. [9] introduced an autonomous AI-enabled industrial sorting pipeline for advanced textile recycling, showcasing innovative solutions to enhance recycling efficiency. Similarly, the European Environment Agency (2022) [10] underscored the role of design in Europe's circular economy, emphasising product durability, repairability, and recyclability. Furthermore, the European Commission (2022) [11] outlined comprehensive strategies to create a greener, more competitive textile sector through its EU Strategy for Sustainable and Circular Textiles.

The circular economy model encourages innovative business practices that prioritise sustainability. This includes the adoption of circular business models that focus on product life cycle management, reverse logistics, and extended producer responsibility [12, 13]. Such models not only enhance the eco-efficiency of textile production but also foster collaboration between manufacturers and designers to create sustainable products [12]. For example, the integration of digital technologies and data analytics can improve transparency and traceability in textile supply chains, facilitating better waste management and recycling efforts [14].

A recent report by Reconomy [15] examined the current state of the circular economy in the fashion industry, exploring its challenges, benefits, and pathways for increased sustainability. Challenges remain in the widespread adoption of circular economy practices in the textile sector. Barriers such as lack of awareness, inadequate infrastructure for waste management, and the complexity of textile recycling processes hinder progress [13, 16]. Moreover, the fast fashion industry exacerbates these challenges by promoting overconsumption and rapid product turnover, leading to increased textile waste [17]. Addressing these barriers requires a concerted effort from all stakeholders, including policymakers, industry leaders, and consumers, to foster a culture of sustainability and circularity [18].

In conclusion, the integration of eco-design principles within the circular economy framework is crucial for the sustainable transformation of the textile industry. By prioritising sustainability in design and production processes, the industry can significantly reduce its environmental impact while promoting economic viability and social responsibility. Continued research and innovation, alongside collaborative efforts among stakeholders, will be essential to overcoming existing challenges and attaining the full potential of a circular textile economy.

ECO-DESIGN AND CIRCULAR ECONOMY PRACTICES IN EUROPE AND ROMANIA

Eco-design plays a crucial role in advancing sustainability within the fashion and textiles industry. Across Europe, numerous companies and initiatives have embraced eco-design principles, integrating circular economy strategies, responsible material sourcing, and innovative production techniques to reduce environmental impact. According to the European Environment Agency (EEA), eco-design strategies have significantly contributed to reducing waste and energy consumption across various industries [19]. Countries such as Sweden, Germany, and the Netherlands [20] have been at the forefront of implementing sustainable design principles, promoting extended product lifecycles, recyclability, and responsible consumption.

Spain has also made significant progress in integrating eco-design and circular economy strategies into the textile industry. Ecoalf, a Spanish brand, is widely recognised for its commitment to sustainability by transforming marine plastic waste and other recycled materials into high-quality fashion products. By adopting a closed-loop production system, Ecoalf minimises its environmental impact while setting an example for responsible textile manufacturing. Similarly, Recover™, a Spanish textile recycling company, plays a crucial role in reducing waste by producing high-quality recycled cotton fibres. Their innovative approach to fibre regeneration aligns with circular economy principles and contributes to reducing the need for virgin cotton.

In Romania, eco-design is gaining momentum as companies integrate sustainability into their production processes. Bi Eco Fashion, for instance, exemplifies how local businesses are incorporating environmentally friendly materials and ethical manufacturing practices. Another notable example is ALTRNTV, a Romanian initiative that embraces circular economy principles by promoting upcycled fashion and responsible consumer behaviour. The ALTRNTV shop not only offers sustainable clothing but also raises awareness about eco-friendly practices, demonstrating how small businesses can drive change in the industry [21]. Additionally, research collaborations and European initiatives, such as Erasmus+ projects (2023-1-ES01-KA220-HED-000157440-Supporting Entrepreneurship in Eco Design-FASHION.ED), have supported the development of innovative solutions in the sector. Studies on traditional Romanian textiles and their potential for sustainable applications also contribute to the growing body of knowledge on eco-design [22].

In this study, we intend to highlight best practices from Romanian companies, focusing on key aspects such as environmental sustainability, circular economy principles, social responsibility, and education. By showcasing these examples, we aim to inspire further adoption of eco-design strategies that contribute to a more sustainable and responsible fashion industry.

EXAMPLES OF GOOD PRACTICES IN ECO-DESIGN IN ROMANIA

The identification of eco-design best practices within Romania's textile sector was conducted by analysing 6 businesses from different parts of Romania that integrate sustainable strategies into their operations. These best practices were identified based on information provided directly by the companies, as well as publicly available data from company websites, press articles, and academic publications.

The selection of the companies in this study was based on their documented and evident involvement in sustainable practices within the fashion and textile industry. The selection criteria focused on the following aspects: using eco-design principles in their product development processes; implementing strategies that align with models of the circular economy; demonstrating social responsibility through fair labour practices or assistance for vulnerable groups; participating in sustainability-related educational or awareness-raising initiatives; and having publicly available information (websites, articles, reports) that details their sustainable practices were the main focus of the selection criteria. These criteria ensured that the selected companies – Atelier MERCI, Atelierul de Pânză, Bi ECO FASHION, Ițe Urbane, Poartă-mă cu flori, and REDU – represent relevant and diverse examples of best practices in eco-design within the Romanian textile sector.

The study used a qualitative, thematic framework based on four major pillars of sustainable development in the fashion industry to analyse and classify the best practices used by the chosen companies: *environmental sustainability*, which includes the use of eco-friendly materials, waste reduction, and non-polluting production processes; *circular economy* principles, which include reuse, repair, recycling, upcycling, and closed-loop systems; *social responsibility*, which includes ethical labour practices, marginalized group inclusion, and community engagement; and *education* and awareness, which focuses on educating customers, staff, or the general public about sustainability issues.

This analytical framework made it possible to compare the businesses' practices in an organised manner and made it easier to find recurring themes, creative strategies, and transferable models that other textile industry players could use as a source of inspiration.

The selected six companies exemplify sustainable textile production and are from various regions of Romania.

Atelier MERCI [23] – Operating under ALTRNTV LIFESTYLE SRL, Atelier MERCI is a Bucharest-based sustainable fashion brand that prioritises ethical production over fleeting fashion trends. Its mission centres on creating garments that respect customers, the environment, and the community by using organic and natural materials with minimal environmental impact.

Atelierul de Pânză is a social enterprise developed by the Viitor Plus Association, established in 2009 in Bucharest with the objective of providing sustainable alternatives to plastic bags. The initiative not only focuses on reducing plastic waste but also fosters social inclusion by employing individuals from disadvantaged backgrounds [24].

Bi ECO FASHION [25] – a niche artisanal fashion brand dedicated to reducing waste and pollution. The brand limits production to a small series of four pieces per design, cutting fabric manually using traditional tailoring techniques. Since all production is handled internally, they can be reproduced upon request, preventing excessive production and resource depletion. This strategy is in line with the company's dedication to eliminating waste and promoting responsible consumption.

Ițe Urbane [26] – a Bucharest-based prêt-à-porter creative studio launched in early 2020 with a commitment to producing high-quality, durable garments in an environmentally and socially responsible manner. The company integrates recycling and upcycling into its production process, ensuring that its designs minimise waste and promote sustainability.

Poartă-mă cu flori [27] – a sustainable fashion brand from Neamț County, known for both its eco-friendly materials and its unique natural dyeing techniques. The company uses plant-based dyes derived from saffron, roses, marigolds, and oak leaves, following the traditional Romanian method of *boitul cu buruieni* (herbal dyeing).

REDU [28] – is a pioneering initiative offering ethical and sustainable alternatives to conventional fashion. Based in Iași, REDU upcycles textile waste collected from local garment manufacturers to create new products, each carrying a unique story of transformation.

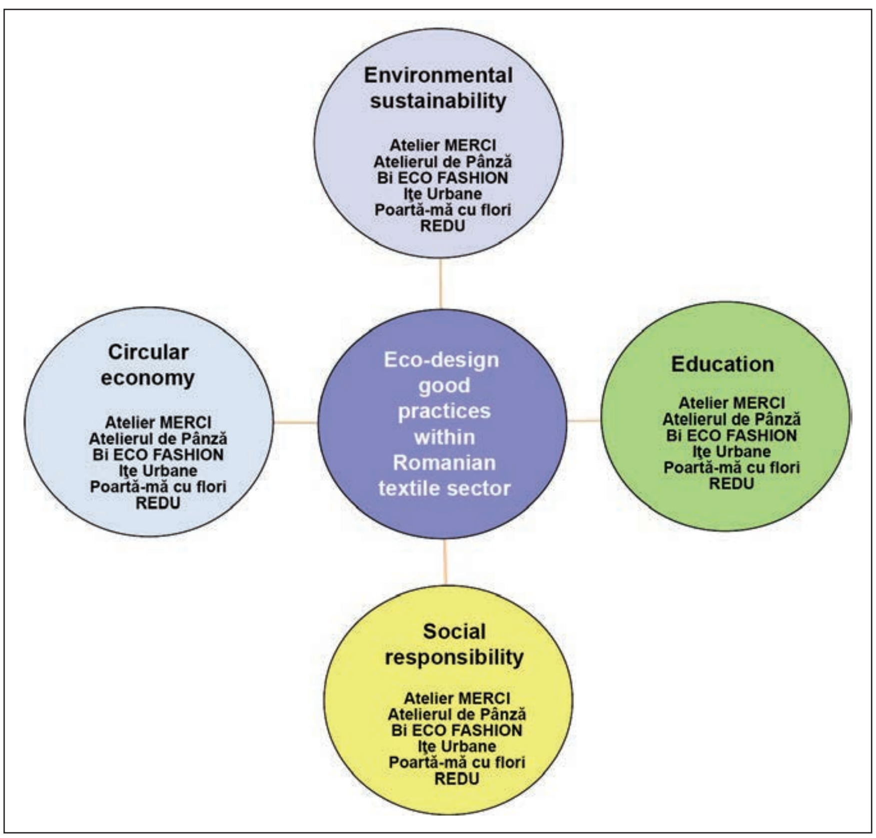

Fig. 1. Eco-design good practices in the Romanian textile sector

As the first entrepreneurial project in Romania dedicated to systematic textile waste reduction, REDU plays a crucial role in promoting circular fashion.
The identified best practices within these companies can be categorised into four main areas, which will be explored in detail in the following sections.

Environmental sustainability

Atelier MERCI produces all its garments exclusively from natural or organic materials, such as organic cotton, hemp, and linen. The fabrics used are certified by the Global Organic Textile Standard (GOTS) and OEKO-TEX**.** The company prioritises sustainable packaging, using locally produced biodegradable, plastic-free packaging with natural adhesives instead of synthetic or petroleum-based ones. By minimising transportation distances from production to customers, ATELIER MERCI effectively reduces its carbon footprint.
Atelierul de Pânză is committed to reducing environmental impact by offering 100% cotton tote bags and Puzzletex accessories, which serve as sustainable alternatives to plastic bags. The company prioritises the use of natural, biodegradable materials, ensuring that its products contribute to lowering plastic waste and pollution. By promoting reusable, long-lasting textile solutions, Atelierul de Pânză encourages consumers to adopt eco-conscious shopping habits, reducing their reliance on disposable plastic.
Additionally, the company's manufacturing process follows sustainable practices, minimising textile waste and ensuring ethical production standards. Through these efforts, Atelierul de Pânză actively supports environmental conservation by offering practical and responsible solutions for daily consumption.
Bi ECO FASHION manufactures all its coloured garments using ECONYL® regenerated nylon, a material derived from waste such as discarded fishing nets, fabric scraps, and carpets destined for landfills. This fabric is infinitely recyclable, enabling endless possibilities for designers and consumers. The company's environmental impact is further minimised as production is centralised in a single location, reducing transportation emissions. Moreover, the high-quality materials ensure that the garments are long-lasting.
At *Ițe Urbane*, the design, production, and distribution processes are all centred on resource efficiency and waste minimisation. The company predominantly utilises natural fabrics sourced from Romania or other European countries. Their garments are designed to be durable both in terms of quality and timeless style. Production is limited to small batches and, whenever possible, made-to-order to prevent overproduction and stock accumulation. The dyeing process incorporates plants harvested from the company's garden or purchased locally. Furthermore, all products are packaged in reusable cotton tote bags to eliminate plastic use. As part of its commitment to sustainability, Ițe Urbane plants a tree for every order placed.
Poartă-mă cu flori distinguishes itself not only by using sustainable materials but also through its unique dyeing techniques. The brand employs plant-based dyes derived from saffron, roses, marigolds, oak leaves, and other botanicals. This process is based on a traditional Romanian method called "boitul cu buruieni" (herbal dyeing).
REDU is a pioneering initiative in Romania, committed to reducing textile waste by transforming discarded materials into high-quality, sustainable products. The company follows an innovative upcycling model, collecting fabric scraps from garment factories in Iași and repurposing them into clothing, accessories, and utility items. Each product tells a unique story of transformation, emphasising the potential of textile circularity.
A key aspect of REDU's environmental sustainability strategy is its zero-waste approach. By carefully selecting and reusing textile scraps, the company minimises the environmental footprint associated with textile production and disposal. This practice not only reduces landfill waste but also extends the lifecycle of materials that would otherwise be discarded.

Circular economy

Atelier MERCI recycles products received from donations. By reintroducing these products into the manufacturing process, the company contributes both to reducing the need for raw materials and to reducing the amount of textile waste.
Atelierul de Pânză integrates circular economy principles into its business model by focusing on waste reduction and resource efficiency. The company ensures that textile scraps are repurposed, contributing to a zero-waste production cycle (the decor cushions are filled with textile waste obtained by shredding textile waste, which, due to their very small size, cannot be used even at Puzzletex. Even the label used is made of recycled cardboard. Puzzletex accessories, made from leftover fabric, exemplify this commitment by transforming excess materials into new, functional products instead of discarding them. This approach not only minimises environmental impact but also fosters a sustainable consumption mindset, encouraging customers to shift towards responsible, long-term use of everyday items.
Bi ECO FASHION focuses on implementing circular economy principles from the product design phase. In their design process, they have eliminated, as much as possible, rigid components such as accessories and buttons to facilitate easier deconstruction and recycling. Their minimalist approach incorporates mono-material designs that enable easy disassembly, while the use of threads with the same composition as the garment's fabric supports an endless supply loop by reintegrating discarded textiles into the production cycle. In addition to recycled materials, they also utilise natural fabrics such as linen.
Ite Urbane emphasises sustainability by creating clothing that is both durable and timeless, reducing the need for frequent replacements. They prioritise the use of natural and biodegradable materials,

ensuring that their products have a minimal environmental footprint. Additionally, through its take-back program, Ite Urbane encourages consumers to return used goods for recycling or repurposing, thereby keeping materials in circulation and reducing waste.
Poartă-mă cu flori focuses on creating garments that are designed for longevity and adaptability. They utilise modular design approaches, allowing pieces to be easily adjusted or updated, which extends the product's lifecycle. The company also engages in local production, minimising transportation emissions and supporting the local economy. By sourcing materials responsibly and promoting repair over disposal, Poartă-mă cu flori aligns with circular economy strategies designed to reduce waste and optimise resource utilisation.
By integrating sustainable practices throughout all aspects of its operations, from material sourcing to product design and community engagement, *REDU* sets a strong example of how the fashion industry can transition toward a circular economy while reducing its environmental impact. The company has implemented its system for collecting used clothing items and offers repair and alteration services to extend the lifespan of textile products. Additionally, it has developed over 50 new product patterns, based on which nearly 6,200 new products have been created using recovered textile materials from the most local and natural sources possible.

Social responsibility

Atelier MERCI supports various medical and social causes and is actively involved in charitable initiatives. For example, it donates Atelier MERCI products to the Romanian Red Cross, which sells them in its charity shop, Bine Boutique. The funds raised are used to support the medical and social causes of the MERCI Charity Boutique association.
Atelierul de Pânză is strongly committed to supporting and integrating people with disabilities – more than half of its employees are individuals facing such challenges
Bi ECO FASHION demonstrates social responsibility by promoting ethical production practices and fair labour conditions. Their commitment to using recycled and natural fabrics supports not only environmental sustainability but also responsible manufacturing processes that prioritise workers' well-being. By integrating ethical principles into their operations, Bi Eco Fashion contributes to a more socially responsible fashion industry, advocating for fair treatment and sustainable livelihoods within the textile sector.
Ițe Urbane operates as a slow fashion atelier, focusing on ethical principles. They utilise natural fibres and collaborate with local tailors who are fairly compensated. Their mission is to develop high-quality, sustainable products crafted with care and respect for both the environment and people, reflecting a deep responsibility towards future generations.
Poartă-mă cu flori is a Romanian brand that emphasises traditional craftsmanship and cultural heritage. They collaborate with local artisans to create unique, handcrafted clothing items, thereby supporting local communities and preserving traditional skills. Their approach fosters social responsibility by promoting cultural sustainability and providing fair economic opportunities to artisans.
The team at *REDU* has donated over 65% of the collected clothing to vulnerable individuals, while a quarter of the items, after sorting and cleaning, have been resold at very low prices to community members. Additionally, they have organised multiple editions of the Solidarity Bazaar and participated in numerous alternative fairs, where vulnerable individuals received free clothing, footwear, blankets, and other essential items.

Education

By providing 100% cotton bags, *Atelierul de Pânză* enable people to use fewer plastic bags. Additionally, they have developed a social webshop that gathers and sells products from various social enterprises in the country. This platform not only markets eco-friendly products but also builds and shares knowledge about branding, social impact, and other relevant topics, thereby educating both consumers and producers about sustainable
Atelier MERCI guides marginalised Romanian craftspeople on transitioning to sustainable packaging and improving waste recycling processes, thereby educating and supporting small artisans in adopting eco-friendly practices.
While *Bi ECO FASHION* primarily focuses on creating eco-friendly products, it contributes to raising awareness among consumers about the importance of environmentally responsible choices in the fashion industry.
Ițe Urbane prioritises respect for both the environment and people. The company focuses on producing durable, high-quality garments made from natural fibres and collaborates with local tailors who receive fair compensation. Their mission also includes educating consumers about the value of slow fashion and the importance of responsible consumption.
Poartă-mă cu flori conducts a range of activities designed to increase awareness about the importance of reducing textile waste, particularly that of highly polluting fabrics. Additionally, the company promotes sustainable alternatives to chemical dyeing by advocating for the use of plant-based textile dyeing techniques.
Education is at the core of *REDU*'s activities, both through consistent online communication and numerous events aimed at fostering a collective environmental mindset and enhancing local community awareness of the social and environmental impact of the textile and apparel industry. The organisation has participated in and hosted multiple events, including the REcreation workshop, all designed to promote production and consumption models that minimise waste through sharing, reuse, repair, refurbishment, and recycling of existing materials and products as extensively as possible.

Additionally, REDU draws attention to the negative environmental impact of the textile industry, both from a producer and consumer perspective, while educating the public on how to extend the lifespan of clothing, how to properly collect and repair garments, and how to repurpose them into useful items.

DISCUSSION

The practices observed in these Romanian companies are consistent with global trends in sustainable fashion. It is very important to use eco-friendly materials, implement recycling programs, and adopt sustainable dyeing and finishing processes to minimise environmental impact.

Furthermore, research on the Romanian textile industry underscores the significance of integrating sustainable practices to enhance competitiveness and align with international standards. The adoption of eco-design principles not only contributes to environmental sustainability but also offers economic advantages by meeting the growing consumer demand for responsible fashion choices [29].

The companies studied demonstrate a strong commitment to *environmental sustainability* through various practices. For instance, Atelier MERCI utilises sustainably produced vegan and organic materials in their handcrafted clothing, minimising the environmental impact associated with conventional textile production. Similarly, Ițe Urbane focuses on creating durable, high-quality products using natural fibres, thereby reducing reliance on synthetic materials and promoting biodegradability.

These practices align with broader industry trends emphasising the use of eco-friendly materials. According to a report by ECOS, implementing eco-design requirements for textiles is crucial for mitigating the environmental impact of fast fashion and promoting the use of sustainable materials [30].

Several of the companies integrate *circular economy* principles into their operations. REDU embodies circularity by collecting used clothing, offering repair services, and designing new products from recovered textiles, thereby extending the lifecycle of materials and reducing waste.

These initiatives reflect a growing emphasis on upcycling and recycling within the fashion industry, with upcycling increasingly embraced by luxury brands and businesses as a strategy to address environmental concerns and promote sustainability.

The companies studied also demonstrate a commitment to *social responsibility*. Atelier Merci provides guidance to marginalised Romanian craftspeople on transitioning to sustainable packaging and improving waste recycling processes, thereby supporting small artisans in adopting eco-friendly practices. This strategy not only enhances environmental sustainability but also fosters social equity by empowering disadvantaged communities.

Such practices are consistent with findings from a study on sustainable manufacturing in Romanian SMEs, which emphasises the importance of integrating social and environmental considerations into business operations to achieve long-term success [31].

Education plays a pivotal role in promoting sustainable fashion practices among consumers and industry stakeholders. REDU places education at the core of its activities, engaging local communities through educational initiatives and workshops that encourage a shift toward conscious consumerism.

These educational efforts align with broader industry movements aimed at raising awareness about the environmental impact of fashion.

CONCLUSIONS

Approximately 10% of global greenhouse gas emissions are generated by the fashion industry. The processes involved in textile production are significant consumers of water and electricity, and the chemical dyeing of garments has a substantial impact on the contamination of freshwater resources. Therefore, businesses that produce products from textile waste and dye fabrics with plant-based materials could serve as an inspiration for making the industry more sustainable.

The study highlights that the main eco-design strategies in textile companies in Romania include the use of sustainable materials in production processes, the creation of products designed to last over time, ensuring durability in terms of resistance, quality, and style. It also emphasises the collection of textile waste, which, after sorting, is either reintroduced into use through donations to disadvantaged individuals or transformed into other types of textile products that are then reintegrated into the economic circuit. Reducing the environmental impact of textiles is achieved by preferring to create items from natural, recyclable, and biodegradable materials sourced locally or as close as possible to minimise the negative effects of transportation. This includes the use of sustainable, biodegradable packaging that is plastic-free and uses natural adhesives instead of synthetic or petroleum-based ones, as well as the ecological dyeing of products using plants. The social responsibility of the studied firms is demonstrated through safe working conditions and fair wages, the promotion of ethical labour standards, care for disadvantaged individuals through donations, and the employment of people with disabilities. Particular attention is also given to educational and informational activities aimed at raising awareness in the local community about the social and environmental impact of the textile and garment industry. This includes the importance of reducing textile waste (especially polluting waste), learning how to extend the life of clothing items, understanding how they should be collected, repaired, and transformed into useful items, and the possibility of replacing chemical dyeing of textiles with plant-based dyeing, which does not negatively affect the environment.

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New approach for design and development of multi-role aerial module for management of the pedological drought

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ABSTRACT – REZUMAT

New approach for design and development of multi-role aerial module for management of the pedological drought

Soil drought, seen as the depletion of soil water reserves at watering depths below the readily accessible water content, is a challenging problem for humanity, with a massive negative impact on social, economic, and environmental activities. This paper proposes a new approach to the management of soil-induced drought disasters.

In this respect, 8 variants of fabrics (used as matrices of composite materials) and 3 variants of composite structures, used in the construction of collapsible multi-roll aerial modules for soil drought, have been developed and tested in INCDTP-accredited laboratories. Thus, the structures have been tested in terms of tensile behaviour, the strength and elongation at break, respectively the strength and elongation at tear. The experiments carried out, as well as the experience of specialists in the design of technical textile structures for special applications, have shown that the manufacturing of textile supports used as matrices for composite materials used in the construction of collapsible multi-roll aerial modules for pedological drought, structures specific to textile articles with special uses are used, for which programming schemes have been obtained.

The particularly restrictive conditions imposed by the field of use, in conjunction with the values obtained from the physical-mechanical testing of composite fabrics and structures, required the use of specialised software to obtain digital solutions. The results obtained as a result of FEM simulation predicted the behaviour of textile structures, composites, and the air module under dynamic conditions.

Keywords: *multi-roll aerial module, pedological drought, aerial mulching, CAD-CAM, modelling, FEM*

O nouă abordare pentru proiectarea și dezvoltarea unui modul aerian multirol pentru gestionarea secetei pedologice

Seceta pedologică, văzută ca epuizarea rezervei de apă din sol la adâncimi de udare sub conținutul de apă ușor accesibil, este o problemă provocatoare pentru umanitate, cu un impact negativ masiv asupra activităților sociale, economice și asupra mediului.

Această lucrare propune o nouă abordare a managementului calamităților declanșate de seceta pedologică.

În acest sens, au fost dezvoltate și testate in laboratoarele acreditate ale INCDTP 8 variante de țesături (utilizate ca matrici ale materialelor compozite) și 3 variante de structuri compozite, utilizate la construcția modulelor aeriene colapsabile multirol pentru seceta pedologică. Astfel, structurile au fost testate din punct de vedere al comportării la tracțiune, fiind determinate forța și alungirea la rupere, respectiv forta si alungirea la sfâșiere. Experimentările realizate, precum și experiența specialiștilor în proiectarea structurilor textile tehnice pentru aplicații speciale au evidentiat faptul că, pentru realizarea suporturilor textile utilizate ca matrici pentru materialele compozite utilizate la construcția modulelor aeriene colapsabile multirol pentru seceta pedologica se utilizează structuri specifice articolelor textile cu utilizări speciale, pentru care au fost obținute schemele de programare.

Condițiile deosebit de restrictive impuse de domeniul de utilizare, coroborate cu valorile obținute în urma testării fizico-mecanice a țesăturilor și structurilor compozite, au impus utilizarea unui software specializat pentru obținerea soluțiilor digitale. Rezultatele obținute ca urmare a simulării cu FEM au predicționat comportarea în condiții dinamice a structurilor textile, materialelor compozite și implicit a modulului aerian.

Cuvinte-cheie: *modul aerian multirol, secetă pedologică, mulcire aeriană, CAD-CAM, modelare, FEM*

INTRODUCTION

Extreme weather events in recent years have shown that the Earth's health is deteriorating at an accelerating rate. Dry areas on the Earth's surface have increased and are susceptible to accelerated degradation and desertification through loss of fertility [1–3]. Desertification is a real threat, provoked both by human activities (excessive or inefficient water use, overgrazing and deforestation, excessive urbanisation and industrialisation, etc.) and climate change (rising average temperatures, increasing intensity and frequency of droughts and other extreme weather events, etc.) [2–5].

Soil is the “fragile skin” that anchors all life on Earth and from which biodiversity springs, and it has been damaged by almost 50% in the last 150 years of its existence [3, 6].

According to the European Commission’s World Atlas of Desertification, more than 75% of the land is already degraded, and more than 90% could be degraded by 2050. Globally, a total area the size of the EU (~ 4 million km^2) is being degraded every year, with economic impacts of billions of euros annually. At the same time, the accelerating loss of forests will make mitigation efforts more challenging [4, 7, 8]. Global warming exacerbates droughts and concurrent heat waves in many parts of the world, leading to an increase in the frequency of natural disasters such as severe vegetation fires, and significant impacts on water resources and human health [6, 9]. The depletion of the soil water reserve at watering depths below the readily accessible water content is considered a “pedological drought”. In terms of agrometeorological drought indices, the moisture level generates 3 levels of pedological drought: moderate (35% – 50%), severe (20% – 35%), and extreme – below the wilting point (0% – 20%) [10, 11]. When lands are extremely dry, they are susceptible to erosion, and the topsoil is rapidly removed, further degrading the land surface. When talking about forested areas, fires and irresponsible logging are major causes of soil erosion [12, 13]. Measures to mitigate post-fire erosion mainly aim at reducing the kinetic energy of raindrops that would cause heavy run-off, thus enhancing water infiltration and limiting the detachment and transport of soil particles [8, 14]. This is achieved either by creating physical barriers on slopes and in the catchment, by building gabion-like structures for hydrological routing and control, or by covering the burnt soil with organic or inorganic protective layers (“mulching”) or by vegetation recovery [9]. Mulch layers are most often in the form of agricultural residues (wheat, barley, or rye straw) or heterogeneous wood residues produced “in situ” or “ex-situ” (chips, shavings, chips of saw, branches, or from logs. Covering the burnt areas with a medium-thick layer of mulch (about 5 cm) accelerates native vegetation recovery by maintaining moisture and protecting it from heat and solar radiation. This gives the seeds in the soil a better chance to germinate and stabilise the burnt areas. Aerial interventions are a viable solution for soil protection through mulching but require adequate logistics for the storage, transport, and spreading of mulch bales. Among the textile structures used in aerial mulching operations are knitted (knotless) cargo nets, woven or combined polyester (PES), polyamide (PA), or polypropylene (PP) strips.

This paper presents an innovative solution in the field of computer-aided design using specialised software for the realisation of a collapsible multi-roller aerial module for mulching. In this respect, textile moulds used for composite materials and composite fabrics used in the construction of a collapsible multi-roll aerial module for mulching were subjected to experiments.

MATERIALS AND METHODS

Materials used

For a digital design of the modelling and simulation of a multi-role structure intended for interventions in areas affected by soil drought, 8 woven textile structures were tested and analysed, from the point of view of physical-mechanical behaviour (table 1):

- Determination of maximum force and elongation at maximum force using the strip method, according to SR EN ISO 13934-1/2013.
- Determination of tear force of wing-shaped test specimens, according to SR EN ISO 13937-3/ 2000.

The images and graphs from these experiments are presented selectively in figures 1–6 and for the coated fabrics in figures 7–10.

Table 1

PHYSICAL-MECHANICAL BEHAVIOUR OF WOVEN TEXTILE STRUCTURES

Variant	Raw material		Weave	Yarn fineness	
	warp	weft		warp	weft
T1	100% cotton	100% cotton	1/1	200dtex x 2	200dtex x 2
T2	100% PES	100% PES	D2/1	167dtex/36fx1/150Z	167dtex/36fx1/150Z
T3	100% PES	100% PES	ripstop	76dtex/36fx1/800Z	76dtex/36fx1/350Z
T4	100%PA6.6	100%PA6.6	D2/2	660dtex/120fx1	660dtex/120fx1
T5	100%PES	100%p-aramid 100% PES R: 2:1	R2/1	1100dtex/192fx1/80Z	1100dtex/1192fx1 1100dtex/192fx1/80Z
T6	100%p-aramid	100%p-aramid 100% PES	RB1/2	1670dtex/192fx1/80Z	1670dtex/1192fx1 1100dtex/192fx1/80Z
T7	100%PA6.6	100%PA6.6 100% p-aramid R: 2:2	P2/2	880dtex/120fx1	880dtex/120fx1 660dtex/120fx1
T8	100%PA6.6	100%PA6.6	1/1	660dtex/120fx1	660dtex/120fx1

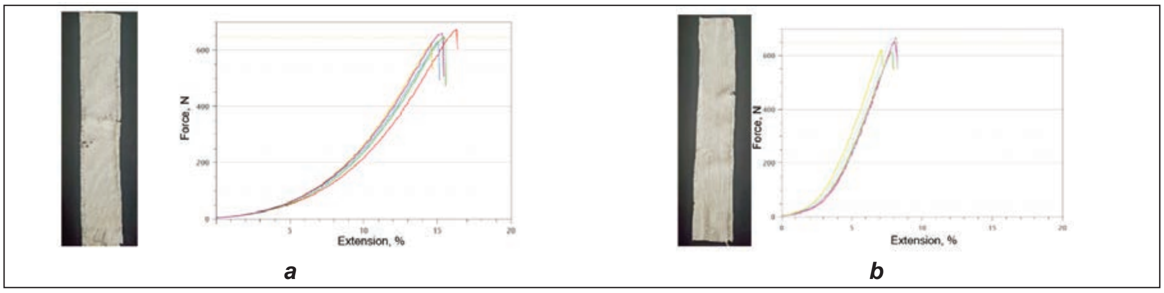


Fig. 1. Maximum breaking force with the strip specimen and corresponding stress-elongation diagrams for 100% cotton fabric (T1): *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

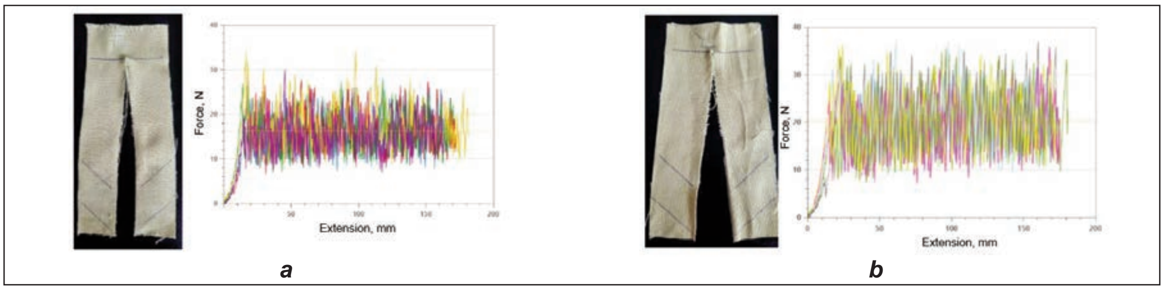


Fig. 2. Maximum tear force with a wing-shaped test piece and the corresponding stress-elongation diagrams for 100% cotton fabric (T1): *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

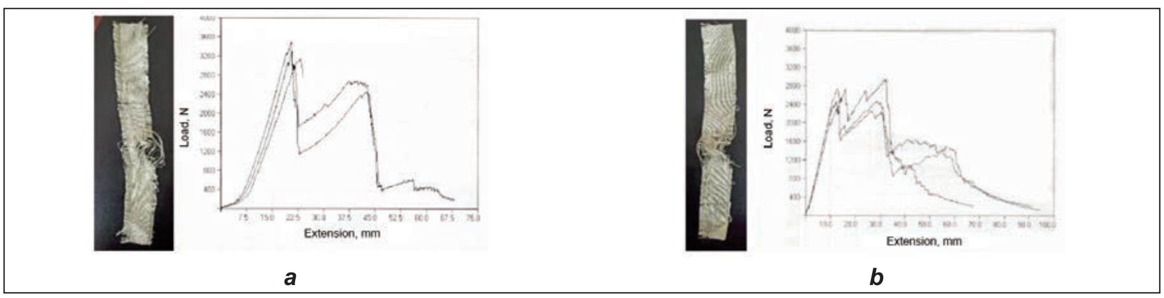


Fig. 3. Maximum breaking force by strip specimen method and corresponding stress-elongation diagrams for fabric 30 % p-aramid / 70 % PES (T5): *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

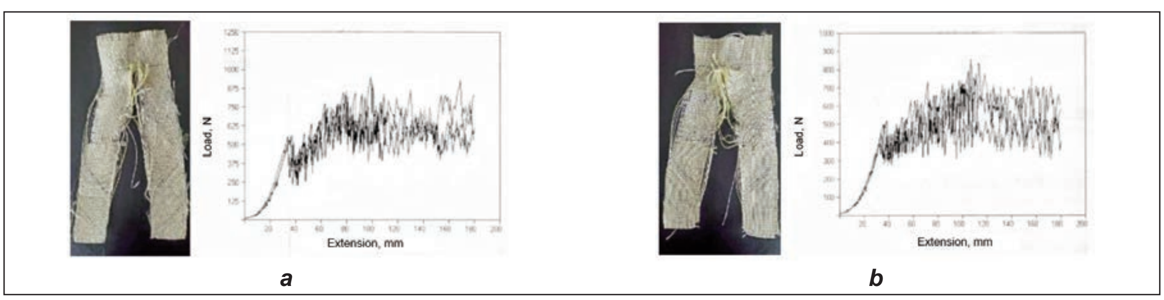


Fig. 4. Maximum tear force of specimens (wing-shaped) and corresponding stress-elongation diagrams for fabric 30 % p-aramid/ 70 % PES (T5): *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

Fig. 5. Maximum breaking force by the strip specimen method and corresponding stress-elongation diagrams for fabric 100% PA 6.6 (T8): *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

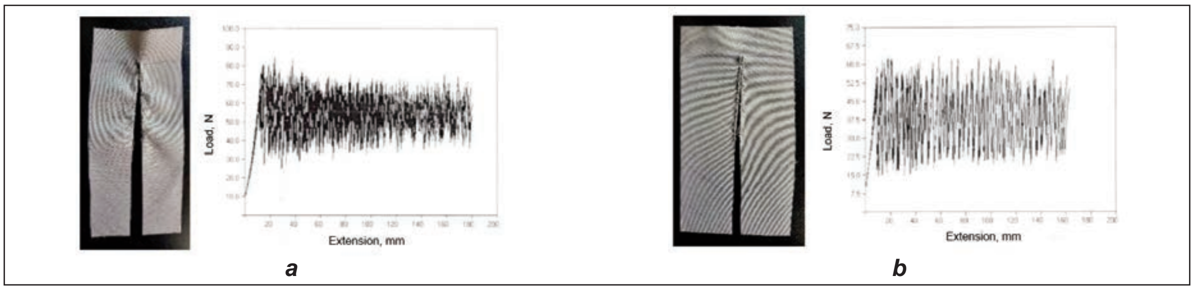


Fig. 6. Maximum tear force of specimens (wing-shaped) and corresponding stress-elongation diagrams for fabric 100% PA 6.6 (T8): *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

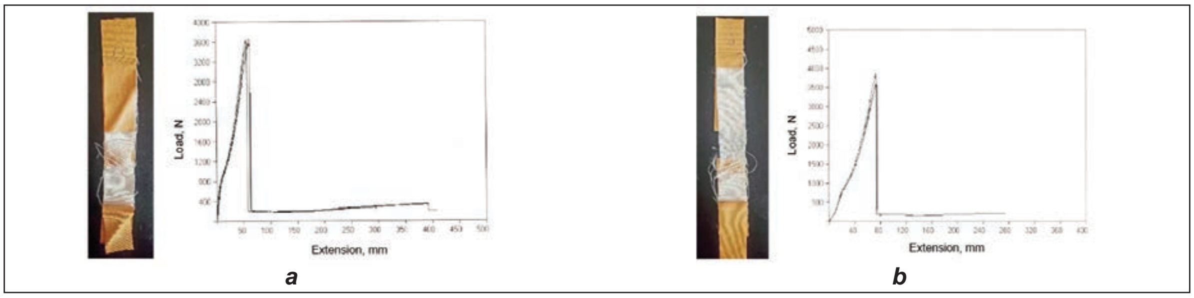


Fig. 7. Maximum breaking force by the strip specimen method and corresponding stress-elongation diagrams for 100% PA6.6 film-coated fabric: *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

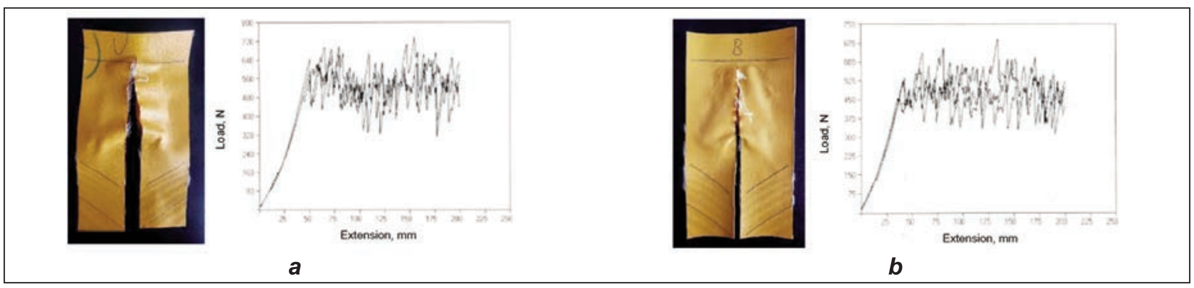


Fig. 8. Maximum tear force of specimens (wing-shaped) and corresponding stress-elongation diagrams for 100% PA6.6 film-coated fabric: *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

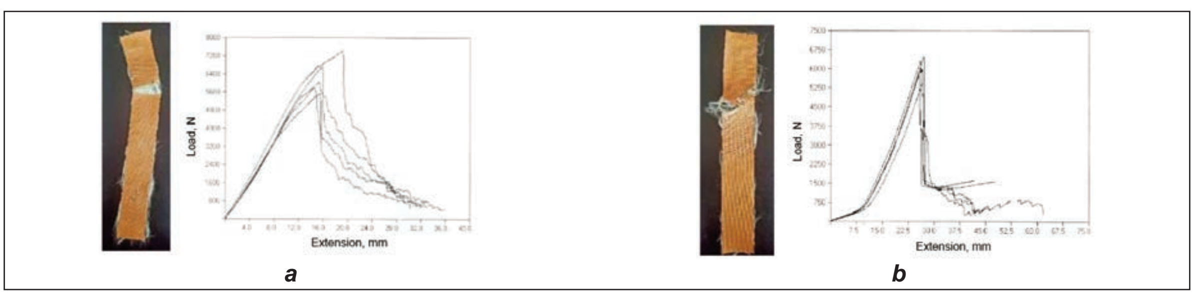


Fig. 9. Maximum breaking force by strip specimen method and corresponding stress-elongation diagrams for fabric 80% p-aramid / 20% PES: *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

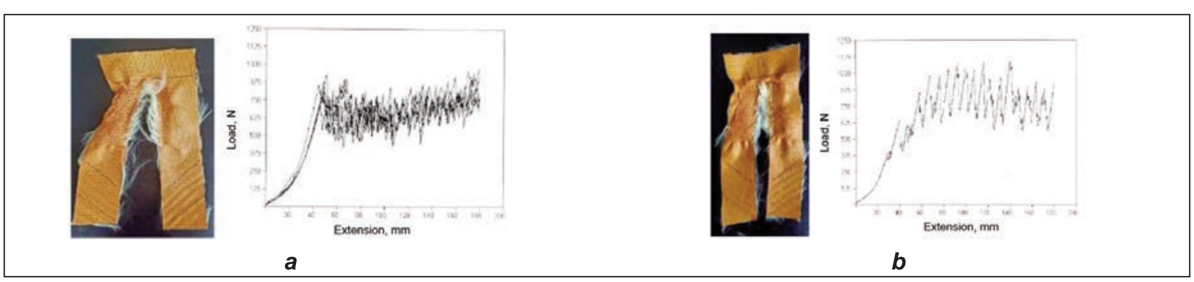


Fig. 10. Maximum tear force of specimens (wing-shaped) and corresponding stress-elongation diagrams for fabric 80% p-aramid / 20% PES: *a* – testing in the warp direction (U); *b* – testing in the weft direction (B)

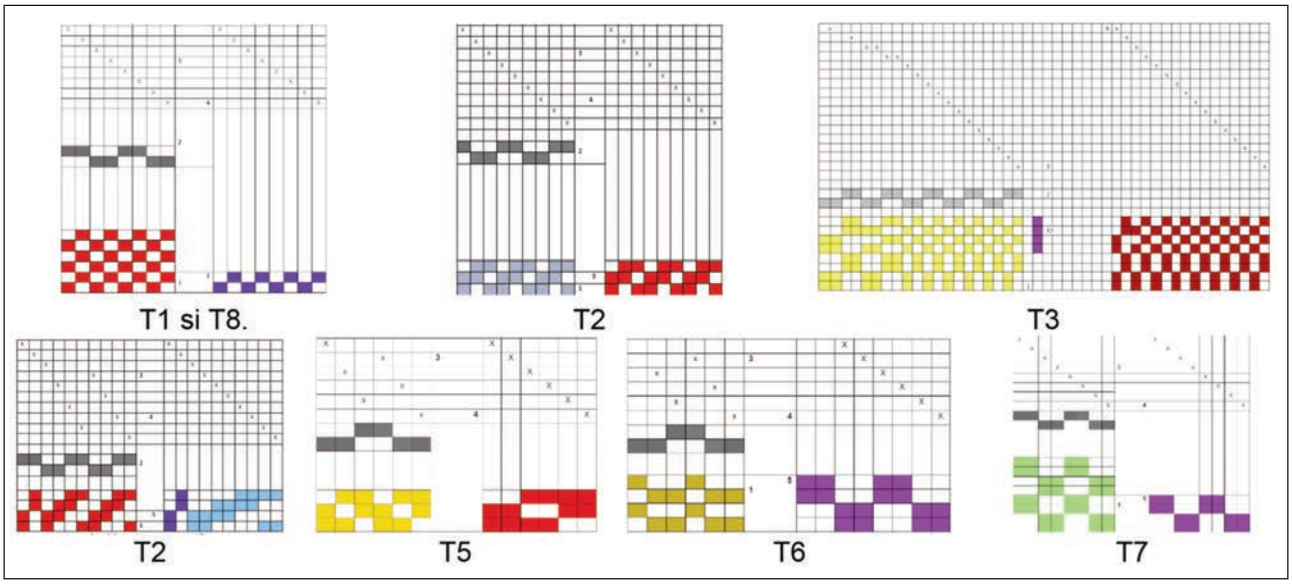


Fig. 11. Programming schemes of woven structures T1 – T8:
1 – weave; *2* – reed; *3* – drawing-in; *4* – sinker command; *5* – pattern card

Programming schemes for textile structures

Experiments carried out in INCDTP-accredited laboratories, as well as the experience of specialists in the design of technical textile structures for special applications have shown that the realization of textile supports used as matrices for composite materials used in the construction of collapsible multi-roller aerial modules for fire and soil drought and of flow arresters, specific structures are used for textile articles with special uses, for which the programming schemes are defined according to figure 11.

CAD for the functional model of a multi-roll collapsible aerial module for soil drought

The digital design carried out by INCDTP specialists, based on the results obtained from the tests and experiments carried out (used as input data), allowed the CAD, with the help of a specialised program, to create the functional model of the collapsible multi-roll aerial module for pedological drought. The CAD model obtained (at $t=0$) for the collapsible aerial module for soil drought is shown in figure 12 (Sketcher and Part Design).
The theoretical foundation of the construction of this type of aerial module was based on the theories of Fluid Mechanics, which allowed the use of the following working hypotheses:

a) the environment is continuous for all the situations taken into account, i.e. the mass distribution is considered to be continuous in the occupied volume, from a mathematical point of view, it is considered to be continuous;
b) the infinitesimal internal forces in the medium are considered to be statistical averages of the interaction forces between the constituent elements, the effect of the static average being independent of the individual state of the constituent elements (solid, in the case of the collapsible multi-roll air module for soil drought);
c) dA (area) was considered a (sufficiently small) size on which the force dF acts, which does not depend on the individual state of the elements in dA;
d) the environment is loaded with concentrated forces Fi and distributed loads pi, and the external loads give rise to internal forces, hence stresses;
e) the stress vector (defined as mean values) is defined as $t = \dfrac{\Delta F}{\Delta A}$ and decomposes into a normal

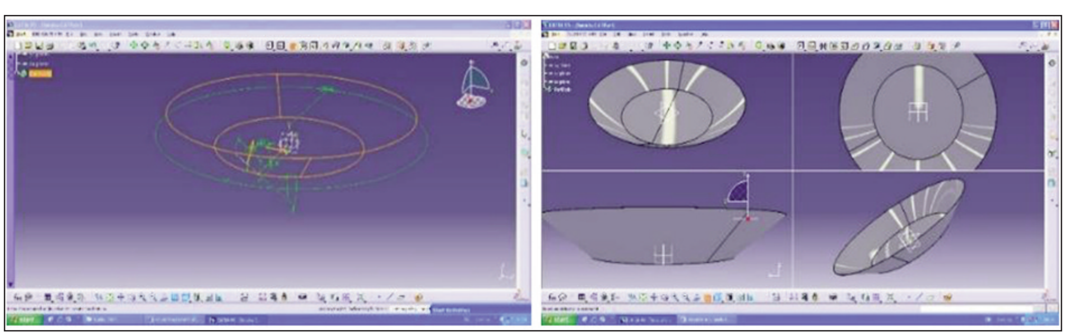


Fig. 12. Digital solution for collapsible aerial mode for soil drought at time $t=0$

component $-\sigma$ and a shear component tangent to the surface τ, these (τ_{xy}, τ_{xz}, τ_{yx}, τ_{yz}, τ_{zx}, τ_{zy}) all not being independent;

f) the stress tensor is of the form:

$$\sigma = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{bmatrix}$$

g) the stress state at a point is defined by equilibrium conditions of the form:

$$\sigma_x \mathrm{d}yt - \tau_{yx} \mathrm{d}xt + \left(\sigma_x + \frac{\delta\sigma_x}{\delta x}\mathrm{d}x\right)\mathrm{d}yt +$$

$$+ \left(\tau_{yx} + \frac{\delta\sigma_{yx}}{\delta y}\mathrm{d}y\right)\mathrm{d}xt + f_x \mathrm{d}x\,\mathrm{d}t = 0$$

$$\frac{\delta\sigma_x}{\delta x} + \frac{\delta\tau_{yx}}{\delta x} + f_x = 0; \quad \frac{\delta\sigma_y}{\delta y} + \frac{\delta\tau_{xy}}{\delta x} + f_y = 0$$

or three-dimensional (for FEM simulation):

$$\frac{\delta\sigma_x}{\delta x} + \frac{\delta\tau_{yx}}{\delta y} + \frac{\delta\tau_{zx}}{\delta z} + f_x = 0;$$

$$\frac{\delta\tau_{xy}}{\delta x} + \frac{\delta\sigma_y}{\delta y} + \frac{\delta\tau_{zy}}{\delta z} + f_y = 0;$$

$$\frac{\delta\tau_{xz}}{\delta x} + \frac{\delta\tau_{yz}}{\delta y} + \frac{\delta\sigma_z}{\delta z} + f_z = 0;$$

h) the variation of stress around an isolated point is demonstrated using a tetrahedron with rectangular surface vectors $\vec{\imath}$, $\vec{\jmath}$, $\vec{k}$ of the axis system;

i) the balance of elementary forces in each direction is:

$$\overline{p_x} = \sigma_x \vec{\imath} + \tau_{xy} \vec{\jmath} + \tau_{xz} \vec{k}$$

$$\overline{p_y} = \tau_{yx} \vec{\imath} + \sigma_y \vec{\jmath} + \tau_{yz} \vec{k}$$

$$\overline{p_z} = \tau_{zx} \vec{\imath} + \tau_{zy} \vec{\jmath} + \sigma_y \vec{k}$$

j) the Von Mises criterion (for the interpretation of the Gauss solutions resulting from the simulation) means the probability of occurrence of cracks at the level of the contact of the structure with the fluid) and from a mathematical point of view, represents the square root of the second invariant of the stress tensor, i.e. in Cartesian form:

$$J_2 = \tau_{zy}^2 + \tau_{xz}^2 + \tau_{xy}^2 + \frac{1}{6}\left[(\tau_{yy} - \tau_{zz})^2 + (\tau_{zz} - \tau_{yy})^2\right]$$

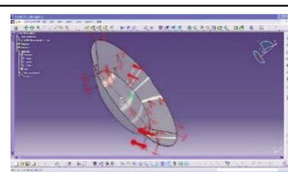
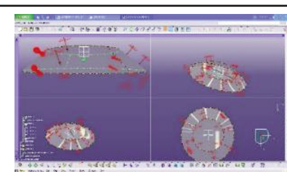
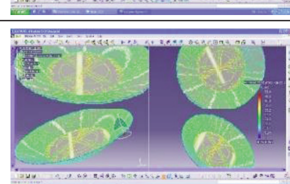
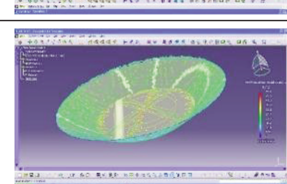
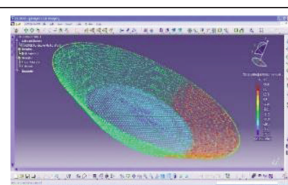
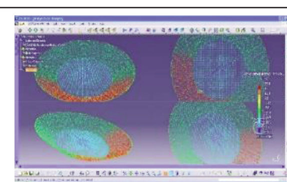
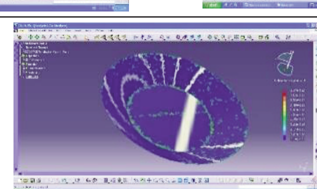
k) input for each product considered – represented by: the system of units, the reference system, the geometry of the structure, the material from which the structure is to be made, the type of element for discretising the structure, the type of analysis to be performed, the conditions on the contour (pre-processing stage).

l) the idealisation of the contour was made possible with the help of the sketcher application of the integrated system. The shape of the 2D element that will be the starting point for the 3D model to be subjected to structural analysis, the dimensional constraints, and the 2D and 3D geometries (Part Design) were customised.

RESULTS AND DISCUSSIONS

With the Generative Structural Analysis module, it was possible to generate the finite element structure

Table 2

STRUCTURAL ANALYSIS		
Studied situation	**Visuals**	
View constraints, stresses, and loads		
Von Mises stress (nodal values): [0, 65.2] N_m2		
Stress principal tensor: [–41.8; 25.8] N_m2		
Errors: [2.14e–017; 1.07e–012] J		

in two steps, namely: discretisation and introduction of finite element properties. The FEM model solution created for the MF was done with the help of specialised software. Post-processing allowed visualisation of the results for 3 distinct situations, respectively:

- A. For the situation where the MF has a 5000 kg mass load, $t_0 = 0$ s;
- B. In case MF has deployed a part of the load and has 2000 kg left, $t_1 = t_0 + \varepsilon$ s;
- C. For the situation where MF is empty, $t_2 = t_0 + \varepsilon + \gamma$ s.

The solver included in the program enabled the structural analysis program, which revealed the following: nodal values (Von Mises), principal stress vector, and errors (table 2 for the most difficult situation, i.e. where MF has a 5000 kg mass load, la $t_0 = 0$ s). The stress state (possible cracks) at the contact level of the composite structure with the fluid was predicted using the Von Mises criterion explained above.

CONCLUSIONS

The stress state in the system (possible cracks) likely to occur at the contact of the composite structure with turbulent moving air was predicted using the Von Mises criterion, according to which the solid body boundary state occurs when the shape-modifying specific potential energy reaches the material's characteristic boundary value.

For the composite material from which the collapsible multi-roll module for soil drought is made, a permissible resistance of the order of +009N_m2 is required.

ACKNOWLEDGMENTS

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Infrared thermography used for handball footwear heat detection during the training

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ABSTRACT – REZUMAT

Infrared thermography used for handball footwear heat detection during the training

The purpose of this paper is to present an experimental thermal transfer analysis of sports footwear to identify the areas that ensure the best foot ventilation for comfort and performance in training sessions. The measurements were performed on seven athletes (subjects) during a handball training session, wearing the same footwear that the handballers typically use for indoor sports. The thermographic recordings were made during training at five different times: moment zero (before the start of training), moment one (2 minutes of training), moment two (5 minutes of training), moment three (15 minutes of training), and moment four (at the end of the handball training session). For the other three subjects, although they have different models of the same sports footwear, the analysis of the thermal distribution values shows that they are within the minimum and maximum limits of the four subjects analysed in the paper. Based on the thermographic values recorded, a mathematical model was determined using polynomial regression in Matlab to predict temperature values outside the range of the experimental data. In the present paper, research was carried out in order to identify the thermal transfer of indoor sports shoes used in handball training so as to detect the heat exchange between the foot and the outdoor environment. Thermography can be a valuable tool for manufacturers to evaluate the effectiveness of a shoe's insulation and ventilation systems. By using thermography, manufacturers can assess how well the footwear regulates temperature and moisture, which are crucial factors in maintaining comfort and performance for athletes, particularly in a high-intensity sport like handball.

Keywords: *thermal imaging, Flir ResearchIR Max, heat transfer, indoor sports*

Termografie în infraroșu utilizată pentru detectarea căldurii încălțămintei de handbal în timpul antrenamentului

Scopul acestei lucrări este de a prezenta o analiză experimentală a transferului termic al încălțămintei sportive pentru a identifica zonele care asigură cea mai bună ventilație a piciorului pentru confort și performanță în sesiunea de antrenament. Măsurătorile au fost efectuate pe șapte sportivi (subiecți) în cadrul unei sesiuni de antrenament de handbal, purtând aceeași încălțăminte de handbal utilizată pentru sporturile de sală. Înregistrările termografice au fost efectuate în timpul antrenamentului în cinci momente diferite: momentul zero (înainte de începerea antrenamentului), momentul unu (2 minute de antrenament), momentul doi (5 minute de antrenament), momentul trei (15 minute de antrenament) și momentul patru (la sfârșitul sesiunii de antrenament la handbal). Pentru ceilalți trei subiecți, deși au modele diferite ale aceleiași încălțăminte sport, analiza valorilor distribuției termice arată că acestea se încadrează în limitele minime și maxime ale celor patru subiecți analizați în lucrare. Pe baza valorilor de înregistrare termografică obținute, a fost determinat un model matematic folosind regresia polinomială în Matlab pentru a prezice valorile de temperatură din afara intervalului datelor experimentale. În lucrarea de față, cercetarea a fost efectuată cu scopul de a identifica transferul termic al pantofilor sport de interior utilizați în antrenamentele de handbal, astfel încât să se detecteze schimbul de căldură dintre picior și mediul exterior. Termografia poate fi un instrument valoros pentru producători, pentru a evalua eficiența sistemelor de izolare și de ventilație ale unui pantof. Prin utilizarea termografiei, producătorii pot evalua cât de bine reglează încălțămintea temperatura și umiditatea, care sunt factorii esențiali în menținerea confortului și performanței sportivilor, în special într-un sport de intensitate ridicată precum handbalul.

Cuvinte-cheie: *imagistică termică, Flir ResearchIR Max, transfer de căldură, sporturi de interior*

INTRODUCTION

Research on using infrared thermography for handball footwear heat detection during training is limited, but there are some studies that have explored the use of this technique in other sports and activities [1, 2]. Infrared thermography is a quick and easy technique to implement, requiring only a thermal imaging camera and a trained operator. By regularly monitoring the heat generated within handball footwear during training sessions, coaches and athletes can proactively address issues before they become more serious problems. One study published at an international level investigated the use of infrared thermography to monitor foot temperature changes in runners during a marathon. The researchers found that infrared thermography was a reliable and effective method for detecting variations in foot temperature, which could help identify potential injury risks and inform training strategies. Another work has focused on enhancing the thermal container and physiological comfort of athletes through thermographic evaluation of sportswear materials [3–6]. In the case of handball footwear, thermography can be used to analyse the heat distribution inside the shoe during physical activity.

Thermography can provide real-time data on temperature distribution inside the shoe, allowing manufacturers to identify any areas of potential heat build-up or poor ventilation. This information can help them make informed design decisions to optimise the shoe's performance and comfort. By using thermography in handball footwear, manufacturers can assess the effectiveness of the shoe's insulation and ventilation systems. This technology can help identify hot spots or areas of discomfort within the shoe, allowing for modifications to improve overall comfort and performance. This information can help designers create more efficient and comfortable footwear for handball players. Numerous studies have explored the intersection of sustainability and footwear, emphasising the importance of sustainability in the design, production, and end-of-life management of sports footwear. This research highlights the potential benefits of adopting sustainable materials, processes, and practices in handball footwear to minimise environmental impact and promote long-term sustainability within the sports industry [7–9]. As regards the material used in the assembly of the sports footwear presented in this work, this is a knitted textile material. The knitted textile material is made from a structure with retained links and loop deposition, made of a poly filament yarn, 100% PES, made on a 14''E fineness knitting machine. The knitted material has 12 links in the row direction (horizontal) and 12 rows in the string direction (vertical) /1 cm. Weight 0.651 g/1 cm^2. Characteristics include wear resistance, high elasticity. By integrating sustainable and technologically advanced materials in the design of handball footwear, it is possible to improve both performance and comfort while reducing the environmental footprint of sports equipment [10, 11].

MATERIALS AND METHODS

Experimental research on footwear temperature according to the journal format

While there is limited research specifically focused on infrared thermography in handball footwear, these studies suggest that infrared thermography can be a valuable tool for monitoring foot temperature changes during training sessions in various sports. Further research specifically focused on handball footwear and players could provide valuable insights into the potential benefits of using infrared thermography in this context. Thermography measurements were conducted at the University Sports Club in Oradea using the FLIR SC 640 thermal imaging camera, a portable thermographic scanning device with the most powerful IR detector available, a resolution of 640 × 480 pixels, and an exceptional thermal sensitivity of <0.04°C. The thermal imaging camera featured in figure 1 includes a laser pointer, a germanium lens, an SD card, a USB, and a video connector for enhanced functionality.

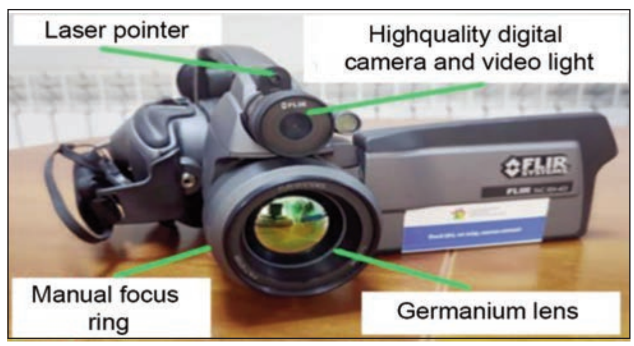

Fig. 1. Thermal imaging camera FLIR SC 640 components

a *b*

Fig. 2. IR and real spectrum image of the seven subjects: *a* – infrared image; *b* – real image

Fig. 3. Footwear image for footwear type A used for indoor sports

The data presented in this study is significant as it showcases the minimum and maximum thermal distribution values of footwear type A for indoor sports, selected as the most representative for the seven subjects involved in handball training analysis. Analysis of the other 3 subjects, although having different models of the same sports footwear, shows that the thermal distribution values are within the minimum and maximum limits of the seven subjects analysed in the paper. In this research work, thermography measurements were performed as the most representative four athletes (subjects) were selected from the seven subjects analysed, as shown in figure 2, who have worn sports footwear type A shown in figure 3 (subjects 1, 2, 3 and 4) in a handball training session. Based on the temperature distribution value for handball footwear, we used the polyfit function in Matlab to predict temperature values outside the range based on the mathematical model determined from the experimental data using polynomial regression [12–14].

RESULTS AND DISCUSSION

Thermographic scans were conducted on athletic footwear at five distinct intervals: moment zero (before training commencement), moment one at 2 minutes into training, moment two at 5 minutes into training, moment three at 15 minutes into training, and moment four at the completion/end of handball training. The purpose of these scans was to pinpoint the regions that promote optimal foot ventilation to enhance comfort during physical activity. As shown in figure 4 of the left foot of subject 1 at time zero (before the start of handball training), the maximum temperature along the line Li1, positioned on the central part of the foot, is 27.1°C, and the minimum temperature is 24.2°C. The temperature variation along the Li1 line is 2.9°C, and the emissivity is 0.83, at time zero for subject 1. On the side along the Li2 line, the maximum temperature is 28.3°C, and the minimum temperature is 24.5°C, at time zero for subject 1. The temperature variation along the Li2 line is 3.8°C, and the emissivity is 0.83 at time zero for subject 1. As shown in figure 4 for the left foot of subject 1 at time one (before the start of handball training), the maximum temperature along the line Li3, positioned on the central part of the foot, is 27.4°C, and the minimum temperature is 25.6°C. The temperature variation along the Li3 line is 1.8°C, and the emissivity is 0.83, at time zero for subject 1. On the side along the Li4 line, the maximum temperature is 28.0°C, and the minimum temperature is 25.3°C, at time zero for subject 1. The temperature variation along the Li4 line is 2.7°C, and the emissivity is 0.83 at time zero for subject 1.

In figure 4, for the right foot of subject 2 at time zero (before the start of handball training), the maximum temperature along the line Li5, positioned on the central part of the leg, is 28.6°C, and the minimum temperature is 25.2°C. The temperature variation along the Li5 line is 3.4°C, and the emissivity is 0.83, at time zero for subject 2. On the side along the Li6 line, the maximum temperature is 28.5°C, and the minimum temperature is 25.0°C, at time zero for subject 2. The temperature variation along the line Li6 is 3.5°C, and the emissivity is 0.83, at time zero for subject 2.

For the left foot of subject 2 at time zero, the maximum temperature along the Li7 line positioned on the central side is 27.4°C, and the minimum temperature is 24.9°C. The temperature variation along the Li7 line is 2.5°C, and the emissivity is 0.83, at time zero for subject 2. On the side along the Li8 line, the maximum temperature is 28.8°C, and the minimum temperature is 25.9°C, at time zero for subject 2. The temperature variation along the line Li8 is 2.9°C, and the emissivity is 0.83, at time zero for subject 2. Thermography measurements for subject 3 for the left foot at time zero (before starting the handball training) show that the maximum temperature along the Li9 line, positioned at the centre of the foot, is 27.5°C, and the minimum temperature is 24.6°C. The temperature variation along the Li9 line is 2.9°C, and the emissivity is 0.95, at time zero for subject 3. On the side along the Li10 line, the maximum temperature is 28.7°C, and the minimum temperature is 25.2°C, at moment zero for subject 3. The temperature variation along the Li10 line is 3.5°C, and the emissivity is 0.83, at moment zero for subject 3. For the right foot of subject 3 at time zero, the maximum temperature along the Li11 line positioned on the central side is 28.3°C, and the minimum temperature

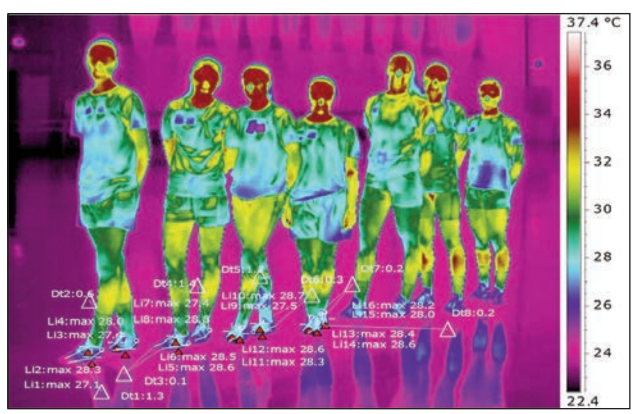

Fig. 4. Variation of sports footwear type A temperature at time zero in the 4 subjects in the infrared

is 25.4°C. The temperature variation along the Li11 line is 2.9°C, and the emissivity is 0.83, at time zero for subject 3. On the side along the Li12 line, the maximum temperature is 28.6°C, and the minimum temperature is 27.0°C, at time zero for subject 3. The temperature variation along the line Li12 is 1.6°C, and the emissivity is 0.83, at time zero for subject 3. In figure 4, for the right foot of subject 4 at time zero (before starting the handball training), the maximum temperature along the Li13 line, positioned at the centre of the foot, is 28.4°C, and the minimum temperature is 25.4°C. The temperature variation along the Li13 line is 3.0°C, and the emissivity is 0.83, at time zero for subject 4. On the side along the Li14 line, the maximum temperature is 28.6°C, and the minimum temperature is 25.7°C, at time zero for subject 4. The temperature variation along the line is 2.9°C, and the emissivity is 0.83, at time zero for subject 4. For the left foot of subject 4 at time zero, the maximum temperature along the Li15 line positioned on the central side is 28.0°C, and the minimum temperature is 26.2°C. The temperature variation along the Li15 line is 1.8°C, and the emissivity is 0.83, at time zero for subject 4. On the side along the Li16 line, the maximum temperature is 28.2°C, and the minimum temperature is 26.5°C, at time zero for subject 4. The temperature variation along the line Li16 is 1.7°C, and the emissivity is 0.83, at time zero for subject 4. The graphs realised with the help of Matlab presented in figure 5 show the measured temperature variation along the lines afferent to subject 1, subject 2, subject 3 and subject 4 on each footwear at time zero and approximation curves realised by polynomials of 4th degree.

In the case of subject 1 at time zero, as shown in figure 5, *a*, the relation obtained is a polynomial function of degree four (equation 1).

$$y = 0.005547x4 - 0.6184x3 + 25.67x2 - 469.9x + 3224 \quad (1)$$

The R-squared value of the model is 0.9099, indicating that approximately 90.99% of the variance in the data is explained by the model. In the case of subject 2 at time zero, as shown in figure 5, *b*, the relation obtained is a polynomial function of degree four (equation 2).

$$y = 0.02032x4 - 2.234x3 + 91.59x2 - 1660x + 11250 \quad (2)$$

The R-squared value of the model is 0.9022, indicating that approximately 90.22% of the variance in the data is explained by the model. In the case of subject 3 at time zero, as shown in figure 5, *c*, the relation obtained is a polynomial function of degree four (equation 3).

$$y = 0.00638x4 - 0.7086x3 + 29.31x2 - 534.5x + 3651 \quad (3)$$

The R-squared value of the model is 0.9727, indicating that approximately 97.27% of the variance in the data is explained by the model. In the case of subject 4 at time zero, as shown in figure 5, *d*, the relation obtained is a polynomial function of degree four (equation 4).

$$y = 0.008946x4 - 0.9873x3 + 40.62x2 - 737.7x + 5015 \quad (4)$$

The R-squared value of the model is 0.9274, indicating that approximately 92.74% of the variance in the

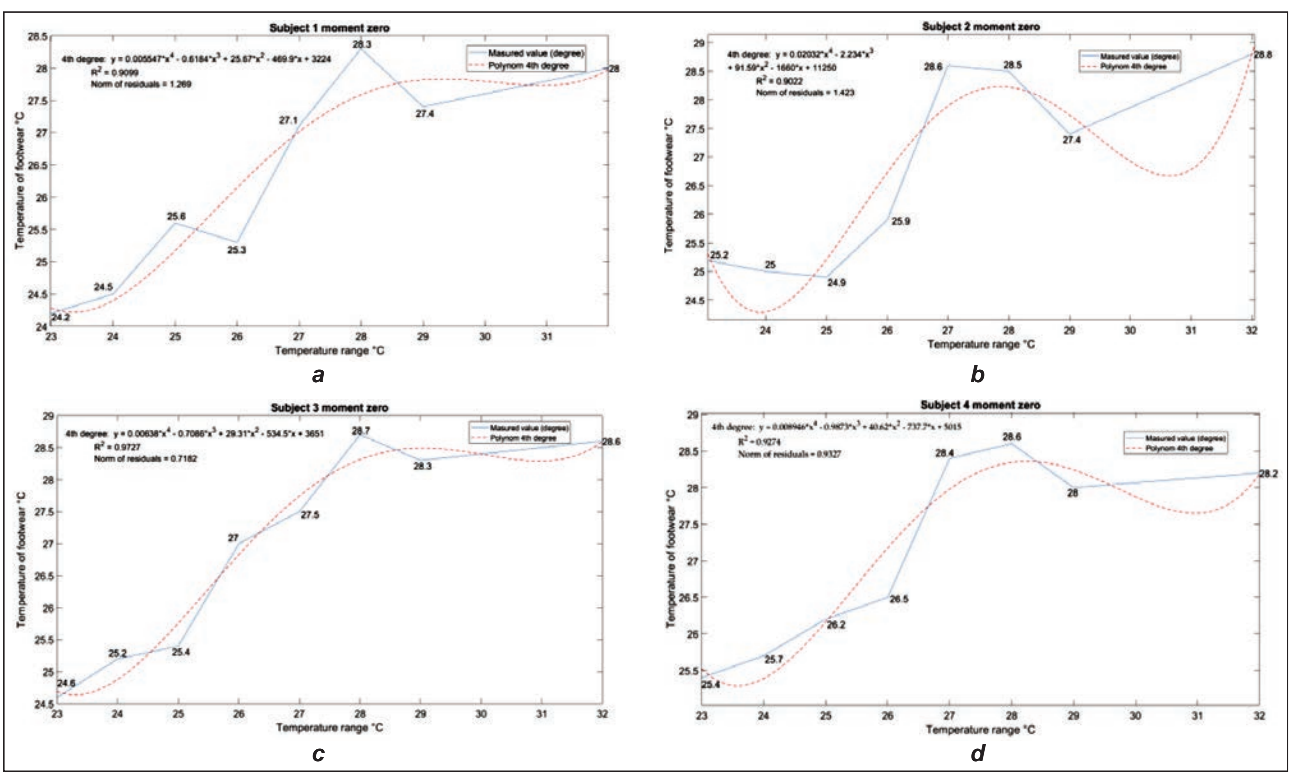

Fig. 5. Temperature variation on sports footwear type A for: *a* – subject 1 at time zero; *b* – subject 2 at time zero; *c* – subject 3 at time zero; *d* – subject 4 at time zero

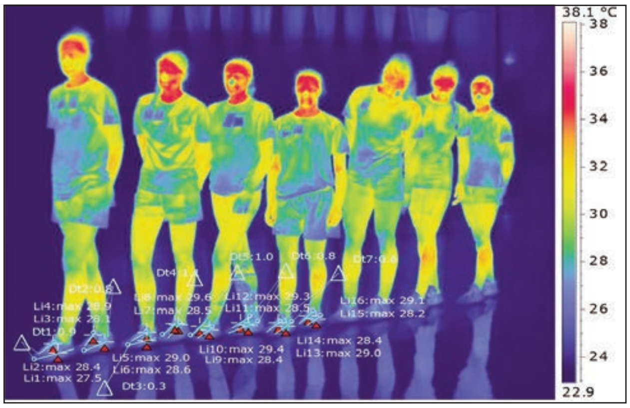

Fig. 6. Variation of sports footwear type A temperature at time one on the 4 subjects in the infrared

data is explained by the model. As shown in figure 6 for the left foot of subject 1 at time one (two minutes of training), the maximum temperature along the line Li1, positioned on the central part of the foot, is 27.5°C, and the minimum temperature is 24.0°C. The temperature variation along the Li1 line is 3.5°C, and the emissivity is 0.83, at time one for subject 1. On the side along the Li2 line, the maximum temperature is 28.4°C, and the minimum temperature is 25.3°C, at time one for subject 1. The temperature variation along the Li2 line is 3.1°C, and the emissivity is 0.83 at time one for subject 1.

As shown in figure 6 for the right foot of subject 1 at time one (two minutes of training), the maximum temperature along the line Li3, positioned on the central part of the foot, is 28.1°C, and the minimum temperature is 24.7°C. The temperature variation along the Li3 line is 3.4°C, and the emissivity is 0.83, at time one for subject 1. On the side along the Li4 line, the maximum temperature is 28.9°C, and the minimum temperature is 25.6°C, at time one for subject 1. The temperature variation along the Li4 line is 3.2°C, and the emissivity is 0.83 at time one for subject 1. In figure 6, for the right foot of subject 2 at time one (two minutes of training), the maximum temperature along the line Li5, which is positioned on the central part of the leg, is 29.0°C, and the minimum temperature is 24.9°C. The temperature variation along the Li5 line is 4.0°C, and the emissivity is 0.83, at time one for subject 2. On the side along the Li6 line, the maximum temperature is 28.6°C, and the minimum temperature is 25.5°C, at time one for subject 2. The temperature variation along the line Li6 is 3.1°C, and the emissivity is 0.83, at time one for subject 2. For the left foot of subject 2 at time one, the maximum temperature along the Li7 line positioned on the central side is 28.5°C, and the minimum temperature is 25.1°C. The temperature variation along the Li7 line is 3.5°C, and the emissivity is 0.83, at time one for subject 2. On the side along the Li8 line, the maximum temperature is 29.6°C, and the minimum temperature is 26.2°C, at time one for subject 2. The temperature variation along the line Li8 is 3.4°C, and the emissivity is 0.83, at time one for subject 2. Thermography measurements for subject 3 for the left foot at time one (two minutes of training) show that the maximum temperature along the Li9 line, which is positioned at the centre of the foot, is 28.4°C, and the minimum temperature is 25.0°C. The temperature variation along the Li9 line is 3.4°C, and the emissivity is 0.83, at time one for subject 3. On the side along the Li10 line, the maximum temperature is 29.4°C, and the minimum temperature is 24.9°C, at moment one for subject 3. The temperature variation along the Li10 line is 4.5°C, and the emissivity is 0.83, at moment one for subject 3. For the right foot of subject 3 at time one, the maximum temperature along the Li11 line positioned on the central side is 28.5°C, and the minimum temperature is 24.7°C. The temperature variation along the Li11 line is 3.8°C, and the emissivity is 0.83, at time one for subject 3. On the side along the Li12 line, the maximum temperature is 29.3°C, and the minimum temperature is 25.3°C, at time one for subject 3. The temperature variation along the line Li12 is 3.9°C, and the emissivity is 0.83, at time one for subject 3.

In figure 7, for the right foot of subject 4 at time one (two minutes of training), the maximum temperature along the Li13 line, positioned at the centre of the foot, is 29.0°C, and the minimum temperature is 24.9°C. The temperature variation along the Li13 line is 4.1°C, and the emissivity is 0.83, at time one for subject 4. On the side along the Li14 line, the maximum temperature is 28.4°C, and the minimum temperature is 24.3°C, at time one for subject 4. The temperature variation along the line is 4.1°C, and the emissivity is 0.83, at time one for subject 4. For the left foot of subject 4 at time one, the maximum temperature along the Li15 line positioned on the central side is 28.2°C, and the minimum temperature is 25.1°C. The temperature variation along the Li15 line is 3.1°C, and the emissivity is 0.83, at time one for subject 4. On the side along the Li16 line, the maximum temperature is 29.1°C, and the minimum temperature is 25.3°C, at time one for subject 4. The temperature variation along the line Li16 is 3.8°C, and the emissivity is 0.83, at time one for subject 4

The graphs realised with the help of Matlab presented in figure 7 show the measured temperature variation along the lines afferent to subjects 1, subject 2, subject 3 and subject 4 on each footwear at time one and approximation curves realised by polynomials of 4th degree.

In the case of subject 1 at time one, as shown in figure 7, *a*, the relation obtained is a polynomial function of degree four (equation 5).

$$y = 0.002347x4 - 0.2734x3 + 11.81x2 - \\ - 223.7x + 1592 \quad (5)$$

The R-squared value of the model is 0.9253, indicating that approximately 92.53% of the variance in the data is explained by the model.

In the case of subject 2 at time one, as shown in figure 7, *b*, the relation obtained is a polynomial function of degree four (equation 6).

$$y = 0.01235x4 - 1.364x3 + 56.18x2 - 1022x + 6957 \quad (6)$$

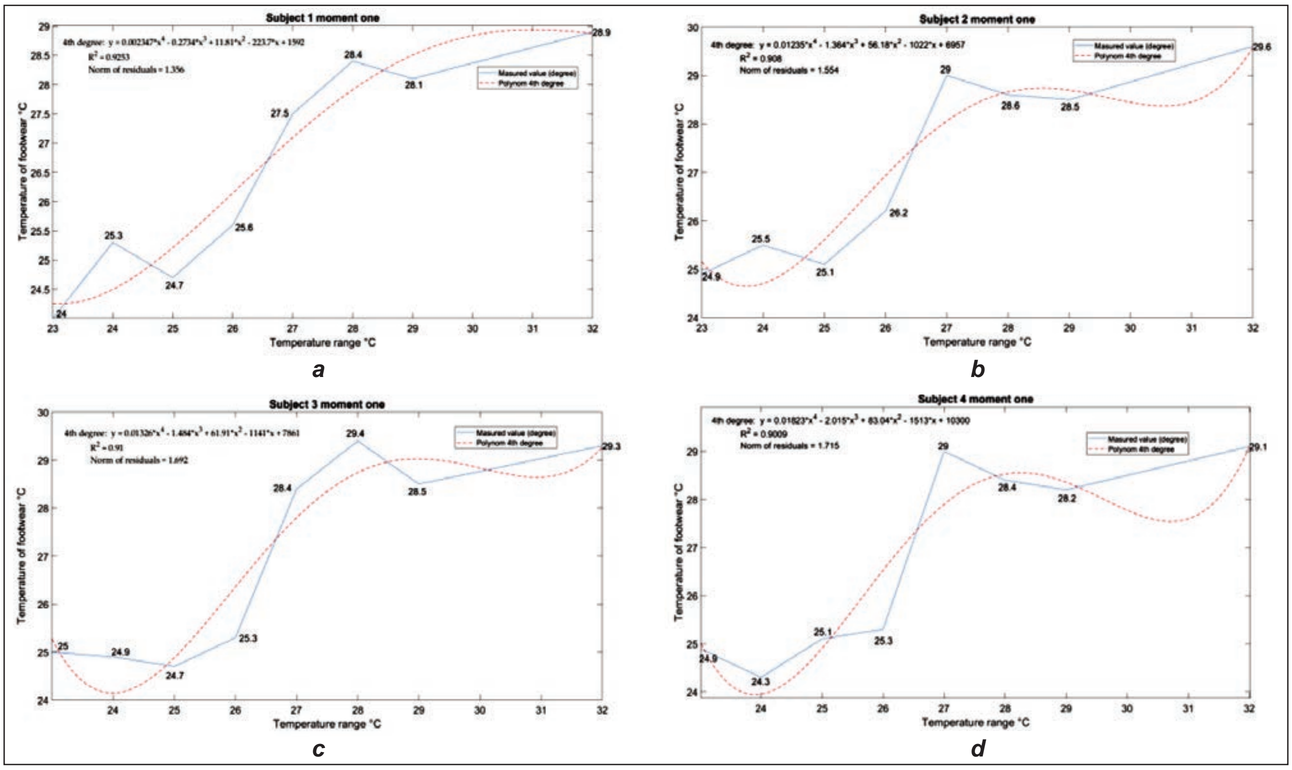

Fig. 7. Temperature variation on sports footwear type A for: *a* – subject 1 at time one; *b* – subject 2 at time one; *c* – subject 3 at time one; *d* – subject 4 at time one

The R-squared value of the model is 0.908, indicating that approximately 90.8% of the variance in the data is explained by the model.

In the case of subject 3 at time one, as shown in figure 7, *c*, the relation obtained is a polynomial function of degree four (equation 7).

$$y = 0.01326x4 - 1.484x3 + 61.91x2 - 1141x + 7861 \quad (7)$$

The R-squared value of the model is 0.91, indicating that approximately 91% of the variance in the data is explained by the model. In the case of subject 4 at time one, as shown in figure 7, *d*, the relation obtained is a polynomial function of degree four (equation 8).

$$y = 0.01823x4 - 2.015x3 + 83.04x2 - 1513x + 10300 \quad (8)$$

The R-squared value of the model is 0.9009, indicating that approximately 90.09% of the variance in the data is explained by the model.

As shown in figure 8 for the left foot of subject 1 at time two (five minutes of handball training), the maximum temperature along the line Li1, which is positioned on the central part of the foot, is 27.5°C, and the minimum temperature is 24.3°C. The temperature variation along the Li1 line is 3.2°C, and the emissivity is 0.81, at time two for subject 1. On the side along the Li2 line, the maximum temperature is 28.7°C, and the minimum temperature is 23.7°C, at time two for subject 1. The temperature variation along the Li2 line is 5.0°C, and the emissivity is 0.81 at time two for subject 1.

As shown in figure 8 for the right foot of subject 1 at time two (five minutes of handball training), the maximum temperature along the line Li3, which is positioned on the central part of the foot, is 28.3°C, and the minimum temperature is 25.2°C. The temperature variation along the Li3 line is 3.1°C, and the emissivity is 0.81, at time two for subject 1. On the side along the Li4 line, the maximum temperature is 29.4°C, and the minimum temperature is 25.4°C, at time two for subject 1. The temperature variation along the Li4 line is 4.0 °C, and the emissivity is 0.81 at time two for subject 1. In figure 8, for the right foot of subject 2 at time two (five minutes of handball training), the maximum temperature along the line Li5, positioned on the central part of the leg, is 29.3°C, and the minimum temperature is 25.5°C. The temperature variation along the Li5 line is 3.8°C, and the emissivity is 0.81, at time two for subject 2. On the side along the Li6 line, the maximum temperature is 29.0°C, and the minimum temperature is 24.9°C, at time two for subject 2. The temperature variation along the line Li6 is 4.0°C, and the emissivity is 0.81, at time two for subject 2. For the left foot of subject 2 at time two, the maximum temperature along the Li7 line positioned on the central side is 28.6°C, and the minimum temperature is 24.3°C. The temperature variation along the Li7 line is 4.3°C, and the emissivity is 0.81, at time two for subject 2. On the side along the Li8 line, the maximum temperature is 29.7°C, and the minimum temperature is 26.4°C, at time two for subject 2. The temperature variation along the line Li8 is 3.3°C, and the emissivity is 0.81, at time two for subject 2. Thermography measurements for subject 3 for the left foot at time two (five minutes of handball

training) show that the maximum temperature along the Li9 line, which is positioned at the centre of the foot, is 28.6°C, and the minimum temperature is 25.3°C. The temperature variation along the Li9 line is 3.3°C, and the emissivity is 0.81, at time two for subject 3. On the side along the Li10 line, the maximum temperature is 30.2°C, and the minimum temperature is 26.2°C, at moment two for subject 3. The temperature variation along the Li10 line is 4.0°C, and the emissivity is 0.81, at moment two for subject 3. For the right foot of subject 3 at time two, the maximum temperature along the Li11 line positioned on the central side is 28.9°C, and the minimum temperature is 27.1°C. The temperature variation along the Li11 line is 1.8°C, and the emissivity is 0.81, at time two for subject 3. On the side along the Li12 line, the maximum temperature is 29.6°C, and the minimum temperature is 27.4°C, at time two for subject 3. The temperature variation along the line Li12 is 2.2°C, and the emissivity is 0.81, at time two for subject 3.
In figure 8, for the right foot of subject 4 at time two (five minutes of handball training), the maximum temperature along the Li13 line, positioned at the centre of the foot, is 29.1°C, and the minimum temperature is 26.9°C. The temperature variation along the Li13 line is 2.2°C, and the emissivity is 0.81, at time two for subject 4. On the side along the Li14 line, the maximum temperature is 28.9°C, and the minimum temperature is 24.4°C, at time two for subject 4. The temperature variation along the line is 4.5°C, and the emissivity is 0.81, at time two for subject 4.
For the left foot of subject 4 at time two, the maximum temperature along the Li15 line positioned on the central side is 28.6°C, and the minimum temperature is 25.0°C. The temperature variation along the Li15 line is 3.6°C, and the emissivity is 0.81, at time two for subject 4. On the side along the Li16 line, the maximum temperature is 29.5°C, and the minimum temperature is 25.2°C, at time two for subject 4. The temperature variation along the line Li16 is 4.2°C, and the emissivity is 0.81, at time two for subject 4.

Fig. 8. Variation of sports footwear temperature at time two on the 4 subjects in infrared

The graphs realised with the help of Matlab presented in figure 9 show the measured temperature variation along the lines afferent to subject 1, subject 2, subject 3 and subject 4 on each footwear at time two and approximation curves realised by polynomials of 4th degree.
In the case of subject 1 at time two, as shown in figure 9, *a*, the relation obtained is a polynomial function of degree four (equation 9).

$$y = 0.01126x4 - 1.253x3 + 52x2 - 953x + 6530 \quad (9)$$

The R-squared value of the model is 0.9687, indicating that approximately 96.87% of the variance in the data is explained by the model. In the case of subject 2 at time two, as shown in figure 9, *b*, the relation obtained is a polynomial function of degree four (equation 10).

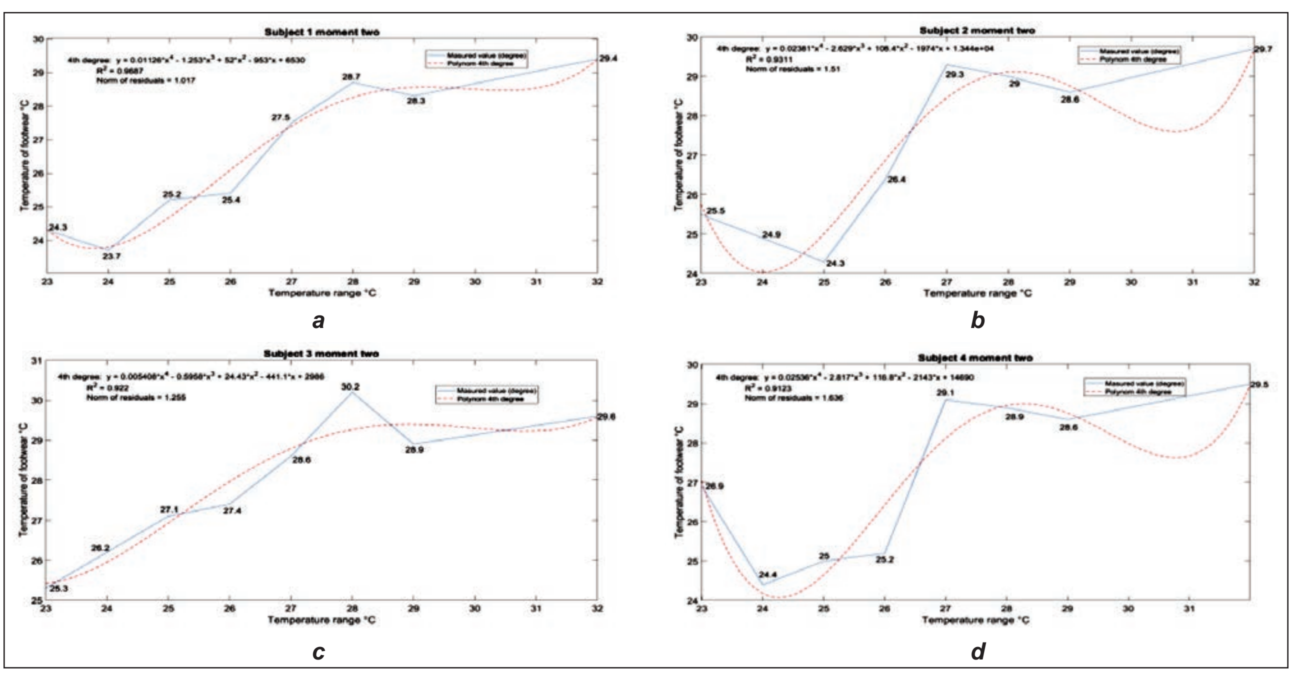

Fig. 9. Temperature variation on sports footwear for: *a* – subject 1 at time two; *b* – subject 2 at time two; *c* – subject 3 at time two; *d* – subject 4 at time two

$$y = 0.02381x4 - 2.629x3 + 108.4x2 - 1974x + 13440 \quad (10)$$

The R-squared value of the model is 0.9311, indicating that approximately 93.11% of the variance in the data is explained by the model. In the case of subject 3 at time two, as shown in figure 9, *c*, the relation obtained is a polynomial function of degree four (equation 11).

$$y = 0.005408x4 - 0.5958x3 + 24.43x2 - 441.1x + 2986 \quad (11)$$

The R-squared value of the model is 0.922, indicating that approximately 92.2% of the variance in the data is explained by the model. In the case of subject 4 at time two, as shown in figure 9, *d*, the relation obtained is a polynomial function of degree four (equation 12).

$$y = 0.02536x4 - 2.817x3 + 116.8x2 - 2143x + 14690 \quad (12)$$

The R-squared value of the model is 0.9123, indicating that approximately 91.23% of the variance in the data is explained by the model.

Fig. 10. Variation of sports footwear type A temperature at time three on the 4 subjects in infrared

As shown in figure 10 for the left foot of subject 1 at time three (15 min of handball training), the maximum temperature along the line Li1, positioned on the central part of the foot, is 30.9°C, and the minimum temperature is 26.5°C. The temperature variation along the Li1 line is 4.4°C, and the emissivity is 0.80, at time three for subject 1. On the side along the Li2 line, the maximum temperature is 30.2°C, and the minimum temperature is 27.7°C, at time three for subject 1. The temperature variation along the Li2 line is 2.5°C, and the emissivity is 0.80 at time three for subject 1.

As shown in figure 10 for the right foot of subject 1 at time three (15 min of handball training), the maximum temperature along the line Li3, which is positioned on the central part of the foot, is 30.4°C, and the minimum temperature is 28.1°C. The temperature variation along the Li3 line is 2.3°C, and the emissivity is 0.80, at time three for subject 1. On the side along the Li4 line, the maximum temperature is 30.7°C, and the minimum temperature is 28.4°C, at time three for subject 1. The temperature variation along the Li4 line is 2.3°C, and the emissivity is 0.80 at time three for subject 1.

In figure 10, for the right foot of subject 2 at time three (15 minutes of handball training), the maximum temperature along the line Li5, which is positioned on the central part of the leg, is 30.6°C, and the minimum temperature is 27.6°C. The temperature variation along the Li5 line is 3.0°C, and the emissivity is 0.80, at time three for subject 2. On the side along the Li6 line, the maximum temperature is 30.3°C, and the minimum temperature is 26.6°C, at time three for subject 2. The temperature variation along the line Li6 is 3.7°C, and the emissivity is 0.80, at time three for subject 2. For the left foot of subject 2 at time three, the maximum temperature along the Li7 line positioned on the central side is 31.7°C, and the minimum temperature is 27.3°C. The temperature variation along the Li7 line is 4.4°C, and the emissivity is 0.80, at time three for subject 2. On the side along the Li8 line, the maximum temperature is 31.2°C, and the minimum temperature is 29.3°C, at time three for subject 2. The temperature variation along the line Li8 is 1.8°C, and the emissivity is 0.80, at time three for subject 2. Thermography measurements for subject 3 for the right foot at time three (15 min of handball training) show that the maximum temperature along the Li9 line, which is positioned at the centre of the foot, is 30.1°C, and the minimum temperature is 26.4°C. The temperature variation along the Li9 line is 3.7°C, and the emissivity is 0.80, at time three for subject 3. On the side along the Li10 line, the maximum temperature is 31.1°C, and the minimum temperature is 26.6°C, at moment three for subject 3. The temperature variation along the Li10 line is 4.5°C, and the emissivity is 0.80, at moment three for subject 3. For the left foot of subject 3 at time three, the maximum temperature along the Li11 line positioned on the central side is 29.7°C, and the minimum temperature is 27.2°C. The temperature variation along the Li11 line is 2.5°C, and the emissivity is 0.80, at time three for subject 3. On the side along the Li12 line, the maximum temperature is 31.0°C, and the minimum temperature is 27.9°C, at time three for subject 3. The temperature variation along the line Li12 is 3.1°C, and the emissivity is 0.80, at time three for subject 3. In figure 10, for the right foot of subject 4 at time three (15 minutes of handball training), the maximum temperature along the Li13 line, which is positioned at the centre of the foot, is 30.5°C, and the minimum temperature is 27.9°C. The temperature variation along the Li13 line is 2.6°C, and the emissivity is 0.80, at time three for subject 4. On the side along the Li14 line, the maximum temperature is 31.0°C, and the minimum temperature is 28.2°C, at time three for subject 4. The temperature variation along the line is 2.7°C, and the emissivity is 0.80, at time three for subject 4. For the left foot of subject 4 at time three, the maximum temperature along the Li15 line positioned on the central side is 29.9°C, and the minimum temperature is 28.3°C. The temperature variation along the Li15 line is 1.6°C,

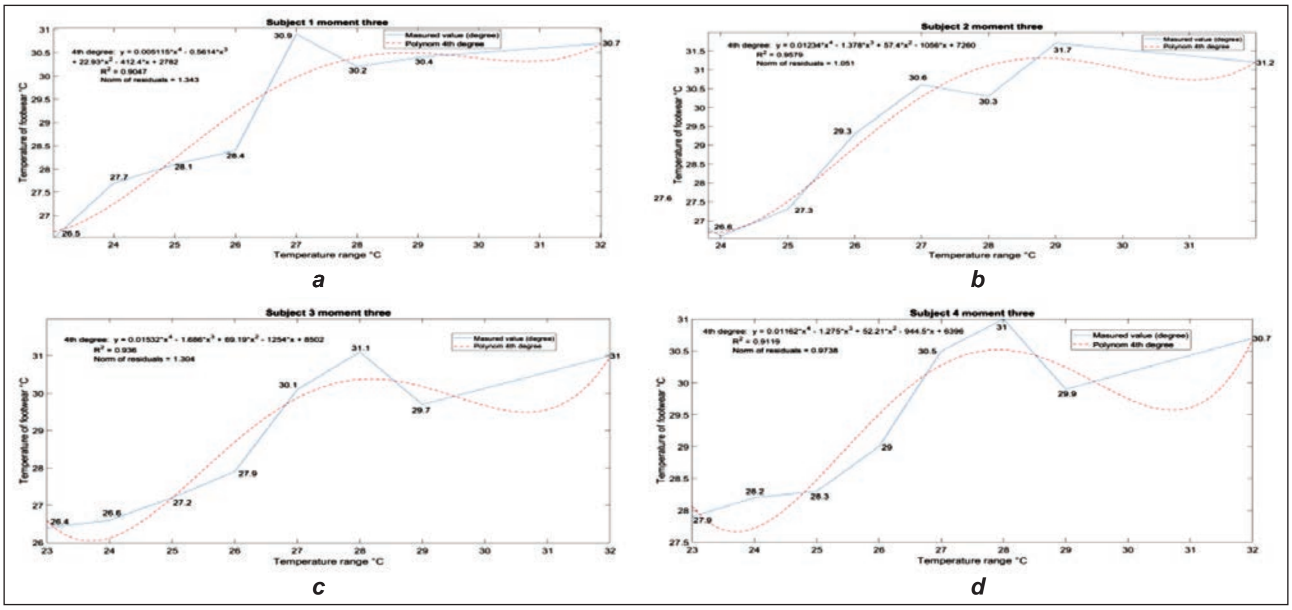

Fig. 11. Temperature variation on sports footwear for: *a* – subject 1 at time three; *b* – subject 2 at time three; *c* – subject 3 at time three; *d* – subject 4 at time three

and the emissivity is 0.80, at time three for subject 4. On the side along the Li16 line, the maximum temperature is 30.7°C, and the minimum temperature is 29.0°C, at time three for subject 4. The temperature variation along the line Li16 is 1.7°C, and the emissivity is 0.80, at time three for subject 4. The graphs realised with the help of Matlab presented in figure 11 show the measured temperature variation along the lines afferent to subject 1, subject 2, subject 3 and subject 4 on each footwear at time three and approximation curves realised by polynomials of 4th degree. In the case of subject 1 at time three, as shown in figure 11, *a*, the relation obtained is a polynomial function of degree four (equation 13).

$$y = 0.005115x4 - 0.5614x3 + 22.93x2 - 412.4x + 2782 \quad (13)$$

This equation has been fitted to the given data, resulting in an R-squared value of 0.9047. An R-squared value of 0.9047 indicates that about 90.47% of the variance in the dependent variable (y) can be explained by the independent variable (x) using this 4th degree polynomial model. In the case of subject 2 at time three, as shown in figure 11, *b*, the relation obtained is a polynomial function of degree four (equation 14).

$$y = 0.01234x4 - 1.378x3 + 57.4x2 - 1056x + 7260 \quad (14)$$

The R-squared value of 0.9579 indicates that 95.79% of the variance in the dependent variable (y) can be explained by the independent variable (x) using this 4th degree polynomial model. This high R-squared value suggests that the model is a good fit for the data. In the case of subject 3 at time three, as shown in figure 11, *c*, the relation obtained is a polynomial function of degree four (equation 15).

$$y = 0.01532x4 - 1.686x3 + 69.19x2 - 1254x + 8502 \quad (15)$$

The R-squared value of 0.936 indicates that approximately 93.6% of the variance in the dependent variable (y) can be explained by the independent variable (x) using this 4th-degree polynomial model. A higher R-squared value suggests that the model provides a good fit to the data. In the case of subject 4 at time three, as shown in figure 11, *d*, the relation obtained is a polynomial function of degree four (equation 16).

$$y = 0.01162x4 - 1.275x3 + 52.21x2 - 944.5x + 6396 \quad (16)$$

This model has an R-squared value of 0.9119, indicating that approximately 91.19% of the variance in the data is explained by the model.

As shown in figure 12 for the left footwear of subject 1 at time four (at the end of handball training), the maximum temperature along the line Li1, which is positioned on the central part of the foot, is 32.8°C, and the minimum temperature is 31.0°C. The temperature variation along the Li1 line is 1.8°C, and the emissivity is 0.79, at time four for subject 1. On the side along the Li2 line, the maximum temperature is 31.1°C, and the minimum temperature is 26.0°C, at

Fig. 12. Variation of sports footwear temperature at time four on the 4 subjects in infrared

time four for subject 1. The temperature variation along the Li2 line is 5.0°C, and the emissivity is 0.79 at time four for subject 1. As shown in figure 12 for the right foot of subject 1 at time four (at the end of handball training), the maximum temperature along the line Li3, which is positioned on the central part of the foot, is 32.2°C, and the minimum temperature is 27.8°C. The temperature variation along the Li3 line is 4.4°C, and the emissivity is 0.79, at time four for subject 1. On the side along the Li4 line, the maximum temperature is 31.4°C, and the minimum temperature is 28.9°C, at time four for subject 1. The temperature variation along the Li4 line is 2.4°C, and the emissivity is 0.79 at time four for subject 1.

In figure 12, for the right footwear of subject 2 at time four (at the end of handball training), the maximum temperature along the line Li5, which is positioned on the central part of the leg, is 32.2°C, and the minimum temperature is 27.8°C. The temperature variation along the Li5 line is 4.4°C, and the emissivity is 0.78, at time four for subject 2. On the side along the Li6 line, the maximum temperature is 31.5°C, and the minimum temperature is 29.4°C, at time four for subject 2. The temperature variation along the line Li6 is 2.1°C, and the emissivity is 0.78, at time four for subject 2. For the left foot of subject 2 at time four, the maximum temperature along the Li7 line positioned on the central side is 33.4°C, and the minimum temperature is 29.1°C. The temperature variation along the Li7 line is 4.4°C, and the emissivity is 0.78, at time four for subject 2. On the side along the Li8 line, the maximum temperature is 31.2°C, and the minimum temperature is 31.7°C, at time four for subject 2. The temperature variation along the line Li8 is 1.9°C, and the emissivity is 0.78, at time four for subject 2. Thermography measurements for subject 3 for the right foot at time four (at the end of handball training), show that the maximum temperature along the Li9 line, positioned on the centre of the foot, is 32.4°C, and the minimum temperature is 30.4°C. The temperature variation along the Li9 line is 2.0°C, and the emissivity is 0.78, at time four for subject 3. On the side along the Li10 line, the maximum temperature is 32.1°C, and the minimum temperature is 28.5°C, at moment four for subject 3. The temperature variation along the Li10 line is 3.6°C, and the emissivity is 0.78, at moment four for subject 3. For the left foot of subject 3 at time four, the maximum temperature along the Li11 line positioned on the central side is 31.5°C, and the minimum temperature is 29.2°C. The temperature variation along the Li11 line is 2.3°C, and the emissivity is 0.78, at time four for subject 3. On the side along the Li12 line, the maximum temperature is 31.4°C, and the minimum temperature is 29.5°C, at time four for subject 3. The temperature variation along the line Li12 is 1.9°C, and the emissivity is 0.78, at time four for subject 3.

In figure 12, for the right foot of subject 4 at time four (at the end of handball training), the maximum temperature along the Li13 line, which is positioned at the centre of the foot, is 32.7°C, and the minimum temperature is 29.6°C. The temperature variation along the Li13 line is 3.1°C, and the emissivity is 0.77, at time four for subject 4. On the side along the Li14 line, the maximum temperature is 32.2°C, and the minimum temperature is 30.3°C, at time four for subject 4. The temperature variation along the line is 1.9°C, and the emissivity is 0.77, at time four for subject 4. For the left foot of subject 4 at time four, the maximum temperature along the Li15 line positioned on the central side is 33.1°C, and the minimum temperature is 30.4°C. The temperature variation along the Li15 line is 2.7°C, and the emissivity is 0.77, at time four for subject 4. On the side along the Li16

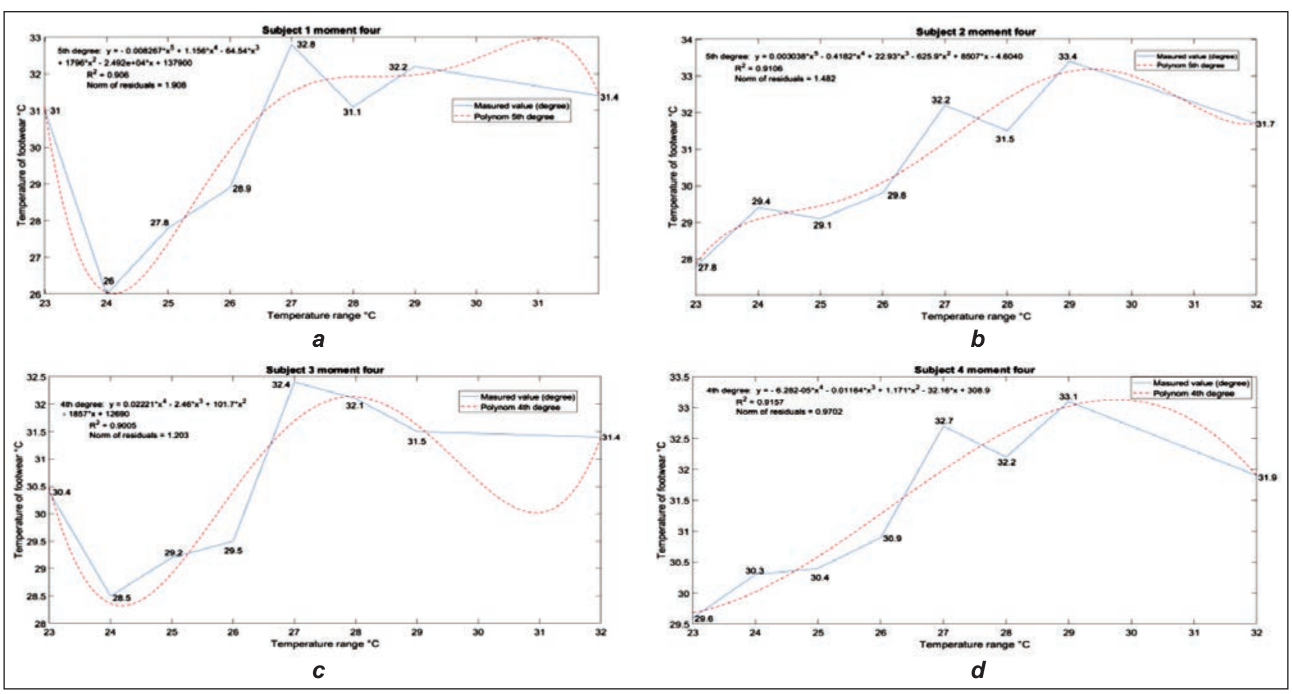

Fig. 13. Temperature variation on sports footwear for: *a* – subject 1 at time four; *b* – subject 2 at time four; *c* – subject 3 at time four; *d* – subject 4 at time four

line, the maximum temperature is 31.9°C, and the minimum temperature is 30.9°C, at time four for subject 4. The temperature variation along the line Li16 is 1.0°C, and the emissivity is 0.77, at time four for subject 4.

The graphs realised with the help of Matlab presented in figure 13 show the measured temperature variation along the lines afferent to subject 1, subject 2, subject 3 and subject 4 on each footwear at time four and approximation curves realised by polynomials of 4th and 5th degree. In the case of subject 1 at time four, as shown in figure 13, *a*, the relation obtained is a polynomial function of degree five (equation 17).

$$y = -0.008267x5 + 1.156x4 - 64.54x3 + 1796x2 - 24920{*}x + 137900 \quad (17)$$

This model has an R-squared value of 0.906, indicating that approximately 90.6% of the variance in the data is explained by the model. In the case of subject 2 at time four, as shown in figure 13, *b*, the relation obtained is a polynomial function of degree five (equation 18).

$$y = 0.003038x5 - 0.4182x4 + 22.93x3 - 625.9x2 + 8507{*}x - 46040 \quad (18)$$

The R-squared value of the model is 0.9106, indicating that approximately 91.06% of the variance in the data is explained by the model. In the case of subject 3 at time four, as shown in figure 13, *c*, the relation obtained is a polynomial function of degree four (equation 19).

$$y = 0.02221x4 - 2.46x3 + 101.7x2 - 1857x + 12690 \quad (19)$$

The R-squared value of the model is 0.9005, indicating that approximately 90.05% of the variance in the

Table 1

THE TEMPERATURE OF THE SPORTS FOOTWEAR DURING HANDBALL TRAINING FOR THE 4 SELECTED SUBJECTS OUT OF THE 7 ANALYSED

Subject	Time zero	Time one	Time two	Time three	Time four
Subject 1	Li1 max 27.1°C	Li1 max 27.5°C	Li1 max 27.5°C	Li1 max 30.9°C	Li1 max 32.8°C
	Li1 min 24.2°C	Li1 min 24.0°C	Li1 min 24.3°C	Li1 min 26.5°C	Li1 min 31.0°C
	Li2 max 28.3°C	Li2 max 28.4°C	Li2 max 28.7°C	Li2 max 30.2°C	Li2 max 31.1°C
	Li2 min 24.5°C	Li2 min 25.3°C	Li2 min 23.7°C	Li2 min 27.7°C	Li2 min 26.0°C
	Li3 max 27.4°C	Li3 max 28.1°C	Li3 max 28.3°C	Li3 max 30.4°C	Li3 max 32.2°C
	Li3 min 25.6°C	Li3 min 24.7°C	Li3 min 25.2°C	Li3 min 28.1°C	Li3 min 27.8°C
	Li4 max 28.0°C	Li4 max 28.9°C	Li4 max 29.4°C	Li4 max 30.7°C	Li4 max 31.4°C
	Li4 min 25.3°C	Li4 min 25.6°C	Li4 min 25.4°C	Li4 min 28.4°C	Li4 min 28.9°C
Subject 2	Li5 max 28.6°C	Li5 max 29.0°C	Li5 max 29.3°C	Li5 max 30.6°C	Li5 max 32.2°C
	Li5 min 25.2°C	Li5 min 24.9°C	Li5 min 25.5°C	Li5 min 27.6°C	Li5 min 27.8°C
	Li6 max 28.5°C	Li6 max 28.6°C	Li6 max 29.0°C	Li6 max 30.3°C	Li6 max 31.5°C
	Li6 min 25.0°C	Li6 min 25.5°C	Li6 min 24.9°C	Li6 min 26.6°C	Li6 min 29.4°C
	Li7 max 27.4°C	Li7 max 28.5°C	Li7 max 28.6°C	Li7 max 31.7°C	Li7 max 33.4°C
	Li7 min 24.9°C	Li7 min 25.1°C	Li7 min 24.3°C	Li7 min 27.3°C	Li7 min 29.1°C
	Li8 max 28.8°C	Li8 max 29.6°C	Li8 max 29.7°C	Li8 max 31.2°C	Li8 max 31.7°C
	Li8 min 25.9°C	Li8 min 26.2°C	Li8 min 26.4°C	Li8 min 29.3°C	Li8 min 29.8C
Subject 3	Li9 max 27.5°C	Li9 max 28.4°C	Li9 max 28.6°C	Li9 max 30.1°C	Li9 max 32.4°C
	Li9 min 24.6°C	Li9 min 25.0°C	Li9 min 25.3°C	Li9 min 26.4°C	Li9 min 30.4°C
	Li10 max 28.7°C	Li10 max 29.4°C	Li10 max 30.2°C	Li10 max 31.1°C	Li10 max 32.1°C
	Li10 min 25.2°C	Li10 min 24.9°C	Li10 min 26.2°C	Li10 min 26.6°C	Li10 min 28.5°C
	Li11 max 28.3°C	Li11 max 28.5°C	Li11 max 28.9°C	Li11 max 29.7°C	Li11 max 31.5°C
	Li11 min 25.4°C	Li11 min 24.7°C	Li11 min 27.1°C	Li11 min 27.2°C	Li11 min 29.2°C
	Li12 max 28.6°C	Li12 max 29.3°C	Li12 max 29.6°C	Li12 max 31.0°C	Li12 max 31.4°C
	Li12 min 27.0°C	Li12 min 25.3°C	Li12 min 27.4°C	Li12 min 27.9°C	Li12 min 29.5°C
Subject 4	Li13 max 28.4°C	Li13 max 29.0°C	Li13 max 29.1 °C	Li13 max 30.5°C	Li13 max 32.7°C
	Li13 min 25.4°C	Li13 min 24.9°C	Li13 min 26.9 °C	Li13 min 27.9°C	Li13 min 29.6°C
	Li14 max 28.6°C	Li14 max 28.4°C	Li14 max 28.9°C	Li14 max 31.0°C	Li14 max 32.2°C
	Li14 min 25.7°C	Li14 min 24.3°C	Li14 min 24.4°C	Li14 min 28.2°C	Li14 min 30.3°C
	Li15 max 28.0°C	Li15 max 28.2°C	Li15 max 28.6°C	Li15 max 29.9°C	Li15 max 33.1°C
	Li15 min 26.2°C	Li15 min 25.1°C	Li15 min 25.0°C	Li15 min 28.3°C	Li15 min 30.4°C
	Li16 max 28.2°C	Li16 max 29.1°C	Li16 max 29.5°C	Li16 max 30.7°C	Li16 max 31.9°C
	Li16 min 26.5°C	Li16 min 25.3°C	Li16 min 25.2°C	Li16 min 29.0°C	Li16 min 30.9°C

data is explained by the model. In the case of subject 4 at time four, as shown in figure 13, *d*, the relation obtained is a polynomial function of degree four (equation 20).

$$y = -0.00006282x4 - 0.01164x3 + 1.171x2 - - 32.16x + 308.9 \quad (20)$$

The R-squared value of the model is 0.9157, indicating that approximately 91.57% of the variance in the data is explained by the model. The measurements were performed on seven athletes (subjects) in a handball training session, wearing the same footwear type A handball used for indoor sports. For the other three subjects, although having different models of the same sports footwear, the analysis of the thermal distribution values shows they are within the minimum and maximum limits of the seven subjects analysed in the paper, Depending on the intensity of the training, the 4 subjects wearing a footwear type A show an increase in temperature along the measured Li1–Li16 lines up to a maximum temperature of 33.4 at the time four analysed in a handball training session.

The temperature of the sports footwear varied during handball training when measurements were taken for the 4 selected subjects out of the 7 analysed, and are presented in table 1.

By implementing eco-friendly materials, transparent supply chains, waste reduction measures, energy efficiency, recycling initiatives, and further innovation, sports footwear brands can reduce their environmental impact and contribute to a more sustainable future.

To conclude, the temperature, increase and emissivity decrease are interconnected phenomena in handball footwear construction. Understanding these relationships is crucial for designing high-quality products that provide optimal thermal performance, comfort, and durability.

CONCLUSIONS

In the present paper, research was carried out in order to identify the thermal variation of indoor sports shoes used in volleyball training so as to detect the heat exchange between the foot and the outdoor environment.

For textile materials used in the manufacture of sports footwear (e.g. nylon, polyester and polypropylene), the emissivity decreases with increasing temperature due to the contact between the foot and the footwear. Heat transfer can become more difficult with decreasing emissivity; the ability of the textile material to release heat is affected, thus resulting in increased heat accumulation and potentially uncomfortable conditions.

Therefore, the test was valuable for showing the temperature distribution along the lines for each shoe and showing the strengths and weaknesses of the design of the tested footwear compared to the research done in the field. In the current study, the authors utilised a thermographic camera placed on a tripod to capture real-time images from various angles of the handball training during both static and dynamic activities. In the case of subjects 1, 2, 3 and 4 using type A footwear, there is an uneven distribution of the maximum temperature variation along the analysed lines Li1, Li2, Li3, Li4, Li5, Li6, Li7, Li8, Li9, Li10, Li11, Li12, Li13, Li14, Li15, Li16 at the five times when the measurements were taken.

In the case of the type A footwear analysed on the four athletes (subjects) during the handball training in the five moments, it can be concluded that the minimum and maximum temperature varies between 24.2°C at subject 1 at moment 0, before the beginning of the training, and 33.4°C at subject 2 at time four, at the end of the training. In the case of subjects 1, 2, 3 and 4, who use type A footwear, it can be seen that the R2 regression of the polynomial function has a value greater than 0.9 within the five analysed moments. In those cases, where the R^2 regression of the polynomial function has a value greater than 0.9, the mathematical model represents the real situation.

Based on the thermographic values recorded, researchers created a mathematical model using polynomial regression in Matlab. This model helps predict temperature values that fall outside the range of the experimental data. By analysing the thermographic data, the team was able to identify patterns and trends in temperature changes. The use of polynomial regression allows for a more accurate estimation of temperatures even in conditions not covered by the original experiments. This approach enhances our understanding of temperature variations and can be useful in various scientific applications.

Taking into account the data obtained from static and dynamic temperature measurements during handball training in type A footwear, predictions of thermal distribution can be made through polynomial regression using neural networks.

The authors of this paper aim to perform temperature measurements during a men's handball training session to examine the distribution along temperature lines between subjects in the same environmental conditions and the advantages obtained by examining each shoe.

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Generational differences in perceptions of AI-generated reviews in online textile purchases: implications for sustainable digital consumption

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ABSTRACT – REZUMAT

Generational differences in perceptions of AI-generated reviews in online textile purchases: implications for sustainable digital consumption

The digitalisation of consumer environments, fueled by artificial intelligence (AI), is reshaping how individuals interact with information and make purchasing decisions. Online reviews – especially those generated by AI – have become a key source of influence across generations. This study investigates how generational cohorts perceive AI-generated reviews and the implications for responsible digital consumption. By examining awareness, trust, and intention to use such reviews, this paper highlights how AI can both enhance transparency and risk undermining consumer trust. The findings suggest that while digital natives are more open to AI-generated content, older generations express skepticism, which has implications for fostering sustainable consumption practices in the digital age. The study calls for greater transparency, education, and ethical design of AI-driven platforms to align with Sustainable Development Goal 12 (Responsible Consumption and Production). This research focuses on online reviews related to textile products, exploring how AI-generated content influences consumer trust and sustainable choices in the textile industry.

Keywords: *artificial intelligence, AI-generated reviews, online reviews, textile industry, sustainable digital consumption*

Diferențe generaționale în percepția recenziilor generate de IA în achizițiile online de produse textile: implicații pentru consumul digital durabil

Digitalizarea mediilor de consum, alimentată de inteligența artificială (IA), remodelează modul în care indivizii interacționează cu informațiile și iau decizii de cumpărare. Recenziile online, în special cele generate de IA, au devenit o sursă cheie de influență pentru toate generațiile. Acest studiu investighează modul în care generațiile percep recenziile generate de IA și implicațiile pentru consumul digital responsabil. Prin examinarea gradului de conștientizare, a încrederii și a intenției de a utiliza astfel de recenzii, acest articol evidențiază modul în care IA poate spori transparența, dar și riscul de a submina încrederea consumatorilor. Rezultatele sugerează că, în timp ce nativii digitali sunt mai deschiși față de conținutul generat de IA, generațiile mai în vârstă exprimă scepticism, ceea ce are implicații pentru promovarea practicilor de consum durabil în era digitală. Studiul solicită o mai mare transparență, educație și proiectare etică a platformelor bazate pe IA, pentru a se alinia la Obiectivul de Dezvoltare Durabilă 12 (Consum și Producție responsabile). Acest studiu se concentrează pe recenziile online legate de produsele textile, explorând modul în care conținutul generat de IA influențează încrederea consumatorilor și alegerile durabile în industria textilă.

Cuvinte-cheie: *inteligență artificială, recenzii generate de IA, recenzii online, industria textilă, consum digital durabil*

INTRODUCTION

The dynamic process of digitalisation. In the context of accelerating digital transformation, artificial intelligence has become a powerful tool influencing how consumers access and process information. Online reviews, increasingly generated by AI, serve as decision-making aids in the textile sector, raising questions around authenticity, trust, and their impact on sustainable consumption of clothing and textile products. In the textile industry, online reviews play a critical role in guiding consumer behaviour. With the rise of AI-generated reviews, there is growing interest in how different generations perceive these reviews, particularly in the context of sustainable and ethical textile consumption. This study contributes to understanding how AI tools might support more informed and responsible purchasing decisions in the fashion and textile sectors. This paper explores how consumers from different generations engage with AI-generated content, with implications for responsible digital behaviour and sustainable economic practices. Unlike AI-based recommendation systems or virtual fashion designers that tailor purchasing suggestions to individual needs and preferences, this study does not examine personalised interaction. Instead, it focuses on the broader perception of automatically generated online reviews. These reviews are not customised but are intended to simulate genuine feedback, and this distinction allows us to assess general consumer trust and behaviour towards AI-generated content, irrespective of personalisation mechanisms. Over time, numerous studies and systematic reviews have explored this transformation's impact and evolution. Currently, the industry is on the brink of the fourth industrial revolution (Industry 4.0), leveraging digitalisation to revolutionise business operations in industrial value chains. We are entering an era where industries are becoming increasingly "smart", mainly through the use of Internet of Things (IoT) technologies, continuous data flows, and predictive analytics. Benefits include improved productivity and profitability through process automation and optimisation, cost reduction, accelerated production, error reduction, enhanced user experiences, and improved carbon footprints for companies [1].

Most industry experts view this transformation positively [2]. Recent BCG and PwC reports anticipate Industry 4.0 will enhance process efficiency by 15–20% and contribute over 20% to revenue generation in the next five years. These outcomes demonstrate that digital technologies offer significant potential for business model innovation in the B2B context, providing new revenue generation opportunities and added value creation. Entities that capitalise on the potential of digitalisation, supplemented by big data and analytics, will outperform competitors in revenue growth and operational efficiency.

Numerous studies have highlighted digital transformation's significant potential in facilitating internationalisation. However, digital transformation can also generate negative effects on internationalisation, such as cybersecurity challenges and compliance with international legislation, negative impacts on communication and performance of different groups or individual employees in various countries, variations in the scope of firms' internationalisation, and differences in consumer interactions with technologies in other countries. Despite this, while most existing studies emphasise the positive impact of digital transformation on firms' internationalisation, its negative effects have not been explored in depth [3].

As part of these changes, online review systems have emerged as complex socio-technical systems where human behaviour and artificial intelligence interact dynamically to shape consumer decision-making processes.

Digital transformation has revolutionised how we live our lives, conduct business, and make consumer decisions [4]. Global spending on digital transformation technologies and services exceeded $216 trillion in 2023 and is projected to reach $35 trillion shortly, highlighting the emphasis on investment as a growth stimulator for organisations [5].

The literature shows that digital transformation influences managerial decisions and actions across various industries and contexts [6]. Recent challenges in the business world, especially those created by the recently concluded COVID-19 pandemic, have pushed organisations to accelerate digital transformation. Despite the lack of consensus among most digital transformation specialists on long-term approaches, it is almost unanimously accepted that as organisations confront digital technologies, they must adapt. A widely accepted definition describes digital transformation as "a process that aims to improve an entity by triggering significant changes in its properties through combinations of informational, computational, communication, and connectivity technologies" [7].

Digitalisation has profoundly transformed all economic and societal sectors, accelerating processes and facilitating access to information and services [8]. This technological revolution has improved operational efficiency, reduced costs, and opened innovation opportunities. In this extensive digitalisation context, artificial intelligence (AI) has exponentially developed and promises to further redefine the technological landscape [9].

Artificial intelligence represents the next evolutionary step in digitalisation, offering advanced analysis, prediction, and automation capabilities. While digitalisation involves transforming data and processes into a digital format, AI goes further by using this data to learn and make intelligent decisions. From machine learning algorithms to neural networks and speech and image recognition systems, AI has the potential to revolutionise entire industries, from healthcare and finance to transportation and entertainment. Understanding these dynamics is essential to achieving the UN's Sustainable Development Goal 12, which promotes responsible consumption patterns, particularly in digital contexts.

HISTORY OF ARTIFICIAL INTELLIGENCE

The history of artificial intelligence (AI) is marked by significant developments that have shaped this field. Early AI concepts date back to ancient mythology and philosophy, but theoretical foundations were established in the 20th century. A critical turning point was the 1956 Dartmouth Conference, where the term "artificial intelligence" was officially coined, laying the groundwork for future research [10].

In the 1980s, AI experienced significant growth due to the development of deep learning techniques by John Hopfield and David Rumelhart, as well as expert systems introduced by Edward Feigenbaum. These systems mimicked human expert decision-making processes and were widely adopted in the industry [11]. A landmark moment was in 1997 when IBM's Deep Blue program defeated world chess champion Garry Kasparov, demonstrating AI's ability to make complex decisions. Subsequent technological advancements culminated in recent achievements such as Google's AlphaGo defeating world champions in the game of Go [12].

These historical developments were enabled by advances in computing power and storage, in line with Moore's law, allowing AI to learn and process large amounts of data at increasing speeds. Today, AI is ubiquitous, applied in various fields from technology and finance to marketing and entertainment [13].

Currently, AI is in a phase of rapid expansion and profound transformation, influencing numerous societal aspects. Recent AI developments have led to significant advances in various fields, including speech recognition, image and text generation, and even robotics.

Artificial Intelligence in 2024 – Technical and Generative AI Advances: Generative technologies, such as extensive language models (LLM) and deep neural networks, have advanced considerably. Models like OpenAI's GPT-4 and Google's Gemini Ultra have demonstrated remarkable capabilities in generating high-quality text and images.

For instance, GPT-4's training cost was estimated at $78 million, reflecting the substantial resource investment required for developing such advanced technologies [14].

Industry and research impact: The industry now dominates AI model development, with many notable models resulting from collaborations between industry and academia. This is due to the need for vast data and computing power for training complex models, resources more readily accessible in the private sector. Generative AI, in particular, has attracted significant investment, with funding growing ninefold in 2023 compared to the previous year [15].

Regulation and ethics: as AI becomes increasingly integrated into daily life, ethical and responsible use concerns have become crucial. There is an urgent need for standardised responsible AI assessments due to the evident risks related to privacy and security and the use of AI to create falsifiable content such as deepfakes in electoral contexts, raising serious disinformation issues [16].

Applications in health and education: Artificial intelligence continues to play a crucial role in healthcare, contributing to drug discovery and disease diagnosis. In education, AI is used to personalise learning processes and provide support to students through virtual assistants. However, this statement must be contextualised. The integration of AI in education is not yet universally applicable across all disciplines or regions. While adaptive learning platforms and virtual assistants are gaining traction in certain educational contexts, their presence is limited and often experimental. Thus, generalisations about AI's role in education should be approached with caution and supported by empirical evidence. The rapid evolution of artificial intelligence is influencing various fields, generating both benefits and challenges. Technical advancements, increased investments, and integration across diverse industries highlight the enormous potential of this technology. However, addressing ethical and regulatory aspects remains essential to ensure the responsible use of AI for the benefit of society, necessitating prompt action from global regulatory entities.

In recent years, artificial intelligence has revolutionised various fields, from healthcare and finance to transportation and entertainment. This advanced technology, capable of learning and adapting, has significantly improved efficiency and precision across multiple sectors. Nevertheless, one of the most fascinating and relevant applications of AI remains the analysis and management of online reviews. These reviews, a vital form of consumer feedback, can now be processed and interpreted at an unprecedented scale and depth thanks to AI's advanced analytical capabilities [17].

Online reviews are opinions, evaluations, and comments posted by consumers on various digital platforms regarding products, services, experiences, or companies. These reviews can be found on e-commerce websites, social networks, forums, blogs, and specialised review sites. They are written by real users who share their experiences to assist other potential consumers in making informed decisions.

Online reviews have become an essential component of the consumer decision-making process. Studies indicate that most buyers read reviews before making a purchase, considering these opinions as trustworthy as personal recommendations. They provide authentic and detailed information about the performance and quality of products and services, contributing to increased market transparency.

The impact of online reviews is profound and diversified, influencing all aspects of the consumer market. For consumers, reviews offer a genuine perspective on products and services, helping them avoid unsatisfactory purchases and find the best available options. It is important to clarify that this study did not analyse AI-generated reviews extracted from specific platforms. Instead, it evaluated user perceptions regarding the presence and impact of such content in digital environments. Therefore, no content was evaluated for truthfulness or specific source credibility. The focus remains on consumer awareness and behavioural intentions regarding the concept of AI-generated reviews in general. They serve as a reliable guide based on other users' experiences, allowing consumers to make more informed decisions and have realistic expectations [18].

For companies, positive reviews can enhance reputation and credibility, attracting more customers and strengthening existing customers' loyalty. At the same time, negative reviews provide valuable feedback, highlighting areas for improvement. This feedback can be used to adjust strategies, address deficiencies, and improve overall customer experience. Companies that proactively respond to reviews demonstrate a genuine concern for customer satisfaction, which can turn criticisms into growth and innovation opportunities.

Regarding the overall market, reviews create a more competitive and transparent environment. They compel companies to continuously improve their products and services to meet consumer expectations. This feedback and adjustment cycle stimulates innovation and raises quality standards, benefiting not only individual consumers and companies but the economy as a whole. Online reviews facilitate a commercial ecosystem where quality and customer satisfaction are central priorities, leading to continuous and healthy market evolution [19, 20].

Online reviews are diverse, but from a classification perspective, we can highlight:

- E-commerce Platform Reviews: Amazon, eBay, and similar sites allow users to rate purchased products and leave detailed comments.
- Social Media Reviews: Facebook, Instagram, and other social platforms offer the possibility to post reviews and share experiences with a broad audience.
- Specialised Review Sites: Yelp, TripAdvisor, and Google Reviews are examples of dedicated review sites covering various domains such as restaurants, hotels, and local services.
- Blogs and Forums: Many consumers choose to post detailed reviews on personal blogs or discussion forums where they can engage in dialogue with other users about their experiences.

Challenges of online reviews. Online reviews' challenges are diverse and complex, affecting both consumers and companies. Fake reviews represent a major issue, as these fabricated or paid opinions can mislead consumers into making inappropriate purchases. These false reviews can distort the general perception of a product or service, undermining consumer trust in the authenticity of online reviews.

On the other hand, managing negative reviews is essential for companies. They must handle criticism carefully, using it as an opportunity to improve their products and services. Responses to negative reviews must be constructive and professional to avoid damaging the company's public image. A proactive and empathetic approach to managing negative feedback can turn a potentially problematic situation into an opportunity to demonstrate commitment to customer satisfaction [21].

Information overload. Information overload is another significant challenge. The abundance of available online reviews can be overwhelming for consumers, making it difficult to select relevant information. Consumers may feel confused or indecisive when faced with many contradictory opinions. In this context, developing algorithms for filtering and organising reviews based on relevance and authenticity becomes crucial to help consumers make informed decisions efficiently. Thus, navigating the large volume of online feedback can become simpler and more useful for users [22, 23].

Generational differences

Conceptual differences between generations represent a complex and challenging subject, including various aspects ranging from cultural values and attitudes to consumption habits and the degree of adoption of digital technologies [24, 25]. In the context of reviews and their impact, these differences become even more evident, influencing how different generations perceive and use online feedback.

- Baby Boomers Born between 1946 and 1964, the Baby Boomer generation grew up during economic prosperity and significant social transformations. This generation is characterised by a strong work ethic and a preference for personal and traditional interactions. Regarding digitalisation, Baby Boomers were initially more reluctant to adopt new technologies. However, as technology has become indispensable, many have started using the internet and digital devices to stay connected and informed.
- In the context of online reviews, Baby Boomers tend to be more cautious and selective. They prefer trusted sources and are more likely to consider reviews written by people they know personally or who are well-regarded in the field. This generation also appreciates detailed and well-argued reviews that provide concrete and relevant information.
- Generation X Born between 1965 and 1980, Generation X witnessed the transition from an industrial to a digital economy. This generation is often considered pragmatic, independent, and adaptable. Generation X grew up with the advent of the first personal computers and the internet, allowing them to quickly adapt to new technologies.
- Regarding online reviews, Generation X is quite active and influential. They frequently use digital platforms to research products and services, emphasising reviews written by authentic users. Generation X appreciates well-structured and balanced reviews that present both positive and negative aspects of a product or service. This generation is also willing to contribute their reviews, believing their feedback can help other consumers make informed decisions.
- Millennials or Generation Y, born between 1981 and 1996, are the first generation to grow up with the internet and digital technology as an integral part of daily life. They are characterised by a high degree of trust in technology and a preference for online interactions and digital mobility.
- Millennials are prolific users of online reviews, both as readers and authors. They rely on online feedback to make quick and informed decisions, preferring short reviews containing essential and authentic information. This generation tends to use multiple review sources and validate them by comparing several platforms. Millennials are also more open to using social networks to express their opinions and influence their friends and followers' consumption behaviour.
- Generation Z Born after 1997, Generation Z is the youngest and most digitalised generation. They are true digital natives accustomed to instant access to information and online interactions. Generation Z is known for its ability to navigate multiple information sources and quickly filter relevant content.
- In the context of online reviews, Generation Z highly values authenticity and transparency. They prefer video reviews or those posted on social media platforms like Instagram, TikTok, and YouTube, where they can see other users' reactions and experiences directly and visually. This generation is also more likely to be influenced by influencers' and online personalities' reviews, which they consider authentic and trustworthy.

Generational differences in digitalisation and consumption habits. These differences are closely related to each generation's context of growing up and evolving. For example, Baby Boomers experienced the transition from analogue to digital technologies, while Millennials and Generation Z grew up in a digitalised environment from the start. These differences are reflected in how each generation adopts and uses technology in daily life.

Regarding consumption habits, Baby Boomers and Generation X are more oriented towards quality products and services, relying on personal experiences and direct recommendations. Millennials and Generation Z, on the other hand, are more open to innovation and exploring new trends, using online reviews and digital feedback to discover new products and services and make quick decisions [26].

MATERIALS AND METHODS

The research section focuses on investigating users' awareness and perception of AI-generated reviews, specifically in the context of online textile product purchases. To obtain concrete and relevant data, we conducted quantitative research using a questionnaire applied to a sample of 150 participants. This approach allows the collection of detailed information regarding the opinions and attitudes of various age groups towards using AI in generating online reviews.

Research methodology

This section details the methodology used to investigate users' awareness and perception of AI-generated reviews. The quantitative research was conducted by applying a structured questionnaire to a sample of 150 people representing various demographic segments.

Sample

The sample consisted of 150 participants selected to represent various age groups and education levels. Participants were selected using a convenience sampling method, but efforts were made to ensure demographic diversity. Inclusion criteria required participants to have at least occasional experience with online shopping and a basic understanding of artificial intelligence concepts. This ensured that respondents were capable of evaluating the concept of AI-generated reviews with sufficient awareness. The questionnaire used in this research was structured into several sections, each targeting a specific set of variables. The questions were formulated to be clear and easy to understand, using a five-point Likert scale (from "Strongly Disagree" to "Strongly Agree").

Questionnaire sections

- Demographics: Questions regarding age, gender, and education level.
- AI Awareness: Questions about users' awareness that reviews can be generated by AI.
- AI Usage Perception: Questions about the usefulness and trustworthiness of AI-generated reviews.
- Preferences and Attitudes: Questions about users' preferences for AI-generated or human-written reviews.
- Authenticity and Ethics: Questions about concerns regarding the authenticity and ethics of AI-generated reviews.

Data collection procedure

Pre-testing the Questionnaire: The questionnaire was pre-tested on a small group of people to ensure the questions' clarity and relevance. Feedback obtained was used to adjust and optimise the final questionnaire.

Data Collection: The questionnaire was distributed online using survey platforms and completed by 150 participants. The estimated time for completing the questionnaire was approximately 10–15 minutes.

Confidentiality and Consent: Participants were assured of the confidentiality of their responses and were asked for informed consent before participating in the study.

Through this research, we aimed for a rigorous and systematic approach, allowing us to obtain relevant and reliable data about users' awareness and perception of AI-generated reviews. This will contribute to a better understanding of this technology's impact on consumer behaviour and the adaptation of marketing strategies accordingly.

Decision problem

AI plays an increasingly important role in generating online reviews, and users' perception of these reviews significantly influences purchasing behaviour. In this context, the decision problem focuses on understanding the level of awareness and perception of AI-generated reviews and identifying age-related differences. The results of this research are essential for companies using or intending to use AI-generated reviews in their marketing strategies.

In the digital era, online reviews are a crucial component of the consumer decision-making process. Authentic reviews written by real users are considered a trustworthy source for evaluating products and services. However, automatically generating reviews through AI raises questions about authenticity, trust, and ethics.

Decision problem aspects

User Awareness: A central aspect of the decision problem is determining how aware users are that many online reviews are generated by AI rather than real people. This awareness may vary significantly by age and education level.

User Perception: Another important aspect is how users perceive AI-generated reviews regarding usefulness, detail, and impartiality. If users consider these reviews as useful and trustworthy as human-written ones, it could positively influence AI adoption in review generation.

Trust and Authenticity: User trust in online reviews is essential. A critical issue is the extent to which AI-generated reviews are perceived as authentic and trustworthy. Concerns about authenticity can negatively impact the acceptance and use of these reviews.

Intention to Use: Determining users' intention to use AI-generated reviews in their future purchasing decisions is essential for companies. If users are willing to use these reviews, companies can invest more in AI technologies for review generation.

Understanding users' perceptions is crucial in managing the integrity and efficiency of interconnected systems where AI-generated and human-generated reviews coexist and influence consumer behaviour.

The decision problem addressed in this research focuses on evaluating users' awareness and perception of AI-generated reviews, emphasising differences across various age groups. Solving this problem will provide companies with valuable information to adapt marketing strategies and effectively use AI technologies for the benefit of consumers.

Research aim

The primary aim of this research is to evaluate users' awareness and perception of AI-generated reviews, identifying significant differences among various age groups. The research aims to provide a deep understanding of how users perceive the authenticity, usefulness, and trustworthiness of AI-generated reviews and determine their intention to use these reviews in purchasing decisions.

Specific research objectives

- Awareness evaluation: determine the level of user awareness regarding the fact that many online reviews are generated by AI, based on different age categories.
- Perception analysis: investigate how users perceive AI-generated reviews in terms of usefulness, detail, impartiality, and authenticity.
- Trust in AI reviews: evaluate users' trust in AI-generated reviews compared to those written by real people.
- Intention to use: determine users' intention to use AI-generated reviews in the future for purchasing decisions.
- Generational differences: identify significant differences in perception and awareness among various age groups (Generation Z, Millennials, Generation X, and Baby Boomers).

Research importance

This research is essential for companies using or intending to use AI-generated reviews in their marketing strategies. By understanding users' awareness and perception, companies can:

- Adapt marketing and communication strategies to address users' concerns and increase acceptance of AI-generated reviews.
- Improve transparency by clearly labelling AI-generated reviews and educating users on their use.
- Develop AI technologies that better meet users' needs and expectations, thus enhancing the shopping experience.

Defining hypotheses

To structure the research and test the relationships between defined latent variables, we propose the following hypotheses, each supported by relevant literature:

- Hypothesis 1: Significant differences exist in the awareness of AI-generated reviews among different age groups [10].
- Hypothesis 2: Awareness of AI-generated reviews positively influences users' attitudes towards AI-generated reviews [4].
- Hypothesis 3: Attitude towards AI-generated reviews positively influences trust in online reviews [1].
- Hypothesis 4: Trust in online reviews positively influences the intention to use AI-generated reviews [19].
- Hypothesis 5: Awareness of AI-generated reviews directly and positively influences the intention to use AI-generated reviews [15].

Analysing the questionnaire and interpreting the results are essential steps in the data collection and decision-making process based on this data. A well-designed questionnaire can provide valuable insights into respondents' opinions, attitudes, and behaviours. Additionally, sustainable digital consumption must consider user satisfaction and perceived value, particularly in sectors like healthcare and education, where trust in digital tools can shape public acceptance and responsible usage. Prior research has shown that user satisfaction with digitally supported public services, such as healthcare education platforms, is directly linked to how these services are financed, promoted, and perceived in terms of quality and transparency [27–32].

RESULTS

The analysis of the questionnaire and the interpretation of the results are important steps in the data collection process and decision-making based on this data. A well-designed questionnaire can provide valuable insights into respondents' opinions, attitudes, and behaviours. Here are the essential steps for analysing a questionnaire and interpreting the results.

The first question in the questionnaire assesses respondents' awareness that many online reviews are generated by artificial intelligence. The results of this question are as follows: approximately 48% of respondents (Strongly Agree + Agree) are aware that many online reviews are generated by AI. This indicates a relatively high level of awareness among users, suggesting that AI is recognised as a relevant technology in review generation. 20% of respondents are neutral, which suggests that they either do not have a clear opinion or are not fully aware of the use of AI in online reviews. Notably, 32% of respondents (Disagree + Strongly Disagree) are unaware that online reviews are generated by AI. This significant percentage shows that there is still a considerable segment of the population that does not recognise AI's influence in this context (figure 1).

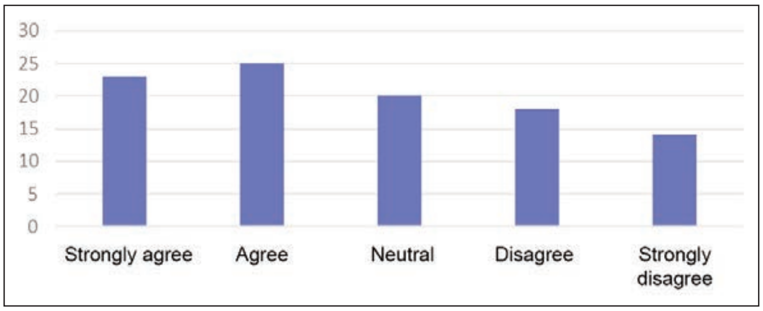

Fig. 1. Response awareness that many online reviews are generated by artificial intelligence

The results indicate a variable level of awareness among users, with nearly half being aware of the use of AI in generating online reviews. This suggests that, although AI technology is widely recognised, there is still a need to increase awareness and educate users about its use in online reviews.

The second question in the questionnaire evaluates users' perception of the usefulness of AI-generated reviews compared to those written by real people, and the results are as follows: Approximately 49% of respondents (strongly agree + agree) consider AI-generated reviews to be as useful as those written by real people. This indicates a fairly high level of acceptance of AI-generated reviews and suggests that many users view these reviews as comparable in terms of usefulness. 19% of respondents are neutral, which may indicate uncertainty or lack of direct experience with AI-generated reviews. Additionally, 32% of respondents (disagree + strongly disagree) do not consider AI-generated reviews to be as useful as those written by real people. This significant percentage suggests that there is resistance to accepting AI-generated reviews and a preference for human reviews (figure 2).

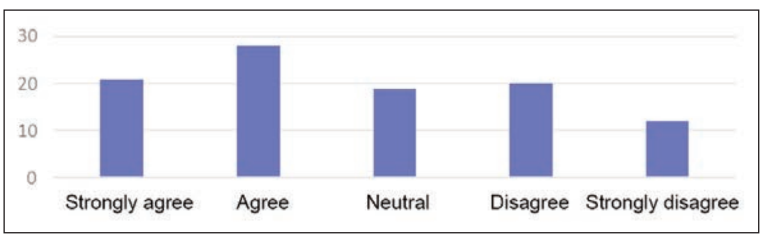

Fig. 2. Users' perception of the usefulness of AI-generated reviews compared to those written by real people

The results indicate that almost half of the respondents find AI-generated reviews as useful as human reviews, but there is still a considerable segment that does not agree with this idea. This suggests a division in the perception of the usefulness of AI-generated reviews, which could influence how these are used and promoted by companies.

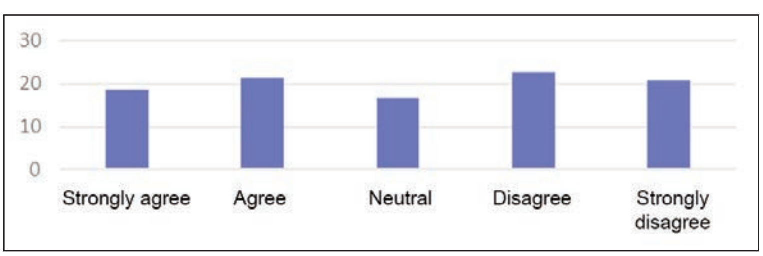

Fig. 3. The level of user trust in online reviews generated by artificial intelligence

The third question in the questionnaire evaluates the level of trust users have in online reviews generated by artificial intelligence, and the results are as follows: Approximately 43.33% of respondents (disagree + strongly disagree) do not trust AI-generated reviews. This significant percentage indicates a fairly high lack of trust in these reviews, which underscores the importance of "human authenticity" in the context of reviews. Approximately 40% of respondents (agree + strongly agree) trust AI-generated reviews. This suggests that there is a considerable segment of the population that sees AI-generated reviews as trustworthy. Additionally, 16.67% of respondents are neutral, which may indicate indecision or lack of direct experience with AI-generated reviews (figure 3).

The results of this question indicate a polarisation in the level of trust users have in AI-generated reviews. Although almost half of the respondents trust these reviews, there is an almost equal proportion that does not consider them trustworthy, reflecting the transitional period we find ourselves in during 2024. To better understand the nuances in perception, results were also disaggregated by generational cohort. Generation Z and Millennials showed a higher level of trust in AI-generated reviews (over 55% positive responses), while Generation X and Baby Boomers exhibited greater scepticism (less than 35% positive).

Furthermore, participants with higher education levels were generally more receptive to AI-generated content, suggesting that education plays a mediating role in acceptance and trust.

The fourth question analysed whether AI-generated reviews are sufficiently detailed to be useful in purchasing decisions. The responses are as follows: There is a diversity of opinions with a relatively balanced distribution between positive and negative responses.

Approximately 40% (Strongly Agree + Agree) consider AI-generated reviews sufficiently detailed, while 37.34% (Disagree + Strongly Disagree) do not agree. It should be noted that AI-generated reviews often follow examples generated by humans, and without a specific request for detail, generative reviews may be simple and sometimes inconclusive. It should also be noted that a vast review can often be hard to follow or considered unnecessary (figure 4).

The fifth question analysed whether consumers prefer to read reviews written by real people rather than AI-generated ones.

The distribution of responses is as follows: A relative majority (46%) prefer reviews written by real people, indicating a clear preference for authenticity and human experience. However, 24.67% of respondents disagree, suggesting openness to AI-generated reviews. These respondents appreciate AI-generated reviews either out of curiosity or because the information provided by AI can index a large amount of data, much superior in quantity compared to that of a person (figure 5).

The sixth question analysed respondents' concern about the authenticity of online reviews, and the distribution of responses is as follows: The majority of respondents (48%) are not concerned about the authenticity of online reviews, while 32.66% are quite interested in the reality behind the words. This suggests a general trust in online reviews, but there is a significant segment with concerns.

It should be noted that respondents cannot always determine whether a review is authentic or not, as it has been shown over time that many consumer opinions can be influenced by various marketing strategies of the retailer. It should also be noted that globally, social media pages have been discovered that urge consumers to purchase in a favourable manner towards certain retailers (figure 6).

The seventh question analysed whether AI-generated reviews improve the online shopping experience. The distribution of responses is as follows: Opinions are quite balanced, with 39.34% (strongly agree + agree) considering that AI-generated reviews improve the shopping experience, while 38.66% (disagree + strongly disagree) do not agree. To increase acceptance and improve user experience, it is necessary to improve the quality and authenticity of AI-generated reviews, promote transparency, and conduct user education campaigns. It should also be noted that many consumer needs or interests in certain products or services are "recorded" in cookies, which facilitates highlighting favourable reviews for previous searches (figure 7).

The eighth question analysed whether AI-generated reviews are impartial. The distribution of responses is as follows: Perception of the impartiality of AI-generated reviews is divided, with 41.33% (strongly agree + agree) considering them impartial, while 41.34% (disagree + strongly disagree) do not agree. To address these concerns, entities must be transparent, implement clear labelling of AI-generated reviews, continuously monitor their quality, and conduct information campaigns to educate users. These measures can help increase trust in AI-generated reviews and improve the user shopping experience (figure 8).

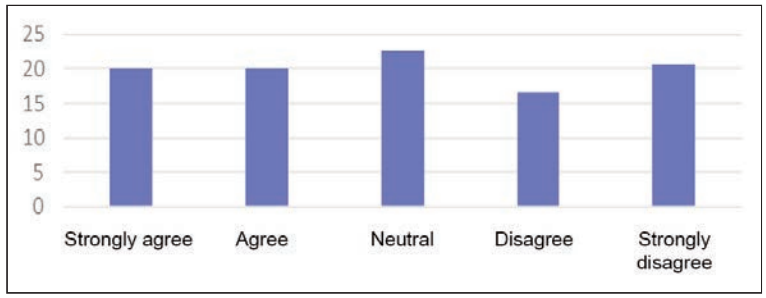

Fig. 4. AI-generated reviews are detailed enough to be useful in purchasing decisions

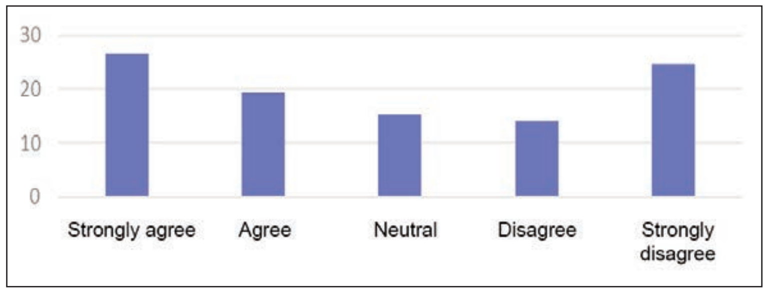

Fig. 5. Consumer preference to read reviews written by real people or generated by AI

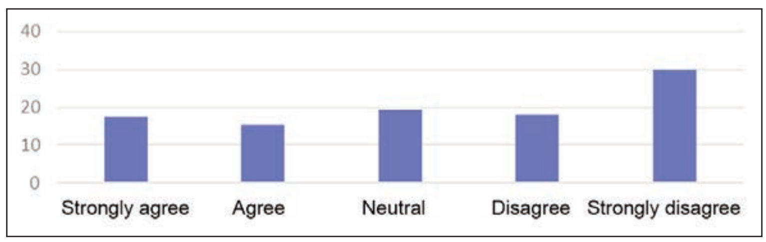

Fig. 6. Concern about the authenticity of online reviews

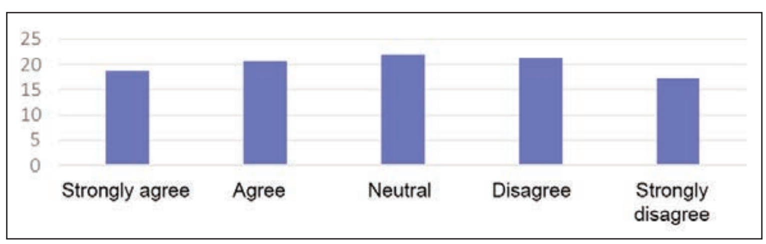

Fig. 7. The extent to which AI-generated reviews improve the online shopping experience

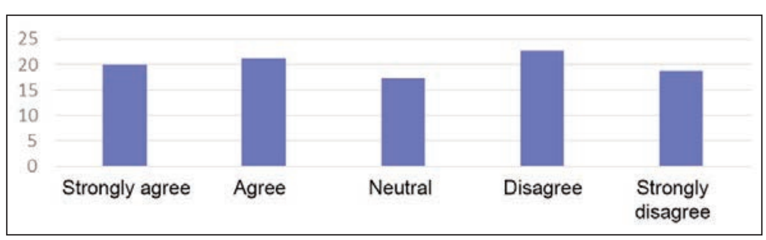

Fig. 8. Impartiality of AI-generated reviews

The ninth question analysed whether AI-generated reviews should be clearly labelled for users. The distribution of responses is as follows: The majority of respondents (44.67%) do not agree that AI-generated reviews should be clearly labelled, while 37.33% agree. This suggests a need for transparency in the use of AI for reviews. It should be noted that the entire phenomenon called “artificial intelligence” will be integrated into everyone’s daily life and will function as a complementary phenomenon to human reviewing actions (figure 9).

The tenth question analysed consumers’ willingness to use AI-generated reviews in their future purchasing decisions. The distribution of responses is as follows: Approximately 42% of respondents are willing to use AI-generated reviews in the future (strongly agree + agree), while 40% are not willing (disagree + strongly disagree). This question shows a polarisation among users regarding their willingness to use AI-generated reviews in the future. Approximately 42% are willing to use them, indicating an openness to this technology, while 40% are hesitant. To increase acceptance of AI-generated reviews, it is essential to improve their quality, promote transparency, and conduct user education campaigns (figure 10).

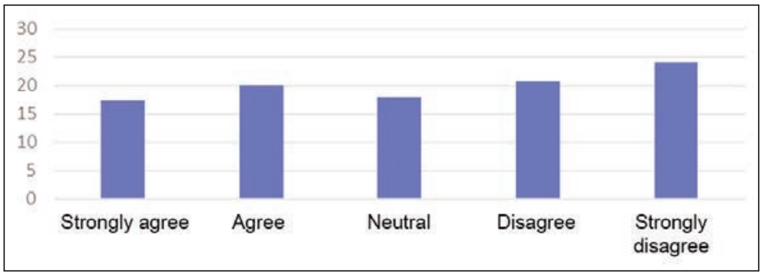

Fig. 9. Clear labelling of online reviews for users

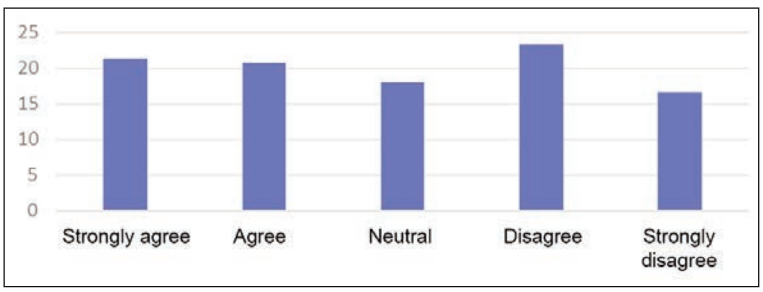

Fig. 10. Consumers’ willingness to use AI-generated reviewss

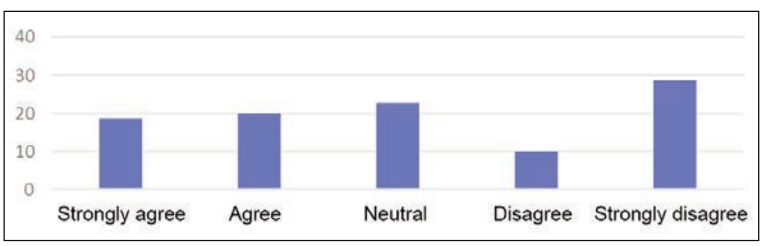

Fig. 11. The degree to which the generation trusts AI-generated reviewss

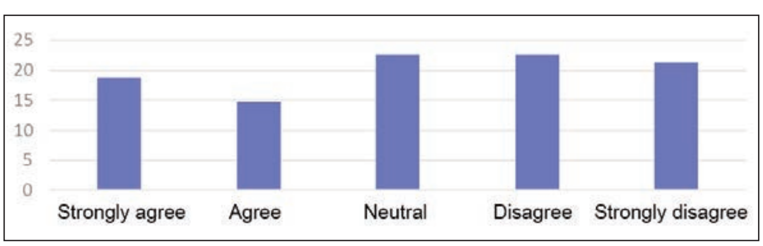

Fig. 12. The degree of coherence and argumentation of online reviews

The eleventh question analysed whether “My generation trusts AI-generated reviews”. This question explored the idea that there is a direct link between age and how new technologies are interacted with. The distribution of responses is as follows: Generational trust in AI-generated reviews is variable, with 38.67% (strongly agree + agree) trusting them, while 38.67% do not trust them (strongly disagree + disagree). The question regarding generational trust in AI-generated reviews shows a clear separation between those who trust and those who do not trust these reviews. To increase acceptance and trust, it is essential to promote transparency, improve the quality of AI-generated reviews, and conduct information and education campaigns for users (figure 11).

The twelfth question explored the perception that “AI-generated reviews are well-argued and coherent”. The distribution of responses is as follows: Perception of the argumentation and coherence of AI-generated reviews is divided, with 33.34% (strongly agree + agree) considering them well-argued and coherent, while 44% (disagree + strongly disagree) do not agree. The question regarding the argumentation and coherence of AI-generated reviews shows a predominantly negative perception, with a significant segment of users not considering these reviews to be well-argued and coherent. To increase acceptance and trust in AI-generated reviews, it is essential to improve their quality, collect user feedback, and conduct education and information campaigns (figure 12).

Demographic insights

The average age of respondents was approximately 40 years, predominantly women from urban areas. The age distribution was as follows: 20% under 30 years old (Generation Z), 35% between 31–45 (Millennials), 30% between 46–60 (Generation X), and 15% over 60 (Baby Boomers). Educationally, 72% held higher education degrees, and 68% were employed in sectors involving frequent interaction with digital technologies. This demographic spread provides a representative snapshot of generational diversity relevant to technology adoption and trust in AI. Respondents are characterised by independence, adaptability, and solid education. They entered the labour market during the transition to the digital era and emphasised the balance between professional and personal life. Generation X is competent in using technology, emphasising financial stability and saving due to the economic crises they experienced, which can justify the conservative tone of many responses.

The results of the research were also used to develop an empirical model based on the previously established hypotheses. The empirical model developed in this research explores the relationships between awareness of AI-generated reviews, user attitudes towards these reviews, trust in online reviews, and the intention to use AI-generated reviews. According to the formulated hypotheses, awareness of AI-generated reviews varies significantly across different age groups and positively impacts both users' attitudes towards these reviews and directly influences their intention to use them. Additionally, a positive attitude towards AI-generated reviews enhances trust in online reviews, which in turn increases the intention to use such reviews.

For the construction of the research variables, the defining items were derived from the questions included in the administered questionnaire. The analysis and interpretation of the data were conducted using the WarpPLS software, which is suitable for Partial Least Squares Structural Equation Modelling (PLS-SEM). WarpPLS allows for the estimation of complex relationships between latent variables and is frequently used in empirical research due to its ability to handle smaller datasets and relax data distribution assumptions compared to traditional SEM methods. The use of WarpPLS in this analysis enabled the evaluation of the significance of the hypotheses and the predictive power of the model, following the recommendations from the relevant literature [27, 28].

To develop a representative SEM analysis, it is essential to evaluate the accuracy of the data and the complexity of the variables used (including the quality of the items and the completeness of each analysis), as well as their consistency and validity. For this purpose, evaluation indicators such as Cronbach's alpha and average variance extracted (AVE) are employed (table 1) [29]. The Cronbach's alpha statistic is used to assess the reliability of the measurement, defined as the degree to which the results are error-free and consistent. To provide a measure of internal consistency [30], this indicator must be represented by a number between 0 and 1, as shown in the table. The WarpPLS software highlights the relationships between variables, and their validity and confirmation are assessed based on the accuracy of the items from which they were derived.

Consequently, the AVE's average validity test is applied; if it meets the coefficient classification criterion, it indicates that the measurements are of high quality and can be used to validate convergence. According to the literature, the reliability coefficient values must exceed the threshold of 0.5 and be lower than any other values provided in each column [31].

Discriminant validity was achieved, indicating that the measurements appropriately reflect the definition and application of the variables within the proposed conceptual model, as shown in table 2.

According to the guide provided by the creator of the WarpPLS software, discriminant validity is assessed through the correlation table among latent variables. In this context, the square roots of the average variances extracted (AVE) are placed on the diagonal and are used to demonstrate that the measurement instruments comply with international standards for discriminant validity testing. To meet the criteria for

Table 1

LATENT VARIABLE COEFFICIENTS

Evaluation indicators	Trust	Int_to_	User_aw	User_Pe	Atitude
Cronbach's alpha	0.819	0.838	0.596	0.618	0.559
Average variances extracted	0.628	0.547	0.518	0.513	0.490
Q-squared	0.875	0.798	-	-	0.839
R squared	0.877	0.852	-	-	0.853

Table 2

CORRELATIONS AMONG LATENT VARIABLES WITH THE SQUARE ROOT OF AVES (EXTRACTED AVERAGE VARIANCE)

Variables	Trust	Int_to_	User_aw	User_Pe	Atitude
Trust	(0.793)1	0.640	0.339	0.767	0.686
Int_to_	0.640	(0.740)	0.601	0.490	0.517
User_aw	0.339	0.601	(0.720)	0.133	0.409
User_Pe	0.767	0.490	0.133	(0.716)	0.565
Atitude	0.686	0.517	0.409	0.565	(0.700)

this test, the square root of the average variance extracted for each latent variable must be greater than any correlation involving that latent variable. Within the latent variable correlation table, the diagonal values of the square roots of the AVE must exceed the values above or below them in the same column. In other words, these diagonal values must be larger than any other value in the same row, whether to the left or right. Given the symmetry of the values in the correlation table, this confirms the initial assumption, namely that there is no 1:1 relationship between the latent variables analysed.

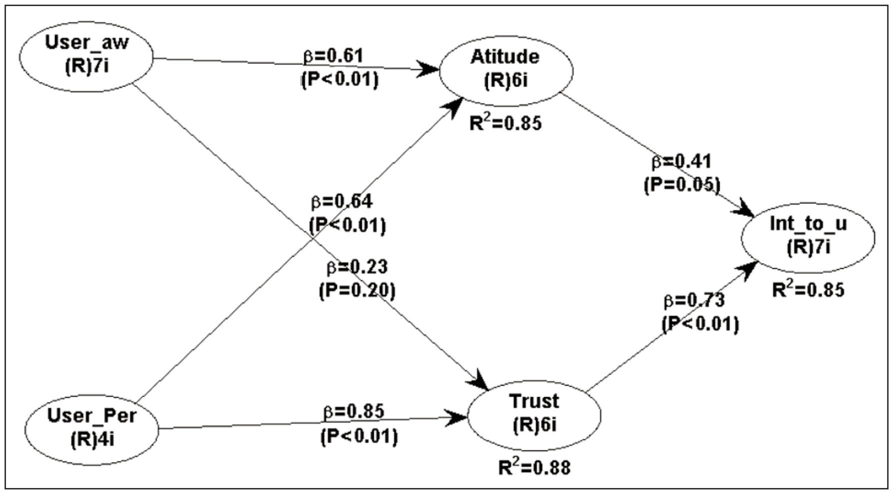

Fig. 13. The proposed conceptual model

The resulting model is presented in figure 13.

The variables are as follows: User_aw – User Awareness, User_Per – User Perception, Attitude – User Attitude, Trust – User Trust, Int_to_u – Intention to Use.

The proposed model examines the relationships between several key variables: User Awareness (User_aw), User Perception (User_Per), User Attitude (Attitude), User Trust (Trust), and Intention to Use (Int_to_u), all of which are central to understanding the adoption of AI-generated reviews. This model was evaluated using WarpPLS, a tool that provides insights through path coefficients (β) and associated p-values, allowing for the assessment of the strength and significance of the hypothesised relationships.

Starting with Hypothesis 2, which posits that awareness of AI-generated reviews positively influences users' attitudes towards these reviews, the analysis shows a significant positive relationship (β=0.61, p<0.01). This result suggests that as users become more aware of AI-generated reviews, their attitudes towards these reviews improve, confirming the hypothesis. This finding is consistent with existing literature, such as the work of Feliciano-Cestero et al. [4], which underscores the critical role that awareness plays in shaping user attitudes toward AI technologies.

Moving on to Hypothesis 3, which suggests that a positive attitude towards AI-generated reviews enhances trust in online reviews, the model provides strong support for this relationship (β=0.73, p<0.01). The significant positive path coefficient indicates that users who have favourable attitudes towards AI-generated reviews are more likely to trust online reviews in general. This aligns with previous research, like that of Porter and Heppelmann [1], which highlights the importance of positive user attitudes in building trust in AI-driven technologies.

Hypothesis 4, which examines the relationship between trust in online reviews and the intention to use AI-generated reviews, is also supported by the model (β=0.73, p<0.01). The data indicates that higher levels of trust in online reviews significantly increase users' intentions to use AI-generated reviews. This finding is corroborated by literature, such as the studies by Patil and Rane [19], which emphasise the critical role of trust in influencing behavioural intentions, particularly regarding the adoption of new technologies.

Hypothesis 5, which proposes that awareness of AI-generated reviews directly and positively influences the intention to use these reviews, receives partial support. The path coefficient for this relationship is positive (β=0.41), but the p-value (p=0.05) suggests that this relationship is only marginally significant. While awareness does have a direct effect on intention, it appears to be weaker than expected, indicating that other factors, such as trust and attitude, might play a more substantial role. This nuanced finding echoes the research of Eloundou et al. [15], which suggests that awareness alone may not be sufficient to drive intention; it must be coupled with other factors like trust.

An additional observation from the model is the strong and significant relationship between User Perception (User_Per) and Trust (β=0.85, p<0.01). Although this was not directly tied to any specific hypothesis in the model, it suggests that user perceptions significantly influence their level of trust. This relationship is well-documented in the literature, with studies like those of Patil and Rane [19] exploring how user perceptions of AI impact trust and subsequent adoption behaviours.

In summary, the model provides robust evidence that awareness, attitude, and trust are crucial factors influencing the intention to use AI-generated reviews. While awareness significantly impacts attitude and, to a lesser extent, intention, the primary drivers of trust and intention appear to be user perception and positive attitudes towards AI-generated content. These findings align with the broader body of research that emphasises the importance of trust and user perception in the adoption of new technologies, as discussed in sources such as Kock [27] and Hair et al. [28].

The conceptual model was tested using WarpPLS and yielded statistically significant results, validating all but one hypothesis with high confidence levels ($p<0.01$). Compared to earlier models, such as those analysing electronic word-of-mouth (eWOM), this research introduces the novel dimension of AI authenticity perception. While traditional models focus on user-generated content, our approach integrates generative AI's impact, offering a timely expansion in the context of Industry 4.0 digital behaviours.

DISCUSSION

This article presents a broad spectrum of awareness and perception regarding AI-generated reviews, demonstrating not only a variety of opinions but also notable demographic differences. Firstly, user awareness of AI-generated reviews is uneven, with approximately 48% recognising that many online reviews are produced by AI algorithms, while a significant 32% are unaware. This division reflects a clear need for more effective user education regarding AI's role in content generation.

In terms of perception, the study reveals a clear split in the perceived utility of AI-generated reviews. Almost half of the respondents consider these reviews as useful as human-written ones, highlighting a notable acceptance of the technology. However, a similar percentage does not share this view, indicating significant resistance to accepting AI-generated reviews as equivalent to human reviews. This divergence in perception indicates a need for adjustments in how AI reviews are presented and contextualised to improve acceptance.

Regarding trust and authenticity, user trust in AI-generated reviews remains low, with 43% expressing a lack of trust. This suggests that human authenticity is still seen as an essential factor in evaluating online reviews. Additionally, concerns about authenticity are significant, emphasising the need for greater transparency and clear labelling to assure users of these reviews' authenticity.

Generational differences reveal how AI-generated reviews are perceived and used. Older generations, such as Baby Boomers and Generation X, show greater caution and preference for human-written reviews, relying primarily on trusted sources and personal experiences. In contrast, Millennials and Generation Z, being digital natives, are much more open to technology and frequently use online reviews for quick decisions. Generation Z, in particular, prefers video reviews and those posted on social media platforms, reflecting a different level of interaction and information consumption.

Moreover, when analysing digital consumer behaviour, previous studies in online retail environments have emphasised the crucial role of electronic word-of-mouth (eWOM) in shaping trust and purchase intentions. Structural equation modelling (SEM) analyses confirm that digital information, including AI-generated content, must be perceived as authentic to influence behaviour effectively [33]. These findings reinforce the importance of transparency and user education in platforms that integrate AI-based review systems.

The impact of AI-generated reviews on the shopping experience is also a central aspect of our study. Opinions on the utility and detail of these reviews are relatively balanced. Approximately 40% of respondents consider AI reviews sufficiently detailed for purchasing decisions, while a similar percentage disagrees, emphasising the need to improve the quality and detail provided by AI reviews to better meet user expectations.

Transparency and labelling of AI-generated reviews are crucial points of interest. Most respondents do not agree with the need for clear labelling, suggesting a gradual acceptance of AI as an integral part of the review process. However, a significant percentage believes that transparency in AI use is essential to increase trust and user acceptance.

The intention to use AI-generated reviews in the future shows a clear polarisation among respondents. Approximately 42% are willing to use these reviews in their future purchasing decisions, while 40% are reticent, indicating a need for user education and trust-building.

AI tools, such as auto-generated reviews, have the potential to encourage more eco-conscious decisions in textile consumption by improving access to relevant product information, sustainability claims, and customer experiences. For this to occur, platforms must ensure transparency, ethical AI deployment, and consumer education. Bridging generational gaps in trust and awareness is key to achieving sustainability goals in the digital commerce space.

This analysis highlights the need for clear education and transparency measures to improve user perception and trust in AI-generated reviews. Companies must conduct effective educational campaigns, implement clear labelling of AI reviews, and continuously improve their quality to meet user expectations and increase acceptance. Adapting marketing strategies based on generational preferences and enhancing the shopping experience through AI reviews are essential to fully leverage this emerging technology's potential.

CONCLUSIONS

The study provides valuable insights into the demographic characteristics, awareness, and perceptions of AI-generated reviews among respondents, predominantly from Generation X, who exhibit a cautious and balanced approach to technology. The findings indicate significant generational differences in how AI-generated reviews are perceived and used, with younger generations being more open to and reliant on technology, while older generations prefer traditional, human-written reviews. This highlights the importance of tailoring AI technologies to meet the distinct preferences of different age groups.

The empirical model developed in this research demonstrates that awareness, attitude, and trust are critical factors influencing the intention to use AI-generated reviews. Specifically, awareness significantly impacts users' attitudes, which in turn enhances their trust in online reviews, ultimately influencing their intention to use AI-generated reviews. However, awareness alone may not be sufficient to drive intention, as indicated by the marginal significance of the direct effect of awareness on intention. This suggests that other factors, such as trust and user perception, play a more substantial role in shaping users' intentions.

The analysis also reveals that trust in AI-generated reviews remains low, with a significant portion of respondents expressing scepticism towards the authenticity of these reviews. This underscores the necessity for greater transparency and clear labelling of AI-generated content to build trust and increase user acceptance. Additionally, the polarisation in respondents' willingness to use AI-generated reviews in future purchasing decisions indicates a need for continuous user education and trust-building efforts.

Overall, the findings emphasise the need for textile companies and online retail platforms to implement effective educational campaigns, improve transparency, and enhance the credibility of AI-generated reviews as a tool to support sustainable consumption. By addressing these concerns and adapting marketing strategies to cater to generational preferences, companies can better leverage the potential of AI-generated reviews to enhance the consumer experience and drive adoption of this emerging technology.

Nonetheless, it is crucial to acknowledge that artificial intelligence cannot replace human cognitive processes, critical thinking, or emotional judgment. AI should be viewed as a supportive tool in the decision-making process, rather than a substitute. Its capacity to enhance efficiency and access to information does not equate to the depth of human perception or ethical responsibility. Responsible AI use must incorporate these limitations.

Furthermore, innovation in digital content consumption must be aligned with technological advances in other sectors. For example, nanotechnologies in healthcare have been paired with digital systems to enhance diagnosis and therapy precision [34]. Drawing a parallel, the use of AI in content generation, including reviews, should follow similar interdisciplinary innovation principles that ensure accuracy, user safety, and ethical deployment.

These actions are essential for ensuring the sustainable development of digital socio-technical systems that depend on trust, transparency, and adaptive communication between AI technologies and users. As AI becomes embedded in digital consumer ecosystems, its responsible implementation can foster more sustainable consumption. Stakeholders, developers, marketers, and regulators must ensure that AI tools like review generators are transparent, fair, and aligned with the goals of sustainable development, especially in promoting informed, responsible consumer decisions.

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Production of woven aramid based protective equipment and improving its ballistic performance

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ABSTRACT – REZUMAT

Production of woven aramid based protective equipment and improving its ballistic performance

In this study, various ballistic armour materials were designed using aramid fibre fabrics. Initially, soft armour designs were tested according to NIJ 0101.03 Level II standards across different configurations. However, the trauma depths observed in these tests exceeded the acceptable limits defined by the standards. To address this, a hard armour design was developed by incorporating reinforcement elements, such as silicon dioxide, graphene nanoplatelets, multi-walled carbon nanotubes, and Ti_3AlC_2 (MAX phases) powders, into the aramid fabrics. These reinforcements were mixed with vinylester resin at concentrations of 3%, 5%, and 10%. The resulting mixture was impregnated into 25-layer aramid fabrics arranged in different orientations to produce composite plates. Ballistic tests were conducted on these plates in accordance with NIJ 0101.03 Level III standards. The tests revealed that the hybrid composite structure absorbed a substantial amount of energy, particularly in the central region of the plates. Plates reinforced with graphene nanoplatelets exhibited penetration under ballistic testing, but an improvement in ballistic performance was observed as the reinforcement density increased. Among all reinforcements, the best ballistic performance was achieved with Ti_3AlC_2 (MAX phase) additives. As a result, prototype designs with enhanced protection levels and improved ballistic performance were successfully produced.

Keywords: *aramid fibres, protective equipment, ballistic performance, ballistic*

Producția de echipamente de protecție pe bază de țesături aramidice și îmbunătățirea performanței balistice a acestora

În cadrul acestui studiu, au fost proiectate diverse materiale balistice pentru armuri utilizând țesături din fibre aramidice. Inițial, modelele de armuri moi au fost testate în conformitate cu standardele NIJ 0101.03 Nivel II în diferite configurații. Cu toate acestea, adâncimile traumatismelor observate în aceste teste au depășit limitele acceptabile definite de standarde. Pentru a remedia această problemă, a fost dezvoltat un model de armură rigidă prin încorporarea unor elemente de armare, precum dioxid de siliciu, nanoplachete de grafen, nanotuburi de carbon cu pereți multipli și pulberi de Ti_3AlC_2 (faze MAX) în țesăturile aramidice. Aceste elemente de armare au fost amestecate cu rășină vinilesterică în concentrații de 3%, 5% și 10%. Amestecul rezultat a fost impregnat în țesături aramidice cu 25 de straturi dispuse în diferite orientări pentru a produce plăci compozite. Testele balistice au fost efectuate pe aceste plăci în conformitate cu standardele NIJ 0101.03 Nivel III. Testele au arătat că structura compozită hibridă a absorbit o cantitate substanțială de energie, în special în zona centrală a plăcilor. Plăcile armate cu nanoplachete de grafen au prezentat penetrare în timpul testelor balistice, dar s-a observat o îmbunătățire a performanței balistice odată cu creșterea densității armăturii. Dintre toate armăturile, cea mai bună performanță balistică a fost obținută cu aditivi Ti_3AlC_2 (faza MAX). Prin urmare, au fost produse cu succes prototipuri cu niveluri de protecție sporite și performanță balistică îmbunătățită.

Cuvinte-cheie: *fibre aramidice, echipamente de protecție, performanță balistică, balistic*

INTRODUCTION

The defence industry is continuously evolving with advancements in engineering applications. The increasing sophistication of firepower and destructive systems has amplified the need for protection. In response, there is a demand for lightweight armour designs that do not compromise personnel mobility. Fibre-reinforced polymer composites have become key materials in advanced engineering applications due to their superior mechanical properties, such as high strength, stiffness, and low weight [1–4]. Furthermore, their adaptability to various shapes enables customisation to meet specific requirements.

The ballistic performance of an armour system is often defined in terms of its “energy absorption” capability [5–7]. Aramid fibre fabrics exhibit significantly higher ballistic performance compared to metallic materials. To further enhance energy absorption and achieve greater energy dissipation, various nanofillers, such as graphene-based fillers, carbon nanotubes, SiO_2, and Ti_3AlC_2, are incorporated into the polymer matrix. These hybrid nanocomposites are a promising solution for engineering applications, offering improved performance in areas like ballistic protection while reducing cost and weight [8–10].

Several studies have been conducted to explore these advancements. For example, Cao et al. [11] investigated the ballistic capabilities of aramid fabrics impregnated with a shear-thickening fluid (STF) containing Pst-EA nanospheres at varying densities. They found that higher reinforcement density improved slip resistance by increasing friction between fabric threads, significantly enhancing the fabric's tear resistance. Similarly, Gao [12] studied the microstructure, mechanical properties, and fracture mechanisms of ceramic plates made from Ti_3AlC_2 powders sintered at different temperatures and durations. Their results indicated that as the density of the plates increased, their strength and fracture toughness improved, with a 15% increase in fracture toughness observed. They concluded that Ti_3AlC_2 powders could enhance energy absorption through increased strength and fracture toughness.

Costa et al. [13] designed and produced personal protective armour reinforced with graphene-based nano-pallets on aramid and jute fabrics. Their cost-benefit analysis revealed that hybrid nanocomposites could reduce armour weight and cost by 7% and 40%, respectively, without compromising performance. Xu et al. [14] examined the ballistic performance of two types of B_4C incorporated into an STF with SiO_2, producing samples with different combinations. Their ballistic tests showed that single-layer Twaron fabric treated with pure STF increased the ballistic limit velocity from 114 m/s to 160 m/s. Moreover, they found that a three-layer B_4C/STF/Twaron composite outperformed three layers of pure Twaron but was less effective than four layers of pure Twaron. An optimisation study demonstrated that placing one layer of B_4C/STF/Twaron composite in front of five layers of pure Twaron could improve overall ballistic resistance by 10% while maintaining similar areal density.

Divya et al. [15] used finite element modelling to compare the ballistic performance of carbon nanotubes (CNTs) and Kevlar fabrics under identical threat and boundary conditions. Their results showed that CNTs outperformed Kevlar, with significantly lower maximum deformation values, suggesting that CNTs should be more widely adopted in ballistic applications.

In this study, the ballistic performance of plates enhanced with carbon nanotubes, graphene, SiO_2, and Ti_3AlC_2 (MAX phases) will be comprehensively evaluated at the NIJ Level III standard. The evaluation will involve CT 709 plain weave and CT 736 2×2 basket weave fabrics.

Table 1

MATERIALS USED IN THE PROJECT AND COMPANIES SUPPLIED

Material	Company
Multi-Walled Carbon Nanotube	Nanograph
Silicone Dioxide (SiO_2) Nanopowder	Nanograph
Graphene Nanoplatelet	Nanograph
Ti_3AlC_2 MAXene	Nano Chemazone
CT-709 Aramid	Teijin
CT 736 Aramid	Teijin
Vinylester	Composite market

MATERIALS AND METHODS

Materiel

In this study, the initial phase involved designing soft (unreinforced) armour using aramid fabrics with varying layer counts between 6 and 32. For this purpose, CT-709 and CT-736 aramid fabrics were cut to the required dimensions, and multiple designs were created based on the number of layers.

The study utilised four different reinforcement elements: Multi-Walled Carbon Nanotubes (MWCNTs), Graphene Nanoplatelets, SiO_2 Nanopowder, and Ti_3AlC_2 (MAX phases). CT-709 and CT-736 ballistic fabrics were incorporated, with Vinylester resin serving as the matrix material. Figure 1 illustrates the materials used in the scope of the project, while table 1 provides a list of the suppliers for the relevant materials.

Figure 1 presents the SEM images of the four reinforcement elements utilised in the project: Multi-Walled Carbon Nanotubes, Graphene Nanoplatelets, SiO_2 Nanopowder, and Ti_3AlC_2 (MAX phases). These SEM images were provided by the respective suppliers.

General properties of Aramid woven fabric CT 709 and CT 736 ballistic fabrics as reinforcement are given in table 2.

The properties of the fibres used in the preparation of reinforcement structures are given in table 3.

Close-up views of the Aramid woven fabrics used in the study are shown in figure 2.

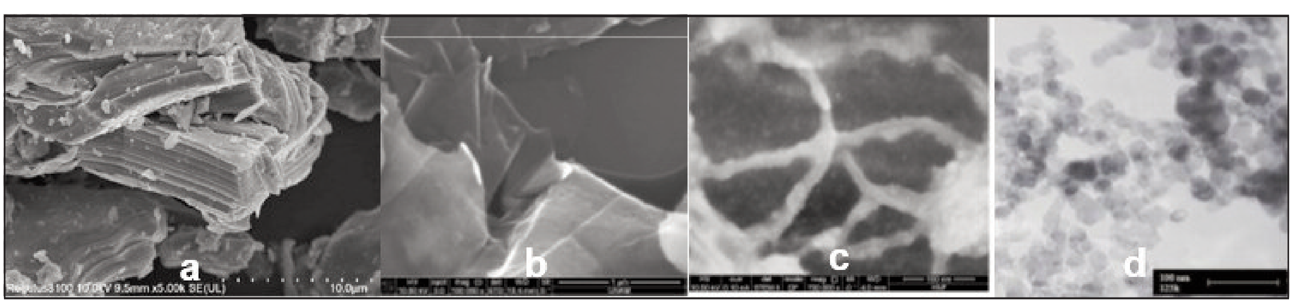


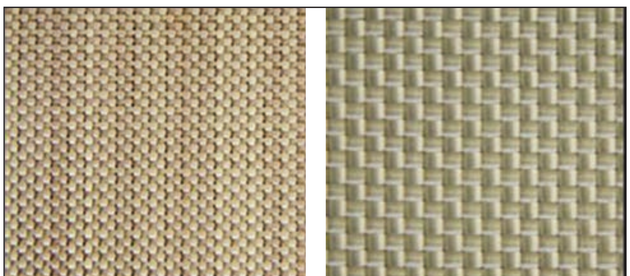
Fig. 1. SEM images of reinforcement elements purchased for use in ballistic armour production: *a* – Ti_3AlC_2; *b* – Graphene Nanoplatelet; *c* – Multi-Walled Carbon Nanotube; *d* – SiO_2

Table 2

PROPERTIES OF ARAMID WOVEN FABRIC CT 709 AND CT 736 MATERIALS						
Reinforcement type	**Knitting type**	**Warp/Fill direction of threads (0° – 90°)**	**Thread density (thread/10 cm)**	**Field density (g/m^2)**	**Fold warp/fill (%)**	**Reinforcement thickness (mm)**
Aramid woven fabric CT 709	Plain	Twaron 2000/ Twaron 2000	117/117	220	0.2/0.2	0.23
Aramid woven fabric CT 736	2*2 Basket weave	Twaron 2000/ Twaron 2000	336/336	410	0.8/0.8	0.6

Table 3

MECHANICAL PARAMETERS OF ARAMID FIBRES				
Fabric Name	**Young's modulus (GPa)**	**Stress (cN/Tex)**	**Maximum elongation (%)**	**Density (g/cm^3)**
Twaron 2000	85	235	3.5	1.44



a *b*

Fig. 2. Fabrics used in armour production: *a* – CT 709 Plain weaving; *b* – CT 736 2×2 Basket weaving [16]

a *b* *c*

Fig. 3. Cutting stages of aramid fabrics: *a* – preparation of 30×30 cm dimensions; *b* – cutting with an aramid cutting knife; *c* – cutting fabrics

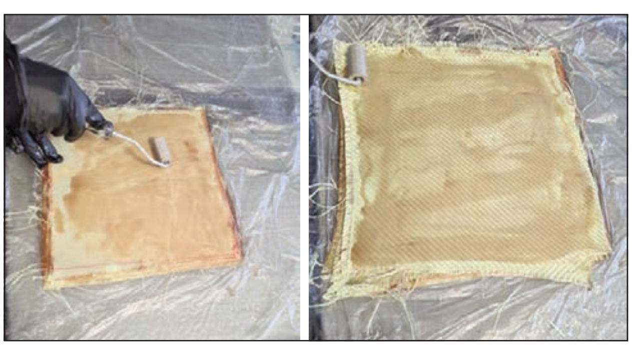


Fig. 4. The process of impregnating fabrics with resin by the hand-laying method

Methods of production of reinforced composite armour

Ballistic fabrics were cut in 30 cm × 30 cm dimensions with an aramid fibre cutting knife, as shown in figure 3. Composite armour plates were fabricated using Al_3C_2 reinforcements and vinylester resin, employing the hand-laying technique for layer-by-layer assembly (figure 4). Each plate consisted of a total of 25 layers: the first 10 layers were CT-709 fabric, followed by 5 layers of CT-736 fabric, and concluded with another 10 layers of CT-709 fabric. This hybrid composite structure was designed to maximise energy absorption by causing the projectile to change direction within the middle layers of the armour. A control sample (C0) was also produced without any reinforcement elements to serve as a baseline for comparison. During the production process, the hot press machine was preheated to 90°C, and the composite was pressed for 20 minutes under a pressure of 10 bar once the temperature was reached. After this, a rapid cooling process was applied for 10 minutes, maintaining the same pressure of 10 bar.

Following the impregnation of resin onto the fabric using the hand-laying method, the curing process was performed using a hot-pressing machine, as illustrated in figure 5. The hot press machine was preheated to 110°C, and the composite was subjected to a pressure of 10 bar for 60 minutes once the target temperature was reached. Subsequently, a rapid cooling process was applied for 10 minutes while maintaining the same pressure of 10 bar. This process enhanced the adhesion between the resin and the fabric, resulting in improved composite integrity. The final samples produced are shown in figure 6.

In this study, experimental factors and their corresponding levels were determined to evaluate their effects on the response variable, as outlined in table 4. By systematically altering the input variables, their impact on the response variable was analysed and interpreted in a structured manner.

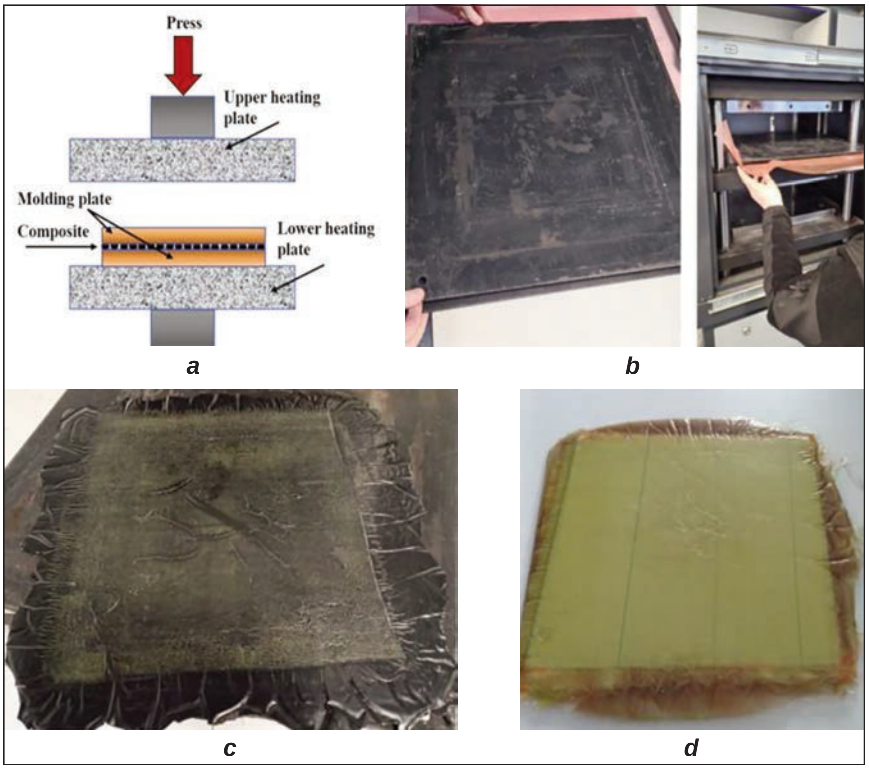


Fig. 5. Photos of: *a* – schematic picture of hot press; *b* – curing process of resin impregnated samples in hot press; *c* – sample with reinforcement added; *d* – sample without reinforcement element

Table 4

PROPERTIES OF THE COMPOSITE PLATES USED IN THIS STUDY			
Sample code	**Reinforcement element**	**Reinforcement rate**	**Weight (g)**
C0	-	0%	1300
C1	Graphene Nanoplatelet	3%	1325
C2	Graphene Nanoplatelet	5%	1349
C3	Graphene Nanoplatelet	10%	1351
C4	SiO_2 Nanopowder	3%	1344
C5	SiO_2 Nanopowder	5%	1344
C6	SiO_2 Nanopowder	10%	1348
C7	$Ti_3 AlC_2$	3%	1367
C8	$Ti_3 AlC_2$	5%	1369
C9	$Ti_3 AlC_2$	10%	1371
C10	Multi Walled Carbon Nanotube	3%	1351
C11	Multi Walled Carbon Nanotube	5%	1356
C12	Multi Walled Carbon Nanotube	10%	1357

Performing shooting tests

In the first phase of testing, a test apparatus conforming to NIJ 0101.03 Level II standards was utilised. The setup featured a 5-meter distance between the firearm's muzzle and the target. A velocity measurement device was positioned at the midpoint of this distance, precisely 2.5 meters from the target. An MP5 pistol was employed during the trials. The bullets used in the tests had a core weight of 8 grams and a diameter of 9 mm, with a total weight of 12 grams, including the core, gunpowder, and cartridge. These bullets, all with a round nose and full metal jacket, were supplied by the Turkish Machinery and Chemical Industry Corporation. Bullet velocities were measured using a ProChrono model chronograph, based on photoelectric principles, manufactured by Competition Electronics Inc. After each shot, the velocity was displayed digitally on the device. As per NIJ standards, Type 1 Roman Plastilina (clay) was employed as the backing material. The clay was prepared in a box according to standard specifications. Targets were marked by placing tape on the front surface of the panels. These tests were conducted at no cost at the Bursa Police College Shooting Range. In the second phase, ballistic tests adhered to NIJ 0101.03 Level III standards using the setup shown in figure 7. In this configuration, the distance between the firearm's muzzle and the target was 15 meters. A velocity measurement device was placed at the midpoint of the trajectory, 12 meters from the target. Full metal jacket (FMJ) bullets with a diameter of 7.62 mm, a length of 26.8 mm, and a weight of 9.7 grams were used. A bullet was classified as achieving full penetration if it either pierced through the panel completely or caused material displacement from the

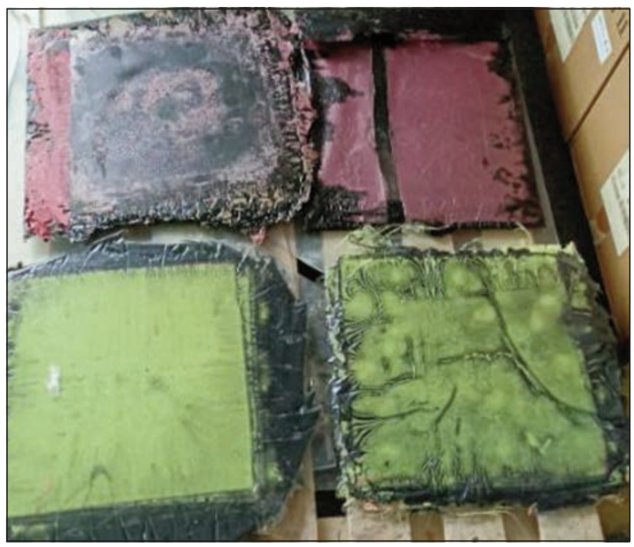


Fig. 6. Completed composite samples

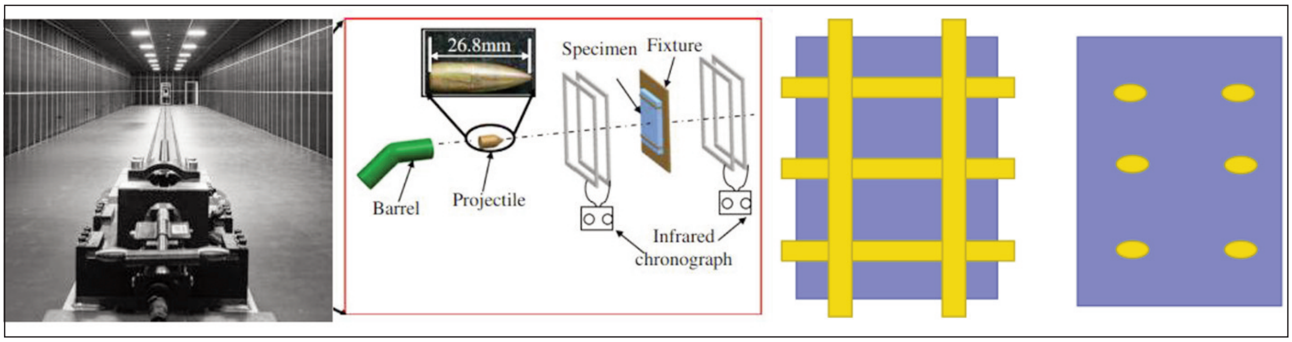


Fig. 7. Schematic illustration of the testing apparatus [17]

Fig. 8. Test setup and examples of tested samples

back of the panel. All other outcomes were recorded as partial penetration. The second-stage ballistic tests were conducted without charge at the NUROL Technology ballistic laboratories, as shown in figure 8. Firing tests were conducted in accordance with NIJ standards. A chronograph device was integrated into the test setup to measure muzzle velocity. The chronograph system included an initial photoelectric screen, a final photoelectric screen, and a data recording system. The tests utilised an OEHLER Research photoelectric display chronograph. Additionally, a test barrel approved by NIJ standards, capable of accommodating a barrel length of 56 cm and designed to withstand maximum pressure, was employed. To ensure accurate muzzle velocity measurements, the barrel was pre-heated by firing single shots prior to testing. The test firearm incorporated a firing mechanism compliant with the standards set by the American International Standards Institute (ANSI) and the Sporting Arms and Ammunition Manufacturer's Institute (SAAMI). The test setup also included a shooting stand that could accommodate barrels of various sizes and calibres, enabling precision firing. Muzzle velocity was calculated by averaging the highest partial penetration velocities and the lowest full penetration velocities across an equal number of rounds, typically six shots per series. The projectile-armour interaction followed the mathematical principles of probability distribution, where the probability of penetration approaches zero at low speeds, approaches unity at high speeds, and increases progressively between these extremes as velocity increases. Table 5 provides the specifications of the ammunition used for NIJ Level II and Level III firing tests.

Determination of trauma depth and diameter

If the bullets do not penetrate the panels after firing, a trauma of a certain diameter and depth forms in the backing material. The depth of this trauma indicates the impact of the bullet on the back of the panel. Following each shot, the depth of the trauma was measured using a calliper with a precision of ±0.02 mm. To better analyse the trauma geometry, a mould was prepared to replicate the trauma shape.

During testing, the kinetic energy from the ballistic impact caused the flat-surfaced backing material positioned behind the ballistic test panel to deform. According to NIJ Level III standards, the maximum allowable depth for such deformation is 44 mm. The

Table 5

CHARACTERISTICS OF AMMUNITION USED FOR NIJ LEVEL II-III SHOTS AND MINIMUM ALLOWABLE CORE VELOCITY

Protection level	Test ammunition	Nominal core weight (g)	Shot quantity	Minimum core speed (m/s)
II	MP5	8	6	367
III	7.62 308 Winchester FMJ	9.7	6	838

ballistic impact results in depressions and swelling on the flat surface of the clay backing layer. Accurate measurement of these depressions requires the use of a flat surface as a reference to ensure consistent and reliable results. For this reason, trauma values were determined by measuring from the highest point of the swelling to the lowest point of the depression, following this standardised approach.
The depression depth encompasses the area from the region marked with dots in figure 8 to the bottom of the pit, even if it extends below the flat surface. Figure 9 illustrates how the depth of the trauma was measured after each shot.

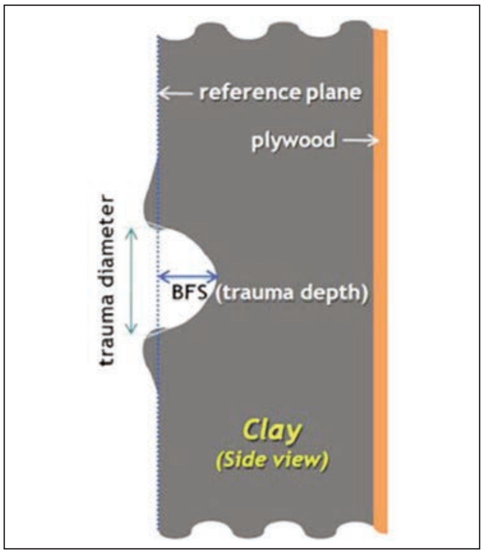


Fig. 9. Determination of trauma depth [17]

RESULTS AND DISCUSSION

When the results of the samples made with unreinforced aramid fabrics in NIJ 0101.03 Level II standards in the first stage were examined, it was seen that the trauma depth exceeded 44 mm. As a result, the 2nd stage was started. At this stage, the experiments were carried out using 7.62 mm FMJ ammunition in accordance with NIJ 0101.03 Level-III. Samples prepared using different reinforcement materials under the same conditions were tested on hot pressed plates. The muzzle velocity applied during the tests (838 m/sec ±15) was within the limits allowed by NIJ III rules.

Depth of trauma

The depth of the trauma occurring in the support material provides information about the ballistic resistance of the energy panels absorbed by the fabric layers. The depth of the trauma shows the effect of the lead energy transmitted behind the panel. If the panels spread the energy over a larger area, the volume of trauma will be lower. If the energy cannot spread over a wide area, a deeper and larger trauma will occur because the same amount of energy affects a smaller area [18, 19]. It is known that as the energy absorbed by the fabric layers increases, the depth and volume of trauma will decrease. It is known that the number of fabric layers has the most significant effect on the depth of trauma, and the increase in the number of fabric layers is the most important parameter in reducing the depth of trauma. However, increasing the number of fabric layers also increases the panel weight. The average trauma depth in a 25-layer fabric was determined as 27.60 mm. In ballistic protection, panel weight should be taken into consideration as well as ballistic performance.

Ballistics and absorbed energies

During a ballistic impact, a shock wave is created in the ballistic plane due to the kinetic energy of the bullet. Some of this energy is absorbed by the fabric layers, and the rest is transmitted to the back of the panel, creating trauma. In panels that emit the energy wave at a higher speed, more energy is absorbed and less energy is transmitted to the back [20–22]. Trauma depth is very important because higher trauma depth causes bone fractures and internal organ bleeding. Therefore, when the panel stops a bullet, it will deform and its strength will decrease. In shooting tests, it was observed that the depth of trauma increased from the first shot to the sixth shot.
Sample configurations and trauma depths performed in the first stage are given in Table 6. The produced samples were tested according to NIJ 0101.03 Level II standards. After the tests, the trauma depths exceeded 44 mm, outside the allowed limits. Since the samples did not meet the standards on the first or 2nd shot, no further shots were made. Therefore, the work continued by adding reinforcement elements to the plates.

Table 6

LAYER THICKNESSES AND TRAUMA DEPTHS PREPARED IN THE STUDY

Sample code	Number of floors	Trauma depth
S1	6	75
S2	8	72.8
S3	10	66.05
Q4	13	64.01
Q5	14	62.04
Q6	15	60.06
Q7	16	58.01
Q8	17	55.80
Q9	18	54.01
Q10	19	52.07
Q11	20	50.05
Q12	32	30.52

Table 7 shows the energy absorption performances of the samples performed in the second stage. The kinetic energy of the bullet is the energy that affects the panels. The produced samples were tested according to NIJ 0101.03 Level-III standards.
Since the mass of the bullet is constant, the energy acting on the panels varies in proportion to the bullet

Table 7

NIJ III Test results			
Sample code	**Average bullet speed (m/s)**	**Trauma depth (mm)**	**Energy absorbed by the panel (EA_{fabric}) (J)**
C0	850	pierced	-
C1	849	pierced	-
C2	857	pierced	-
C3	850	pierced	-
C4	849	pierced	-
C5	852	43	752
C6	851	41	795
C7	853	35	813
C8	848	31	846
C9	849	28	884
C10	858	27	871
C11	852	25	896
C12	848	21	973

speed. Since the bullet speed may vary within tolerances between shots, the energy affecting the panel varies from shot to shot.
The damage characteristics of the plates after firing according to NIJ 0101.03 Level-III are shown in table 7. There is only slight shear deformation and tensile deformation on the front surface of the non-punctured plates.

RESULTS

In this study, various samples were tested for ballistic protection in accordance with NIJ 0101.03 Level II and NIJ 0101.03 Level -III standards. In this context, the results are stated below.
Soft ballistic designs have trauma depths greater than 44 mm. Thanks to the hybrid fabric structure in hard ballistic designs, a significant amount of energy is trapped in the middle part of the composite.
Graphene Nanoplatelet additive did not affect the trauma depth performance of the composite plate.
The sample (C4), produced with 3% SiO_2 reinforcement, was drilled. However, when the reinforcement ratio is 5% (C5) and 10% (C6), the trauma depth is at the desired standards. In addition, it was observed that the absorbed energy values were very close to each other for these two samples.
MultiWallet Carbon Nanotube added samples showed the highest performance. As the nanotube's contribution rate increased, its ability to absorb energy on the plate increased, while the depth of trauma decreased.
Considering the amount of energy absorbed by nanotube reinforced C10 (3%) and C11 (5%) samples, while the C10 sample absorbed 25 J more energy than the C11 sample, the C12 (10%) sample absorbed 77 J more energy than the C11 sample. The C12 sample absorbed 102 J more energy than the C10 sample.
When the weights are compared, the heaviest sample is Multi Walled Carbon. It was found to be Nanotube C12 (10%). However, since there is not a very high difference, it can be said that it is the sample with the highest ballistic performance.
When looking at trauma depths within the framework of standards, the lowest trauma depth is Multi Walled Carbon. The highest trauma depth was SiO_2 when the nanotube belonged to the C12 (10%) sample. Nanopowder C5 (5%) is the sample. The trauma depth of the C5 sample is twice the trauma depth of the C12 sample.
When Ti_3AlC_2 reinforced samples are compared among themselves, when the C8 (5%) and C9 (10%) samples were examined, it was seen that the C7 (3%) sample could absorb 33 J more energy than the C8 sample, and the C9 sample absorbed 38 J more energy than the C8 sample. However, the C9 sample was able to absorb 71 J more energy than the C7 sample. The reinforcement rate increased from 3% to 10%, but the ability to absorb energy increased by 46.47%.
We can list the performance of the reinforcement materials on the plate as follows: Carbon Nanotube > Ti_3AlC_2 > SiO_2 Nanopowder > Graphene Nanoplatelet.

SUGGESTIONS

In this study, the ballistic efficiency of different reinforcement elements at different densities was examined by keeping the fabric coefficient constant. Looking at the results, it was seen that the best performance was obtained with Carbon Nanotubes. In this context, in terms of future studies, the ballistic efficiency of Carbon Nanotube reinforcement can be examined in different fabric layer numbers.
Lighter test samples with better ballistic performance can be obtained by changing the number of layers and reinforcement elements in different combinations.
The directions of the composite fabrics were kept constant within the scope of this study, and the effects of different orientations on ballistic performance can be examined.

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The endoscopic retromuscular approach (laparoscopic and robotic) of lateral abdominal wall hernias – a retrospective analysis from a single centre/single surgeon over 5 years

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ABSTRACT – REZUMAT

The endoscopic retromuscular approach (laparoscopic and robotic) of lateral abdominal wall hernias – a retrospective analysis from a single centre/single surgeon over 5 years

Lateral abdominal wall hernias account for approximately 1–4% of all surgical procedures for abdominal wall repair. The treatment of primary and incisional lateral abdominal wall hernias poses a challenge due to anatomical complexity, given the muscular stratigraphy, adjacent bony structures, and nervous elements, as well as technical difficulties in approach. Currently, there is no standardised surgical technique for the treatment of lateral hernias, with multiple approaches being presented: open, minimally invasive (laparo-endoscopic or robotic), or hybrid. Textile biomaterials are used as a biocompatible interface with the human body, in the form of medical devices, implants and prosthetic systems. The use of knitted biotextiles for non-implantable items and implants has developed greatly in the new field of tissue engineering. We present a 5-year retrospective study that includes cases of primary and incisional lateral abdominal wall hernias treated laparoscopically and robotically in the Centre of Hernia Surgery, Life Memorial Hospital, from June 2016 to December 2022. The study included 24 patients with primary and incisional hernias resolved laparoscopically (eTEP-TAR, eTEP) and 5 cases resolved robotically. The majority of the cases (80.8%) of lateral hernias are incisional; 38.5% are strictly lateral hernias, with the rest having a median component. In the laparoscopic group, eTEP-TAR was performed in 21 cases, and eTEP in 3 cases. In the 5 cases of surgery performed robotically, eTEP-TAR was carried out. No cases of conversion were recorded. For the patients operated on laparoscopically: there was one incident of small bowel injury during adhesiolysis, which was resolved during the same surgical session (with laparoscopic suture). No complications were reported in the group of patients operated on robotically. The average postoperative hospitalisation time was 39 hours. The average follow-up period was 4 years and 6 months, with no complications or recurrences. The eTEP-TAR technique for repairing lateral hernia cases (incisional and primary) is difficult and complex; however, the results are very good if performed correctly, whether laparoscopically or robotically, as demonstrated by the reduced hospital stay, low level of postoperative pain, and rapid recovery of the patients.

Keywords: *robotic eTEP-TAR, abdominal wall reconstruction, incisional hernia, lateral hernia, laparoscopic eTEP abdominal wall reconstruction, textile biomaterials*

Abordarea endoscopică retromusculară (laparoscopică și robotică) a herniilor laterale ale peretelui abdominal – o analiză retrospectivă realizată de un singur centru/un singur chirurg pe o perioadă de 5 ani

Herniile laterale ale peretelui abdominal reprezintă aproximativ 1–4% din toate intervențiile chirurgicale pentru repararea peretelui abdominal. Tratamentul herniilor laterale primare și incizionale ale peretelui abdominal reprezintă o provocare datorită complexității anatomice, având în vedere stratigrafia musculară, structurile osoase adiacente și elementele nervoase, precum și dificultățile tehnice în abordare. În prezent, nu există o tehnică chirurgicală standardizată pentru tratamentul herniilor laterale, existând multiple abordări: deschisă, minim invazivă (laparo-endoscopică sau robotică) sau hibridă. Biomaterialele textile sunt utilizate ca interfață biocompatibilă cu corpul uman, sub formă de dispozitive medicale, implanturi și sisteme protetice. Utilizarea biotextilelor tricotate pentru articole neimplantabile și implanturi s-a dezvoltat foarte mult în noul domeniu al ingineriei tisulare. Prezentăm un studiu retrospectiv pe 5 ani care include cazuri de hernii abdominale laterale primare și incizionale tratate laparoscopic și robotic în Centrul de Chirurgia Herniilor, Life Memorial Hospital, din iunie 2016 până în decembrie 2022. Studiul a inclus 24 de pacienți cu hernii primare și incizionale rezolvate laparoscopic (eTEP-TAR, eTEP) și 5 cazuri rezolvate robotic. Majoritatea cazurilor (80,8%) de hernii laterale sunt incizionale; 38,5% sunt hernii strict laterale, restul având o componentă mediană. În grupul laparoscopic, tehnica eTEP-TAR a fost efectuată în 21 de cazuri, iar eTEP în 3 cazuri. În cele 5 cazuri de intervenții chirurgicale realizate robotic, s-a efectuat eTEP-TAR. Nu s-au înregistrat cazuri de conversie. Pentru pacienții operați laparoscopic: a existat un incident de leziune a intestinului subțire în timpul adeziolizei, care a fost rezolvat în timpul aceleiași sesiuni chirurgicale (cu sutură laparoscopică). Nu au fost raportate complicații în grupul de pacienți operați robotic. Durata medie de spitalizare postoperatorie a fost de 39 de ore. Perioada medie de urmărire a fost de 4 ani și 6 luni, fără complicații sau recidive. Tehnica eTEP-TAR pentru repararea cazurilor de hernie laterală (incizională și primară) este dificilă și complexă; cu toate acestea, rezultatele sunt foarte bune dacă este efectuată corect, fie laparoscopic, fie robotic, așa cum demonstrează durata redusă de spitalizare, nivelul scăzut al durerii postoperatorii și recuperarea rapidă a pacienților.

Cuvinte-cheie*: eTEP-TAR robotic, reconstrucție a peretelui abdominal, hernie incizională, hernie laterală, reconstrucție laparoscopică a peretelui abdominal eTEP, biomateriale textile*

INTRODUCTION

Lateral abdominal wall hernias, both primary and incisional, are less common than medial hernias [1]. Primary lateral hernias (Spigelian hernia) and lumbar hernia (Grynfeltt or Petit) represent 2% of total ventral hernias [2], and incisional hernias depend on the incision made during the initial surgery, subcostal or lumbar incision. Usually, many surgeons operate on lateral hernias using an open approach, but minimally invasive techniques (MIS) (laparo-endoscopic or robotic) are gaining an important place in the surgical arsenal.

Surgical repair of lateral hernias using MIS techniques is challenging for the surgeon due to the proximity of bony structures (the costal margin and iliac crest) and limited access possibilities, the specific position of the patient (lateral or semi-lateral decubitus), special instruments, and the advanced technical skills required for the surgery. Associated paresis of the abdominal wall as a result of muscle denervation is an additional challenging factor that drastically affects postoperative outcomes [3].

According to the classification by the European Hernia Society (EHS), lateral hernias are classified as shown in figure 1: L1 subcostal (between the costal margin and a horizontal line 3 cm above the navel), L2 flank (lateral to the straight abdomen in the area 3 cm above and below the navel), L3 iliac (between the line 3 cm below the navel and the inguinal region), and L4 lumbar (laterodorsal from the anterior axillary line) [4].

Lateral hernias are often associated with medial ones, especially incisional hernias. For this reason, the approach varies depending on each case.

The eTEP-TAR technique (eTEP: enhanced view extraperitoneal, TAR: transversus abdominis release) has proven to be feasible in repairing primary and incisional midline hernias, and for repairing lateral ones, it is necessary to perform TAR at least on the side of the hernia [5–7].

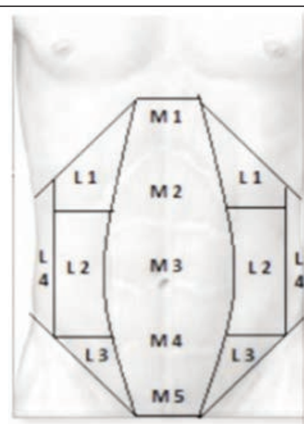

Fig. 1. Classification of incisional hernias by location, according to the EHS guidelines (M – Median, L – Lateral)

The constant interest in the use of biomaterials in surgery is due to the continuously improved properties of biomaterials and the possibility of performing increasingly complex surgical interventions with higher success rates. A surgical mesh is defined as a material network with a grid-like structure that, in medicine, has become synonymous with its use in repairing parietal defects [8]. Surgical meshes can be made from absorbable or non-absorbable materials. Non-absorbable meshes can meet mechanical requirements, are easy to shape during surgery, and have long-term stability. However, complications such as rigidity, recurrence, mesh erosion, and adhesion have been documented. On the other hand, absorbable meshes were developed to reduce long-term complications. These meshes promote the activity of fibroblasts postoperatively. Polylactic acid (PLA) is a material commonly used for soft tissue repair, with a slow degradation rate and stable mechanical properties over short periods. PLA-based composite materials are used both in the pelvic area and in areas affected by hernia. However, after the prosthesis is absorbed, the resulting scar tissue is no longer as strong as it initially was and is not sufficient to provide the necessary support, which can lead to recurrences [9].

This article is a preview and, after gathering a significantly larger number of robotically operated cases, a comparison can be made. Furthermore, it does not aim to compare the two groups of cases (patients operated on robotically and laparoscopically) precisely due to the small number of cases. Additionally, we clarify that we do not intend to describe the eTEP/eTEP-TAR surgical technique, as it has already been a surgical method practised for 8 years, especially in centres dedicated to parietal surgery.

We did not consider it necessary to characterise each case of incisional hernia regarding previous interventions, but following the classification of complex cases according to the definition, the decision was made for them to be performed robotically, while those with reduced complexity were performed laparoscopically.

MATERIAL AND METHOD

Patients

We conducted a retrospective follow-up study of consecutive patients who underwent abdominal wall reconstruction with prostheses for primary or incisional lateral hernias between June 2016 and December 2022. The primary authors of the paper conducted the follow-up examination. All included patients were over 18 years old with primary or recurrent incisional hernias and agreed to participate after giving informed consent. Umbilical hernias, trocar incisional hernias, emergency cases, and parastomal hernias were excluded. Additionally, patients who refused to participate in this study were excluded.

Written informed consent was obtained from each patient. The study was conducted with the approval of the Local Ethics Committee. Demographic data (age, gender, ASA classification, BMI, comorbidities) and hernia characteristics (previous hernia repair, defect location, size and area, type of procedure) were recorded from the data files. All patients underwent a preoperative native abdominopelvic computed tomography (CT) scan to evaluate hernia characteristics (length, width, area and volume of the incisional hernia sac and the peritoneal cavity), presence of mesh (if previously inserted), and the measurements of the abdominal wall muscles (width of the rectus muscle for assessing the retro-rectal space, width, and length of the lateral muscles).

Surgical procedure

All patients received antithrombotic prophylaxis according to the anaesthesia and intensive care protocol. Preoperatively, when the Sabbagh index was greater than 0.25, the abdominal wall was optimised by intramuscular injection with botulinum toxin A (Dysport™ Ipsen Pharma 500 IU) according to the Ibarra-Hurtado technique [10]. Dysport was administered 4 to 6 weeks preoperatively to achieve the maximum effect of muscle relaxation. When larger defects were associated with hernia irreducibility, Progressive Preoperative Pneumoperitoneum (PPP) was performed according to the classical technique previously described by Goni Moreno [11]. The duration and volume of air insufflated are variable depending on the local conditions.
All surgical repairs were performed under general anaesthesia by the same surgeon (Dr. Victor Radu), following the techniques described by Igor Belyansky [5] (figures 2–7). The abdominal wall was reinforced intramuscularly with a monofilament polypropylene prosthesis medium-weight microporous mesh. The surface area of the installed mesh exceeded the area of the defect by more than three times, respecting the principles of the Mesh Defect Area Ratio (MDAR).

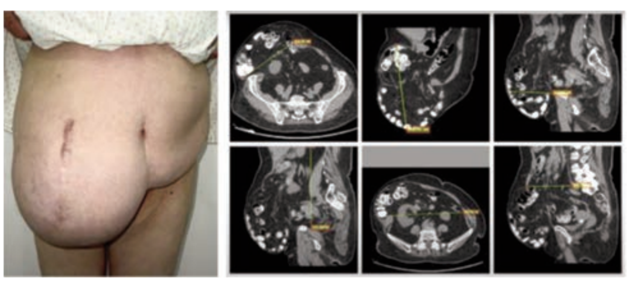

Fig. 2. Right pararectal incisional hernia with loss of domain (L3W3. LOD)

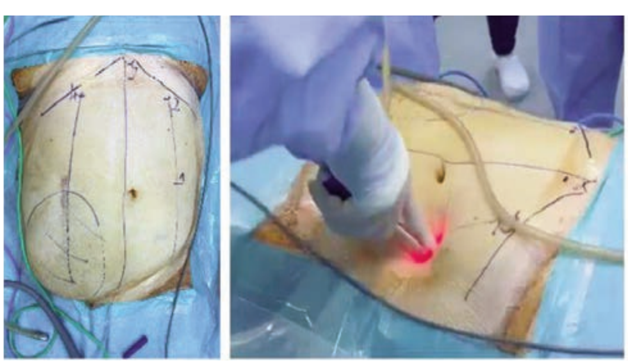

Fig. 3. Optical trocar approach to the retro-muscular space of the rectus abdominis on the left side

Active mobilisation was encouraged from the first hours postoperatively, and the resumption of oral feeding depended on individual digestive tolerance.
During the referred period, 157 patients with various types of incisional hernias were admitted and operated on. Of these, 29 met the inclusion criteria, agreed to participate, signed the informed consent, and were included in the study. The majority of the patients were obese, with 14 of them having a BMI over 30 kg/m² (tables 1–3).

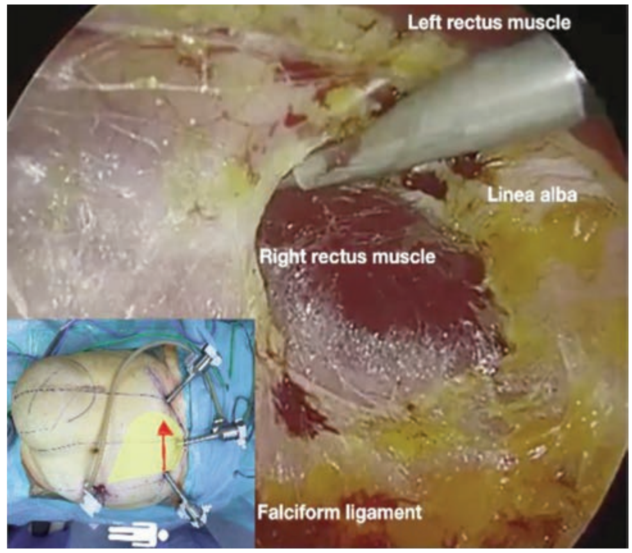

Fig. 4. Crossing of the linea alba anterior of the falciform ligament

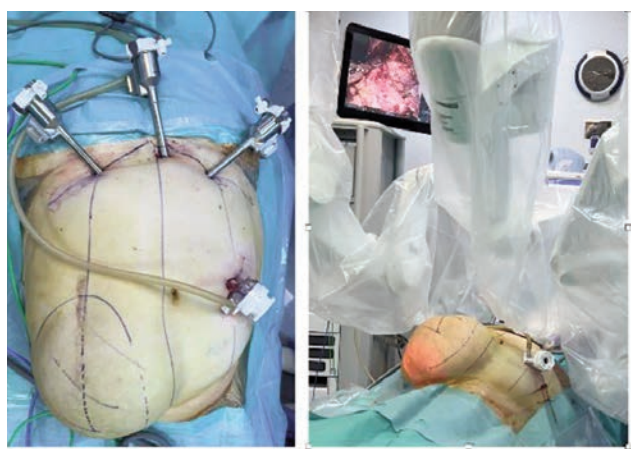

Fig. 5. Subcostal trocarization and robot docking

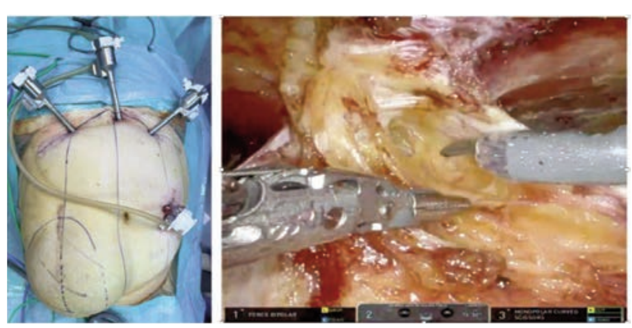

Fig. 6. Retro-muscular dissection by incising the posterior sheaths of the rectus abdominis on their medial edge

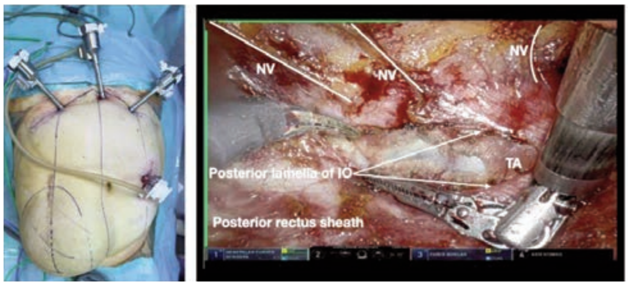

Fig. 7. Identification of anatomical landmarks for TAR

Table 1

DEMOGRAPHIC DATA, COMORBIDITIES, AND PREOPERATIVE CHARACTERISTICS – LAPAROSCOPIC PATIENT GROUP	
Characteristic	**Value**
Patients	n=24
Age (years)	56.50 ± 10.62 (SD)
Male/Female	62.5%/37.5%
ASA Score	2.17 ± 0.7 (SD)
BMI	30.7 ± 5.26 (SD)
Smoker	25%
Dyslipidemia	62.5%
HTA under treatment	41.7%
Diabetes mellitus	29.2%
Coronary disease	12.5%
History of cancer	12.5%

Table 2

LOCALIZATION OF DEFECT HERNIA – LAPAROSCOPIC PATIENT GROUP	
Defect hernia	**No Cases (procent)**
Lateral	10 (41.7%)
Multiple sites	14 (58.3%)

Table 3

DEMOGRAPHIC DATA, COMORBIDITIES, AND PREOPERATIVE CHARACTERISTICS – ROBOTICALLY OPERATED PATIENT GROUP	
Characteristic	**Value**
Patients	n=5
Age (years)	52.6 ± 6.98 (SD)
Male/Female	20%/80%
ASA Score	2 ± 0.54 (SD)
BMI	30.2 ± 4.87 (SD)
Smoker	40%
Dyslipidemia	20%
HTA under treatment	60%
Diabetes mellitus	20%
Coronary disease	40%
History of neoplasm	40%

As a result of this study, a retrospective analysis was conducted on a group of 29 patients who underwent both laparoscopic and robotic surgery for primary and lateral incisional hernias over approximately 5 years (June 2016 – December 2022) at the Abdominal Wall Surgery Centre, Life Memorial Hospital, Medlife, Bucharest.

Within the studied group, 24 patients with lateral abdominal wall hernias, both primary and incisional (some also having a median component), were treated laparoscopically (eTEP-TAR, eTEP), and 5 patients were treated robotically.

Textile biomaterials

The use of knitted biotextiles for non-implantable items and implants has developed greatly in the new field of tissue engineering.

In all surgical repairs, the main mesh was the Parietene macroporous mesh. It is a polypropylene macroporous mesh with large pores (2.0 × 2.4 mm) and has the right balance between rigidity and softness.

The mesh placement into the retrorectus space was done after measurement of the entire area which will be covered by the mesh. The surface covered by the mesh is not the surface of the defect; it is the entire dissected area.

Patients operated laparoscopically

The group of patients who underwent laparoscopic surgery consisted of 16 men and 8 women, with an average age of 55 years, an average BMI of 30 (ranging from 22 to 45), and an average ASA score of 2. Out of the total 24 cases, 21 had incisional hernias, 2 patients had post-traumatic hernias, and there was one mixed case (lateral incisional hernia and inguinal hernia).

Ten of the 24 patients who underwent laparoscopic surgery had only lateral abdominal wall defects (table 4).

Table 4

LOCATION OF HERNIA DEFECTS – ACCORDING TO EHS CLASSIFICATION – PATIENTS MANAGED LAPAROSCOPICALLY			
Localization	**Number of cases**	**Localization**	**Number of cases**
L1	4	M1	5
L2	10	M2	6
L3	11	M3	9
L4	3	M4	5
-	-	M5	1

The diameter of the lateral defects ranges between 3 and 15 cm, with an average of 6 cm. Seven patients from the laparoscopically operated group met the criteria defining a complex case of abdominal hernia. Thus, the 7 cases consist of recurrent hernias,

including 5 cases with a defect diameter greater than 10 cm. Two cases have a BMI over 40.
Within the described surgical procedures, among the 10 cases of strictly lateral hernias, there were 3 cases where eTEP was performed without the need for posterior component separation using TAR: one case of L4 lumbar incisional hernia, one case of right iliac fossa L3 incisional hernia, and one case of post-traumatic L4 lumbar hernia. In the other 7 hernia cases, a unilateral eTEP-TAR was performed (table 5).
For patients with a lateral hernia associated with a defect on the midline (14 cases), eTEP-TAR was performed (unilateral posterior component separation with TAR in 5 cases and bilateral TAR in 9 cases) (figures 8–11).

Table 5

LAPAROSCOPICALLY PERFORMED INTERVENTIONS		
	Number of patients	**Procent (%)**
eTEP	3	12.5
eTEP- TAR unilateral	12	50
eTEP-TAR bilateral	9	37.5

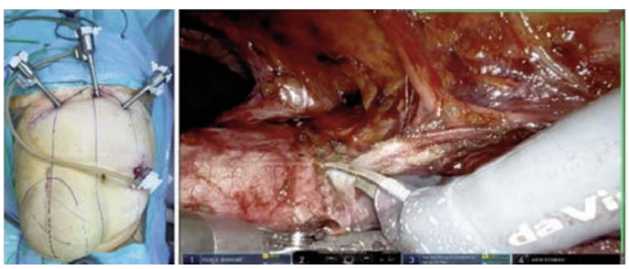
Fig. 8. TAR on the right side

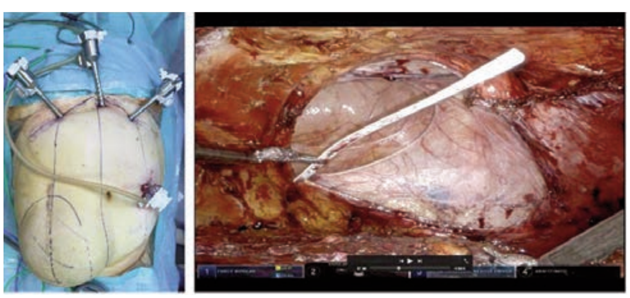
Fig. 9. Hernia reduction and defect measurement

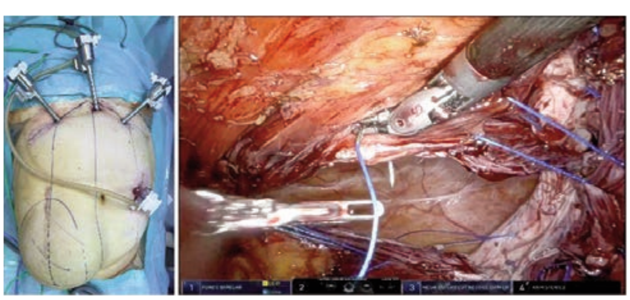
Fig. 10. Closing the defect with 3 different wires, placed in a “Mercedes star”


Fig. 11. Retro-muscular prosthesis

RESULTS AND DISCUSSION

The average operative time for eTEP interventions is 118 minutes (with a minimum of 65 minutes and a maximum of 175 minutes). For eTEP-TAR interventions, the average operative time was 280 minutes (with a minimum of 100 minutes for right L3W2 incisional hernia and a maximum of 510 minutes for a complex right L123 W3 M1W1 R1 case).
When unilateral TAR was performed, the average operative time was 245 minutes, whereas for bilateral TAR, the average time was 330 minutes (minimum 220 minutes and maximum 510 minutes).
No conversions to open surgery were recorded.
The average postoperative hospital stay was 39 hours (ranging from 18 to 163 hours). For patients who underwent eTEP, the average hospital stay was 20 hours, whereas for those who underwent eTEP-TAR, the average was 42 hours. The average number of doses of analgesics administered postoperatively was 2 doses.
An intraoperative incident was reported, involving a serosal injury of the bowel, which was laparoscopically sutured during the operation, and a postoperative event, where one case developed therapeutic erythema on the thorax, which resolved without any correlation to the surgical intervention performed.
The average follow-up period is 4 years and 6 months, conducted via telephone follow-up and physical examination when necessary; no cases of chronic pain or hernia recurrence were recorded.

Robotically resolved cases

The group of patients operated on robotically includes one man and four women, with an average age of 52 years, an average BMI of 30 (ranging from 22.3 to 35.6), and an average ASA score of 2. All five cases involved incisional hernias, both with lateral and medial components, including two cases of incarcerated hernias and one case of recurrent R1 hernia. The defect diameter ranged from 3 to 15 cm. Three patients met the criteria for complex cases [12]: patients with an average defect diameter of 10 cm.
There were no intraoperative or postoperative complications in the robotically operated group. The average postoperative hospital stay was 36 hours (ranging from 17 to 86 hours), and the average number of doses of usual non-morphine analgesics administered postoperatively was 4 doses. Patients were followed for an average period of 13 months, with no

recorded postoperative complications, chronic pain, recurrence, or mortality was zero.

An attempt to compare the two groups does not provide statistical validation due to the heterogeneity of the cases and the small number of patients operated on robotically. A longer operative time can be observed in the robotic group, most likely due to the greater complexity of the cases, but there is a similarity in the postoperative outcomes (hospital stay duration, postoperative complications).

Performing robotic interventions has been in our clinic and practice for approximately 2 years, which is why the follow-up period for the patients is limited.

CONCLUSIONS

The endoscopic approach for lateral hernias using the eTEP/eTEP-TAR technique is both feasible and safe, ensuring a short hospital stay, a low level of postoperative pain, and rapid recovery. It is difficult to analyse the impact of robotic surgery due to the limited number of cases (initial experience and low incidence of lateral hernias). However, considering that predictably difficult and complex cases were selected for robotic surgery, and the study data at least show comparable results with laparoscopic surgery, the positive impact of robot-assisted surgery in abdominal wall reconstruction can be appreciated.

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