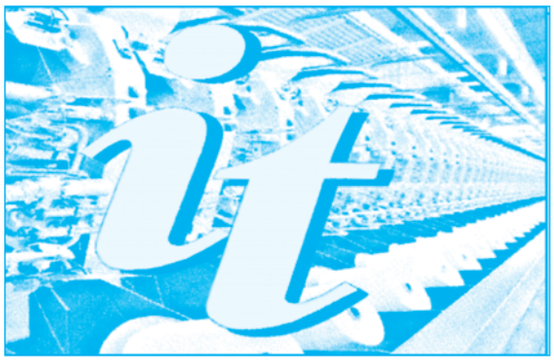

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Adsorption of AR114 onto humic acid-modified Fe_3O_4 nanoparticles

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ABSTRACT – REZUMAT

Adsorption of AR114 onto humic acid-modified Fe_3O_4 nanoparticles

In this study, Fe_3O_4 and humic acid-modified Fe_3O_4 (Fe_3O_4@HA) magnetic nanoparticles were synthesized and used for the removal of Acid Red 114 (AR114) dyestuff from aqueous. The batch adsorption method was used for the experiments. The magnetic nanoparticles, synthesised by an inexpensive and environmentally friendly precipitation process, were characterised by FTIR, SEM-EDX, BET surface area, and XRD analyses. The optimum pH values determined for Fe_3O_4 and Fe_3O_4@HA were the original pH (6.4) and 4, respectively. The equilibrium state was reached after 60 minutes for both adsorbents. The values for Fe_3O_4 and Fe_3O_4@HA were determined as 3.4 mg/g and 3.1 mg/g, respectively, when 10 mg/l initial dyestuff concentration and 2 g adsorbent were used. The results obtained in the adsorption experiments performed for both adsorbents were compatible with the Freundlich isotherm and pseudo-second-order kinetic model. Fe_3O_4 was found to be more efficient than Fe_3O_4@HA in terms of reuse and Fe_3O_4 can be used 5 times without any significant loss of adsorption capacity. The results showed that Fe_3O_4 and Fe_3O_4@HA can be environmentally friendly alternative adsorbents for the removal of hazardous azo dyestuffs from water, and have regeneration possibilities.

Keywords: *Acid Red 114, adsorption, colour removal, Fe_3O_4, humic acid, magnetic nanoparticle*

Adsorbția AR114 pe nanoparticule de Fe_3O_4 modificate cu acid humic

În acest studiu, Fe_3O_4 și nanoparticulele magnetice Fe_3O_4 modificate cu acid humic (Fe_3O_4@HA) au fost sintetizate și utilizate pentru îndepărtarea colorantului Acid Red 114 (AR114) din soluție apoasă. Pentru experimente a fost utilizată metoda de adsorbție în loturi. Nanoparticulele magnetice, sintetizate printr-un proces de precipitare ieftin și prietenos cu mediul, au fost caracterizate prin analize FTIR, SEM-EDX, suprafață BET și XRD. Valorile optime ale pH-ului determinate pentru Fe_3O_4 și Fe_3O_4@HA au fost pH-ul inițial (6,4) și, respectiv, 4. Starea de echilibru a fost atinsă după 60 de minute pentru ambii adsorbanți. Valorile q_e pentru Fe_3O_4 și Fe_3O_4@HA au fost determinate la 3,4 mg/g și, respectiv, 3,1 mg/g, atunci când a fost utilizată o concentrație inițială de colorant de 10 mg/l și 2 g adsorbant. Rezultatele obținute în experimentele de adsorbție efectuate pentru ambii adsorbanți au fost compatibile cu izoterma Freundlich și modelul cinetic de pseudo-ordin doi. Fe_3O_4 s-a dovedit a fi mai eficient decât Fe_3O_4@HA în ceea ce privește reutilizarea, iar Fe_3O_4 poate fi utilizat de 5 ori fără nicio pierdere semnificativă a capacității de adsorbție. Rezultatele au arătat că Fe_3O_4 și Fe_3O_4@HA pot fi adsorbanți alternativi ecologici pentru îndepărtarea coloranților azoici periculoși din apă și au posibilități de regenerare.

Cuvinte-cheie*: Acid Red 114, adsorbție, îndepărtare a culorii, Fe_3O_4, acid humic, nanoparticule magnetice*

INTRODUCTION

Colour prevents light permeability in receiving environments, negatively affects photosynthetic activity, and can cause toxicity in aquatic organisms [1]. Today, methods such as physicochemical processes, membrane systems, and advanced oxidation processes are applied to remove the colour from wastewater [2], while one of the most effective ones is adsorption. In adsorption applications, it is important that the adsorbent used is low-cost, can be easily removed from the water environment, is suitable for reuse, and can be regenerated.

Magnetic nanoparticles are one of the most important adsorbents developed in recent years. Some of their advantages are having large surface areas, high magnetic properties, high removal efficiencies, and easy and fast separation of adsorbent from solution (via magnetic field). In addition, adsorbed pollutants can be separated from magnetic nanoparticles and the adsorbent can be reused [3]. In recent years, iron-based nanoparticles have been widely used in environmental applications. Pan et al. [4] demonstrated the effectiveness of organic acid coatings on the Fe_3O_4 surface in preventing nanoparticles from aggregating in solution and metal adsorption. In various studies, Fe_3O_4 has been used by modifying it with organic substances such as chitosan, humic acid and alginate for the removal of pollutants [5, 6].

Rashid et al. [7] stated that the coating of natural organic materials on the magnetic nanoparticle surface can show lower toxic effects and more environmentally friendly properties. Such thin coatings can prevent aggregation and autoxidation that can be encountered with the use of magnetic nanoparticles alone. In addition, when magnetic nanoparticles are coated with natural organic matter, the potential in adsorption capacity and the selectivity of the nanoparticle increase. Humic acid (HA) is a natural organic macromolecule that is abundant in the world. The high reaction activity of HA is a result of its unique amorphous structure. This is due to the presence of large polycyclic aromatic hydrocarbons and many carboxyls, ether and amino groups in its skeleton [6]. These substances in their structure can show complex properties with types of metal oxides [7]. However, separating HA from the aquatic environment is difficult. For this reason, adsorption with a combination of HA and iron oxide is a promising approach, and the magnetic separation method can be used to separate adsorbents from the water environment. HA is stable at low pH (pH<3) but dissolves at pH>3. This limits the pH range of adsorption. Fe_3O_4@HA is formed by a bond formed between the Fe ions of Fe_3O_4 and the carboxylate groups of HA [8]. By modifying Fe_3O_4 with HA, adsorption can be applied in a wider pH range. As a result of the HA coating on Fe_3O_4, a reduction in the particle size of the adsorbent is expected [8, 9].

In recent years, there have been adsorption studies on the removal of various pollutants using Fe_3O_4@HA in various studies [6–8, 10–12].

One of the studies in which the adsorbent obtained by coating Fe_3O_4 with humic acid was used for colour removal and it was used for the adsorption of methylene blue (MB) from aqueous solutions. They determined that humic acid-coated Fe_3O_4 performed higher MB adsorption than Fe_3O_4 alone. It was determined that the adsorption was compatible with the pseudo-second-order kinetic model, the adsorption isotherm was compatible with the Langmuir model, and the maximum adsorbance amount was 0.291 mmol/g [6]. Rashid et al. synthesized humic acid-coated magnetic nanoparticles and used them for phosphate removal in aqueous media. The optimum pH of 6.6 and maximum adsorption capacity were determined as 28.9 mg/g. Adsorption behaviours were found to be compatible with Freundlich isotherm, Adsorption kinetics were compatible with the pseudo-second-order model [7]. Koesnapardi et al. evaluated phenol adsorption with HA-coated Fe_3O_4 coated with HA at different rates in their study. The optimum pH 5.0 for phenol adsorption is consistent with the pseudo-second-order kinetic model, the adsorption isotherm is compatible with the Langmuir model, and the maximum adsorbance amount is 0.45 mol/g was determined [8]. Peng et al. synthesized Fe_3O_4/HA nanoparticles and used them for Rhodamine B dye removal from aqueous solutions. Rhodamine B adsorption takes less than 15 minutes to reach equilibrium. It is compatible with the Langmuir adsorption model and its qmax is 161.8 mg/g. The optimum pH was determined as (2.53) [12]. However, as a result of the literature search, no study was found on the removal of AR114 from aqueous solutions. In this study, Fe_3O_4 and humic acid-modified Fe_3O_4 (Fe_3O_4@HA) magnetic nanoparticles were synthesized and used for the removal of Acid Red 114 (AR114) dyestuff from aqueous.

MATERIAL AND METHOD

Preparation of Fe_3O_4 and Fe_3O_4@HA

$FeCl_3 \cdot 2H_2O$ and $FeCl_2 \cdot 4H_2O$ (2/1 mol) were dissolved in 50 mL of distilled water. During the preparation of Fe_3O_4@HA, 0.2 g of HA was also added. The solution was stirred rapidly (40°C) for 15 minutes. Then, by slowly adding NH_3, the pH was increased above 11 and ferritin was precipitated. In the next step, it was treated with argon gas, and reflux was made at 80°C with continuous stirring for 2 hours. Finally, the separation of Fe_3O_4 or Fe_3O_4@HA from the aqueous solution was accomplished with a strong magnet. The magnetic nanoparticles obtained were washed with distilled water several times and dried at 80°C for 4 hours in an oven [13].

Adsorbate and adsorption experiments

C.I. Acid Red 114 (AR 114), used as the adsorbate, was obtained from Sigma-Aldrich. AR114 is mainly used for dyeing textiles such as wool, silk, jute and leather [14, 15]. The molecular formula is $C_{37}H_{28}N_4O_{10}S_{32}Na$, and it is a dark red powder dye in the diazo chromophore group. Batch adsorption experiments were carried out in an orbital shaker and at constant agitating speed (200 rpm) at room temperature (25°C). In the adsorption studies, firstly, the effect of different pH values (4, 7, 9 and original pH (6.4)) was evaluated. Subsequent adsorption experiments were carried out at optimum pH. The effect of contact time (with samples taken after 0, 1, 5, 15, 30, 60, 90, 120 and 150 minutes) and the effect of initial dyestuff concentration (with 4, 6, 10 and 15 mg/l initial dyestuff concentration) were determined for both adsorbents. pH adjustment in the dyestuff solution was made with 0.1 N NaOH and 0.1 N HCl. The adsorbent was separated by a strong magnet, then colour measurement was performed in a spectrophotometer. While working at natural pH (original pH), no pH correction was made in the sample. The adsorption capacity (q_t, mg/g) in the adsorption experiments was determined by the following equations (equation 1). Where, C_0 (mg/l) is the initial AR114[2] concentration, C_e (mg/l) is the AR114 concentration in solution at equilibrium, m (g) is the adsorbent mass, and V (l) is the solution volume.

$$q_t = \frac{(C_0 - C_e) \cdot V}{m} \quad (1)$$

Damasceno et al. studied previously the dye adsorption of Fe_3O_4 and the interaction between the dye

molecules and Fe_3O_4 [16]. The interaction between the dyestuff and Fe_3O4@HA can be explained as dye molecules are trapped between the OH groups of HA in the structure of Fe_3O_4@HA nanoparticles as shown in figure 1.

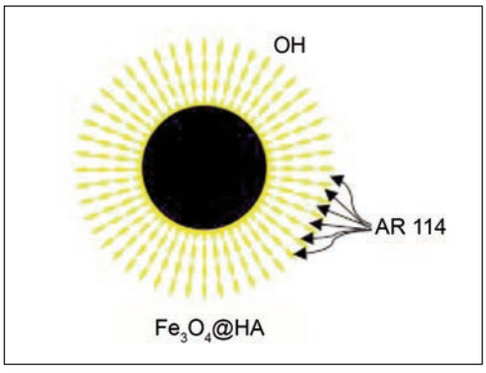

Fig. 1. Interaction between AR 114 dye molecules and Fe_3O_4@HA nanoparticles

Desorption and reuse experiments

After the adsorption experiments, the desorption process was applied to the contaminated adsorbents. In the desorption application, 0.1 g of contaminated adsorbent was added to 50 ml of 9/1 (v/v) methanol/acetic acid solution and shaked. Then the adsorbent is magnetically separated from the solution. The process was repeated until the amount of dyestuff in the solution was less than 0.002 mmol/L. Finally, the adsorbent was washed with distilled water and dried in an oven [17]. Reuse studies were carried out for Fe_3O_4 and Fe_3O_4@HA at optimum pH conditions and within 60 minutes of contact time. Reuse studies were investigated with 7 repetitions.

Analysis

BET surface area was determined with the Quantachrome Quadrasorb SI instrument based on the nitrogen (N_2) gas adsorption technique. SEM-EDX examination was performed with the FEI Quanta FEG 250 model device. In the Bruker Vertex 70 FTIR ATR brand device, descriptive information about the bonds in the structures of the adsorbents was obtained with the ATR technique. XRD analyses were performed on the Panalytical Empyrean instrument. Colour parameter analyses were performed according to the maximum absorbance method by the Thermospectronic Aquamate Spectrometer. Accordingly, scans were made in the spectrometer at wavelengths between 400 nm and 700 nm and the wavelength with the highest absorbance was determined. Colour analyses were performed at 522 nm for AR114.

The pHpzc was determined by adjusting the 0.01 mol/l NaCl solution to different pH values (with 0.1 N NaOH and 0.1 N HCl). It was shaken at room temperature for two days with the lid closed after 0.01 g adsorbent was added. Once the shaking process was completed, the pH values were measured [18]. The pHpzc was accepted as where the initial pH value and the final pH value were equal and recorded as 4 for Fe_3O_4 and 7 for Fe_3O_4@HA. HAs mainly consist of phenol, carboxylic acid, enol, quinone and ether functional groups, but they can also contain sugar and peptides. Phenol and carboxylic groups are more common in HAs structures. The structure of the HA molecule consists of hydrophilic parts containing the OH group and hydrophobic parts containing aliphatic chains and aromatic rings. Phenol and carboxylic groups are responsible for the weak acid behaviour of HAs. Quinones are electron-accepting groups and are responsible for the production of reactive oxygen species. Quinones are reduced to semiquinones stabilized by their aromatic ring, as well as to the more stable hydroquinone. The main properties of HAs, such as solubility, pH dependence, interaction with hydrophobic groups, and metal chelation, depend on their structure, namely amphiphilicity, and the different functional groups that make up each molecule. The pHpzc value of Fe_3O_4@HA is estimated to vary due to the stated structural properties of HA.

RESULTS AND DISCUSSION

Characteristics of Fe_3O_4 and Fe_3O_4@HA

According to the morphological evaluation based on SEM images, it is seen that Fe_3O_4 and Fe_3O_4@HA have similar appearances (figure 2, *a* and *b*). However, when the images were examined in detail, it was determined that the aggregation tendency was high in Fe_3O_4 and low in Fe_3O_4@HA. It can be seen that Fe_3O_4@HA did not have a uniform regular structure. Similar results were obtained in the literature [18, 19]. As a result of EDX, the % distribution of the chemical structure of Fe_3O_4 and Fe_3O_4@HA was evaluated. Accordingly, Fe_3O_4 and Fe_3O_4@HA contain 29.61% and 20.65% Fe, respectively. Fe_3O_4@HA contains 9.17% C, which is due to HA. The FT-IR spectrum for magnetic nanoparticles is shown in figure 2, *c*. A broad peak between 3500 cm^{-1} and 3000 cm^{-1} was observed on both spectras of Fe_3O_4 and Fe_3O_4@HA that was attributed to the O-H groups. The noteworthy peak at 1423 cm^{-1} seen on Fe_3O_4@HA was associated with the vibration of C-H groups [17]. The peaks that appeared below 700 cm^{-1} were associated with Fe-O bonds in iron oxides [9, 20–21]. Fe_3O_4 and Fe_3O_4@HA showed a significant peak at 548 cm^{-1} and 552 cm^{-1}, respectively, which indicated the existence of Fe-O bonds in both samples. As seen in figure 2, *d*, peaks expressing 35.38° (311) and 62.73° (440) crystal planes were observed in the XRD diffraction pattern of Fe_3O_4 nanoparticles. The presence of characteristic peaks indicated that Fe_3O_4 nanoparticles had been successfully synthesized. Fe_3O_4@HA had similar diffraction peaks to Fe_3O_4, which was consistent with the reverse cubic spinel structure [8]. Fe_3O_4@HA (130.7 m^2/g) had a higher BET surface area than Fe_3O_4 (87.6 m^2/g). The average pore diameter for Fe_3O_4 was 5.66 nm, while the mean pore diameter for Fe_3O_4@HA was 3.49 nm.

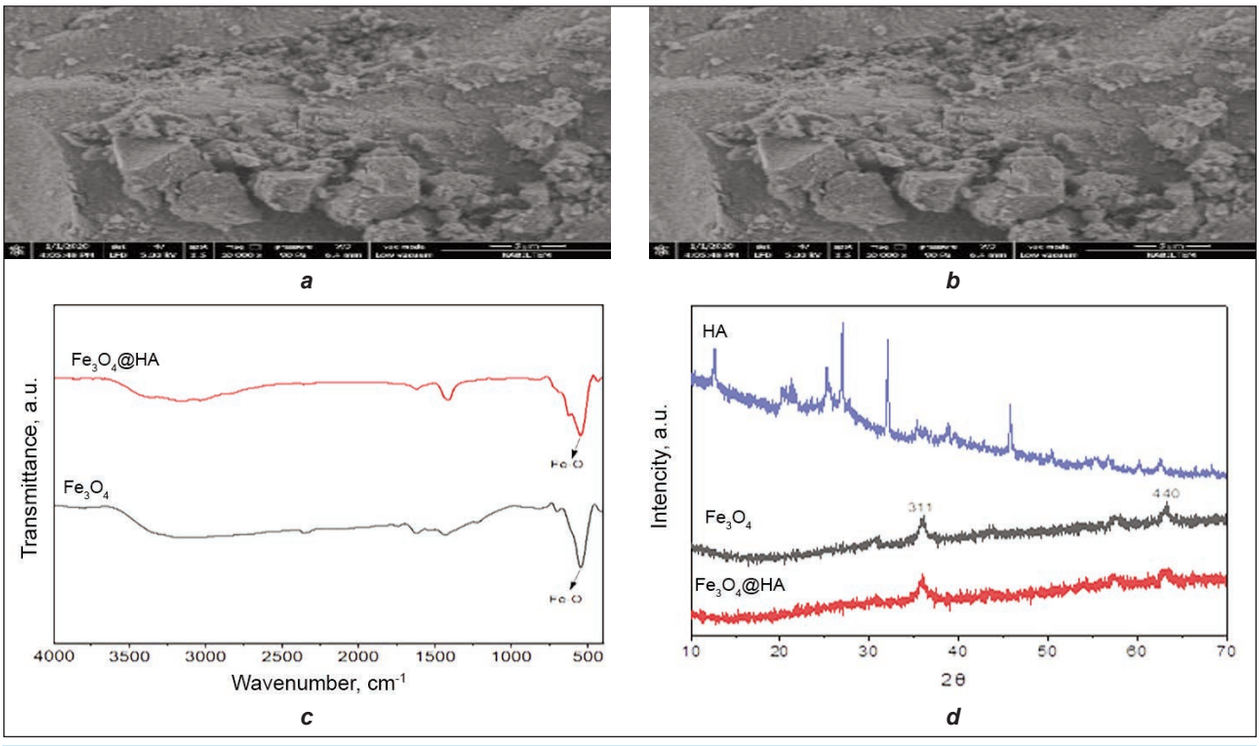

Fig. 2. Characterization of magnetic nanoparticles:
a – SEM image of Fe_3O_4; *b* – SEM image of Fe_3O_4@HA; *c* – FT-IR; *d* – XRD

BET surface areas decreased with the increase in the pore diameter and increased with the decrease in the pore diameter. The pHpzc values were determined as 4 and 7 for Fe_3O_4 and Fe_3O_4@HA, respectively.

The Effect of pH, initial dye concentration, and contact time on adsorption

The effect of pH was investigated for the use of 2 g adsorbents for C_0 = 10 mg AR114/l. In the literature, it was stated that iron nanoparticles dissolve below pH 2 [21], while Fe_3O_4@HA dissolves above pH 12 and deteriorates structurally [6]. For this reason, the effect of pH on the adsorption capacity was evaluated for the pH values of 4, 7, and 9 and the original pH (without pH correction, 6.4). The highest q_e value (3.4 mg/g) for Fe_3O_4 was obtained at the original pH value, while the highest q_e value (3.1 mg/g) for Fe_3O_4@HA was obtained at pH 4. It was stated by Koesnarpadi et al. (2017) [8] that the amount of HA used in the preparation of Fe_3O_4@HA affected the adsorption capacity and increased with the increase in the amount of HA. The pH value with the highest *qe* values was accepted as the optimum pH, and this pH value was taken into account in the kinetic and isotherm studies. The point of zero charges (pHpzc) is the pH value at which the surface charge of the adsorbent is zero, and it is an important parameter to reveal the adsorption state of anions and cations. pHpzc supports the identification of the adsorption mechanism. The pHpzc values of the Fe_3O_4 and Fe_3O_4@HA were determined as 4 and 7, respectively. It is known that in the case of pH > pHpzc, the surface of the adsorbent is negatively charged [22]. For this reason, successful results could not be obtained with Fe_3O_4 at high pH values in the removal of AR114, a complex adsorption mechanism could be effective for both adsorbents in AR114 adsorption which is an anionic dye, and its qe values are low. HA is usually negatively charged. Ligand exchange may be occurred between the anionic dye and the adsorbent surface [23]. For this reason, it is thought that better removal is achieved at pH values above the pHpzc value in the adsorption of Fe_3O_4 and AR114 dyestuff. The fact that this does not happen with Fe_3O_4@HA may be due to the stability that may occur with the binding of HA. The equilibrium state for both adsorbents was reached after 60 minutes. The effect of initial dye concentration on the adsorption of AR114 for both adsorbents is shown in figure 3. With the increase of the initial dyestuff concentration (from 4 mg/l to 15 mg/l), q_e (mg/g) values also increased. With the increase in the initial dye concentration, the q_e value for Fe_3O_4 increased from 0.9 mg/g to 5.34 mg/g and for Fe_3O_4@HA from 0.64 mg/g to 3.1 mg/g. The initial dye concentration provides the driving force for mass transport to the adsorbent surface. The increase in dye concentration increases the driving force and the q_e value increases [24]. It was observed that when the dyestuff concentration was more than 10 mg/l, the q_e value decreased from 3.1 mg/g to 3 mg/g for Fe_3O_4@HA. This situation can be explained by the decrease in the regions of Fe_3O_4@HA that can bind dyestuffs and the presence of low-energy binding regions.

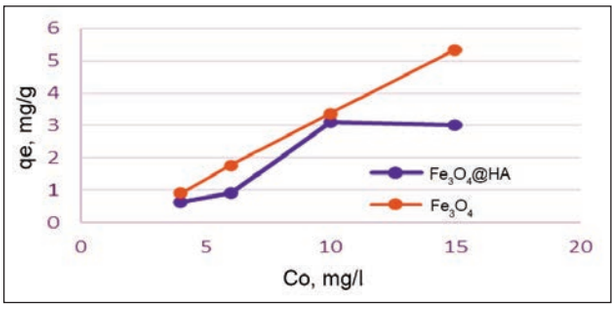

Fig. 3. Effect of initial dye concentration (Orijinal pH (6,4), m = 2 g, t = 60 min for Fe_3O_4, pH 4, m = 2 g, t = 60 min for Fe_3O_4@HA, V = 1 l)

Adsorption isotherms

Adsorption equilibrium studies were performed at initial concentrations between 4 mg/l and 15 mg/l, for 60 min and with 2 g adsorbents to 1 l MB solution. Isotherm studies were carried out under optimum pH conditions (pH 6.4 for Fe_3O_4 and pH 4 for Fe_3O_4@HA). In adsorption equilibrium studies, the maximum adsorption capacity was determined by Langmuir and Freundlich isotherm models. Equations of Langmuir and Freundlich isotherm models are given in equations 2 and 3, respectively.

$$q_e = \frac{q_{max} K_L C_e}{1 + K_L \cdot C_e} \quad (2)$$

$$q_e = K_F \cdot C_e^{1/n} \quad (3)$$

In these equations, q_{max} and q_e (mg/g) represent the maximum adsorption capacity and the adsorption capacity at equilibrium, respectively. K_L (l/mg), K_F ((mg/g)(l/mg)1/n) and 1/n values are Langmuir and Freundlich parameters. In the adsorption of AR114 with Fe_3O_4 and Fe_3O_4@HA, q_{max} and K_L values for Langmuir isotherm, K_F and 1/n values for Freundlich isotherm and regression coefficients (R^2) for both isotherms are given in table 1. When the R^2 values for the adsorption of AR114 with Fe_3O_4 and Fe_3O_4@HA are examined, it can be seen that the Freundlich isotherms are suitable. The R^2 values for Fe_3O_4 and Fe_3O_4@HA were determined as 0.69, 0.95 and 0.52, 0.95 for Langmuir and Freundlich, respectively. The constants determined for the Freundlich isotherm are given in table 1 (constants are not given for Langmuir isotherm since the R^2 value is low for Langmuir isotherm). The plots of the Freundlich isotherm are shown in figure 4.

The 1/n values determined for Fe_3O_4 and Fe_3O_4@HA were 2.49 and 1.33, respectively. If n is $1 < n < 10$, it can be stated that there is a compatibility between adsorbate and adsorbent. In this case, there was a strong interaction between adsorbate and adsorbent. It can be said that the adsorption mechanism was chemisorption. In this study, n values were less than 1. Since the 1/n values were greater than 1, it can be stated that complex adsorption took place [25]. Compliance with the Freundlich isotherm showed that the adsorbent surface had a heterogeneous structure.

Table 1

CONSTANTS FOR FREUNDLICH ISOTHERMS (Original pH (6.4), m = 2 g for Fe_3O_4, V = 1 l, pH = 4, m = 2 g for Fe_3O_4@HA, 60 minutes, V = 1 l)

Freundlich	K_f	1/n	R^2
Fe_3O_4	0.12	2.49	0.95
Fe_3O_4@HA	0.13	1.33	0.95

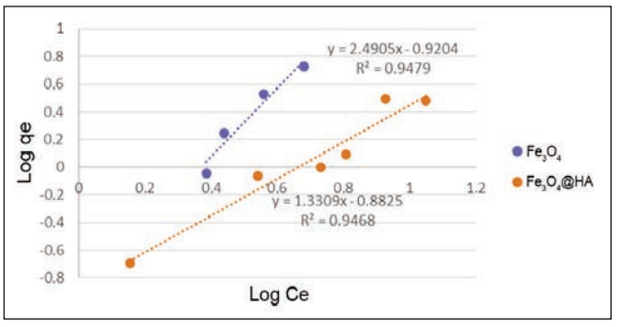

Fig. 4. Freundlich isotherm plots for the adsorption of AR114 with Fe_3O_4 and Fe_3O_4@HA

Reaction kinetics

Kinetic model analyses are based on the amount of adsorbed dyestuff and contact time data. Thus, the time to reach equilibrium and the reaction rate constant can be evaluated in adsorption systems. In this study, pseudo-first order and pseudo-second order kinetic models were used to determine the adsorption kinetics. Equations of pseudo-first order and pseudo-second order kinetic models are given in equations 4 and 5, respectively.

$$q_t = q_e(1 - e^{-k_1 t}) \quad (4)$$

$$q_t = \frac{k_2 q_e^2 t}{1 + k_2 q_e t} \quad (5)$$

where q_e (mg/g) and q_t (mg/g) represent the dye uptake at equilibrium and at time t, respectively. k_1 (1/min) and k_2 (g/mg·min) are reaction rate constants. The results of the evaluation made to explain the adsorption kinetic model are given in table 2 and figure 5. According to table 2, the R^2 values of the pseudo-first-order reaction kinetics were determined as 0.9379 and 0.9493 for Fe_3O_4 and Fe_3O_4@HA, respectively. Likewise, the R^2 values of the second-order reaction kinetics were determined as 0.9977 and 0.9928 for Fe_3O_4 and Fe_3O_4@HA, respectively. When the R^2 values were examined, it was seen that the pseudo-second-order kinetic model explained the adsorption kinetics better for both adsorbents. In addition, when the calculated equilibrium adsorption capacities (qe,calc) in pseudo-second-order model were examined, it was seen that they were quite compatible with the experimental adsorption capacities (qe,exp). Accordingly, it can be stated that the

Table 2

KINETIC PARAMETERS FOR THE ADSORPTION OF AR114 ON Fe_3O_4 AND Fe_3O_4@HA (C_o = 10 mg/l, pH = 6.4, m = 2 g for Fe_3O_4, V = 1 l, t = 60 min and C_o = 6 mg/l, pH = 4, m = 4 g for Fe_3O_4@HA, V = 1 l, t = 60 min)

Pseudo-first order model				
Substance	**qe_{exp} (mg/g)**	**qe_{cal} (mg/g)**	**k_1**	**R^2**
Fe_3O_4	5.31	1.10	0.0336	0.9379
Fe_3O_4@HA	2.17	1.22	0.0393	0.9493
Pseudo-second order model				
Substance	**qe_{exp} (mg/g)**	**qe_{cal} mg/g)**	**k_2**	**R^2**
Fe_3O_4	5.31	5.36	0.129	0.9977
Fe_3O_4@HA	2.17	2.23	0.157	0.9928

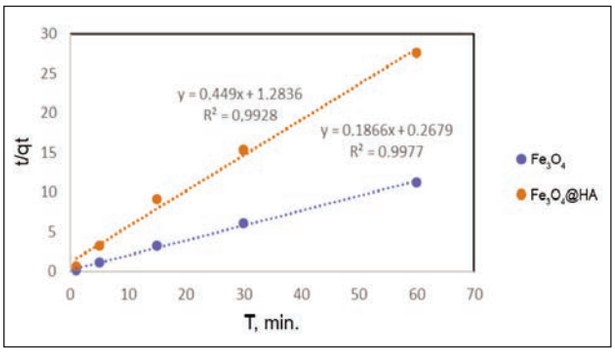

Fig. 5. Plot of pseudo-second order equation for adsorption of AR114 on Fe_3O_4 and Fe_3O_4@HA (C_o = 10 mg/l, pH = 6.4, m = 2 g, V = 1 l, t = 60 min for Fe_3O_4 and C_o = 6 mg/l, pH = 4, m = 4 g, V = 1 l, t = 60 min for Fe_3O_4@HA)

rate-limiting step was chemisorption and the adsorption mechanism depended on both the adsorbate and the adsorbent [26]. While the adsorption rate (k_2) for Fe_3O_4 was 0.129 mg/g·min, the k_2 value for Fe_3O_4@HA was determined as 0.157 mg/g·min.

Reuse experiments

It is economically important that the adsorbents used in adsorption studies can be reused after being regenerated. The most important advantage that distinguishes magnetic nanoparticles from other adsorbents is that they can be recycled and reused. Figure 6 shows the q_e (mg/g) values obtained after reuse. While the q_e value obtained for Fe_3O_4 (C_o = 10 mg/l, m = 2 g, V = 1 L, pH = 6.4 and 60 min) in the first use was determined as 3.45 mg/g, at the end of the 5th use, the q_e value decreased to 2.7 mg/g. After the 7th use, the q_e value decreased to 1.5 mg/g. For Fe_3O_4@HA (m = 2 g, V = 1 l, C_o = 4 mg/l, pH = 4 and 60 min), the q_e value was determined as 0.6 mg/g in the first use, and a decrease in the q_e value was observed after the second use. After the 6th use, the q_e value decreased to approximately 0.11 mg/g. According to the results, it was determined that Fe_3O_4 was more successful in terms of reuse than Fe_3O_4@HA and that it could be used 5 times without a significant decrease in the adsorption capacity of Fe_3O_4. This can be explained by the fact that HA in the Fe_3O_4@HA structure is an organic material, so it cannot remain as stable as Fe_3O_4 during reuse.

CONCLUSION

In this study, the removal of AR114 from aqueous solutions was investigated by batch adsorption experiments by synthesizing Fe_3O_4 and Fe_3O_4@HA. The optimum pH values determined for Fe_3O_4 and Fe_3O_4@HA were the original pH (6.4) and 4, respectively. The equilibrium state was reached after 60 minutes for both adsorbents. *qe* values for Fe_3O_4 and Fe_3O_4@HA were determined with 10 mg/l initial dyestuff concentration and 2 g adsorbents as 3.4 mg/g and 3.1 mg/g, respectively. It was determined that the results obtained in the adsorption experiments performed for both adsorbents were compatible with the Freundlich isotherm and pseudo-second-order kinetic model. It was also determined that Fe_3O_4 was more efficient in terms of reuse than Fe_3O_4@HA and that Fe_3O_4 could be used 5 times without any significant loss of adsorption capacity. As a result, it can be stated that Fe_3O_4 and Fe_3O_4@HA are alternative environmentally friendly adsorbents that can be used in the removal of hazardous azo dyestuffs from water, with regeneration possibility.

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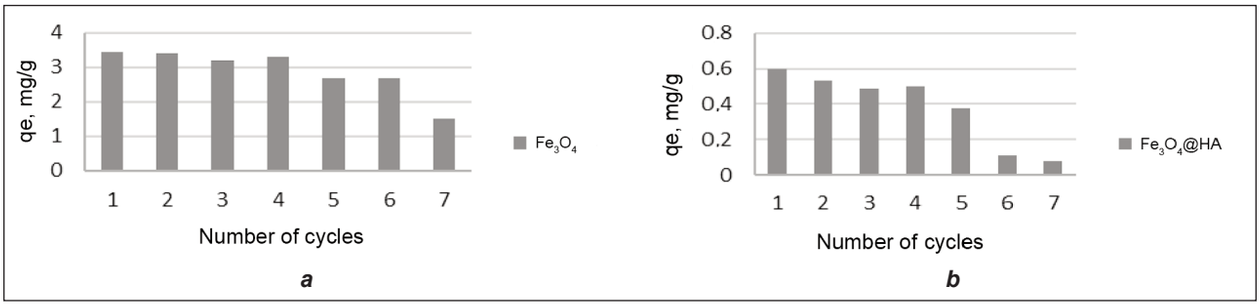

Fig. 6. q_e values depending on the number of reuses after desorption: a) Fe_3O_4 (C_o = 10 mg/l, m = 2 g, original pH (6.4), 60 min, V = 1 l), b) Fe_3O_4@HA (C_o = 4 mg/l, m = 2 g, pH = 4, 60 min, V = 1 l)

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An intelligent garment recommendation system based on case-based reasoning technology

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ABSTRACT – REZUMAT

An intelligent garment recommendation system based on case-based reasoning technology

Garment purchasing through the Internet has become an important trend for consumers. However, various garment e-shopping systems, systematically lack personalized recommendations, like sales advisors in classical shops, to propose the most relevant products to different consumers according to their consumer profiles and successful recommendation cases. In this paper, we propose a consumer-oriented recommendation system by Case-based reasoning techniques and Similarity degree of fuzzy sets, which can be used in a garment online shopping system like a virtual sales advisor. This system has been developed by integrating successful recommendation cases and taking into account consumer profiles. It can effectively help consumers to choose garments from the Internet. Compared with other prediction methods, the proposed method is more robust and interpretable owing to its capacity to treat uncertainty. This paper presents an original method for predicting one or several relevant product profiles from the similarity degree between a specific consumer profile and a successful cases database.

***Keywords**: recommendation system, case-based reasoning, successful cases database, similarity degree*

Un sistem inteligent de recomandare a articolelor de îmbrăcăminte cu tehnologia raționamentului bazat pe caz

Achiziționarea articolelor de îmbrăcăminte prin internet a devenit o tendință importantă pentru consumatori. Cu toate acestea, în diverse sisteme de e-shopping de articole de îmbrăcăminte, lipsesc în mod sistematic recomandările personalizate, cum ar fi consilierii de vânzări în magazinele clasice, pentru a propune produsele cele mai relevante diferiților consumatori în funcție de profilul lor de consumator și de cazurile de recomandare de succes. În această lucrare, este propus un sistem de recomandare orientat spre consumator prin tehnici de raționament bazat pe caz și gradul de similaritate al seturilor fuzzy, care poate fi utilizat într-un sistem de cumpărături online de articole de îmbrăcăminte ca un consilier virtual de vânzări. Acest sistem a fost dezvoltat prin integrarea cazurilor de recomandare de succes și luând în considerare profilul consumatorului. Poate ajuta eficient consumatorii să aleagă articole de îmbrăcăminte de pe internet. În comparație cu alte metode de predicție, metoda propusă este mai robustă și mai interpretabilă datorită capacității sale de a trata incertitudinea. Această lucrare prezintă o metodă originală de predicție a unuia sau mai multor profiluri de produs relevante din gradul de similaritate dintre un anumit profil de consumator și baza de date de cazuri de succes.

***Cuvinte-cheie**: sistem de recomandare, raționament bazat pe caz, baza de date de cazuri de succes, grad de similaritate*

INTRODUCTION

With the rapid development of e-commerce, more and more consumers buy garments via the Internet [1]. For general consumers, the way of consumption is changing considerably. E-shopping is becoming a generally accepted purchasing way due to its economical and convenient features [2]. This situation largely enhances interactions between consumers and shoppers and can help to expand the businesses of fashion brands to all parts of the world with fewer physical restrictions.

A large number of shopping websites already integrate recommendation systems to help their consumers find relevant products to increase their sales [3]. In the developed personalized recommendation systems, data mining techniques, such as association rules mining for offline operations and connection rule excavation for online operations, have been widely used [4]. In practice, to cope with the data explosion on the Internet and retrieve relevant and concise product information out of overflowing advertisements, the methodology of recommending and learning has been used for acquiring the user preference and providing the user with the user adaptive product information.

In the developed personalized recommender systems, intelligent technologies have been used. In this context, we propose in this paper a new consumer-oriented intelligent recommender system. Compared with the existing work which mostly focuses on learning from product data, this system can recommend

garments to a specific consumer by exploiting consumer profile.
2nd section describes how to implement of consumer profile with a fuzzy description of height and a fuzzy description of fat-thin. 3rd section gives an introduction to the details of how to implement of successful case recommendation system, including mathematical methods: case-based reasoning and similarity degree of fuzzy sets. 4th section presents the details of the validation of the recommendation system. 5th section concludes the paper and future work.

FORMALISATION OF THE CONCEPTS AND DATA

The proposed recommender system aims at ranking and selecting the most relevant garments for a specific consumer in terms of body shape fitting and fashion style conformity. In this paper, we illustrate the system with a concrete case: online recommendation of jeans for Chinese women whose ages are from 18 to 25 years old. In this system, the specific consumer needs to input her consumer profile, composed of body shapes, style keywords and visual images.
Moreover, the consumer can visualize the virtual try-on effect by using the Clo3D software. If the consumer is not satisfied with the recommended result, she can identify the unsatisfied body parts and the system will recommend a new product repeatedly by another recommendation module until his satisfaction.

Consumer profile

A consumer profile is a way of describing a consumer directly so that they can be grouped for marketing purposes [5]. A consumer profile can be defined in different aspects, including personal preference, cost requirements, brand requirements, lifestyle, range of age, body shape, desired consumption occasion, recycling effects, and so on.
In this paper, for simplicity, I define the consumer profile (figure 1) as the combination of three parts, i.e. body shapes, style keywords and visual images. The cost and brand effects are not considered here.
The body shapes are used to characterize the body data of the consumer. The style keywords are the verbal description of the consumer of the desired product. The visual images are used to describe the ambience associated with the product desired by the consumer, which cannot be directly expressed in language by himself/herself.

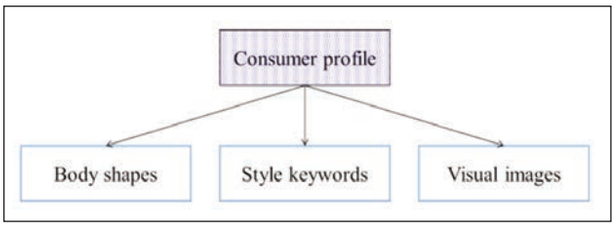

Fig. 1. The proposed consumer profile

Body shapes
Body shapes generally include different body measurements, such as Stature, Chest Circumference, Waist Circumference, Hip Circumference, Neck Circumference, Length of the arm, and Length of the leg. Weight is also considered in some applications.
In my paper, for simplicity, I only consider four parts, i.e. b1: Stature, b2: Chest Circumference, b3: Waist Circumference, and b4: weight. It is easier for general consumers to obtain these data by themselves.
Style keywords
Including a set of emotional keywords used for describing desired fashion styles of garments. The most used style words include: w1: Elegant, w2: Feminine, w3: Young, w4: Sexy, w5: Classic, w6: Romantic, w7: Folk, w8: Sport ($n=8$). To understand each style word, we select one reference picture from several fashion websites and Levis's official website, considered as the most relevant one to this style word.
Visual images
For a non-trained general consumer, style keywords cannot cover all her expectations and preferences. Evaluations with images are relatively more intuitive and closer to her perceptions of garment products. In my paper, for simplicity, I choose 6 pictures of visual images so that each consumer can select the best one according to her expectations: p1, p2, p3, p4, p5 and p6 ($k=6$).
More details about the consumer's profile are given below.

Fuzzy description of height

Normally, we use two indices to describe a human body shape, namely height and fat-thin. However, how to evaluate tall-low and fat-thin is vague. It is for this reason that we use fuzzy sets to express human body shapes [6].
Based on the garment designer's knowledge, tall-low can be expressed by b1, and fat-thin can be expressed by b1 & b4.
According to the Chinese female database of human body shapes, 160A is generally taken as the standard body shape for the Chinese female population, and 145 cm and 175 cm can be considered as the lower and upper bounds of the whole population. We can describe the tall-low as five levels: X1: short, X2: a little short, X3: middle, X4: a little tall, and X5: tall.
The fuzzy function and rules are obtained by uniformly dividing the whole range of the body shapes in height into 5 classes or 5 fuzzy values, denoted as X1, X2, X3, X4, and X5 (figure 2).

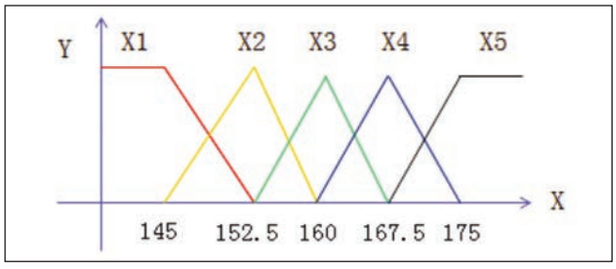

Fig. 2. Fuzzy function (tall-short)

Fuzzy description of fat and thin

BMI (Body Mass Index = Weight in Kilograms / (Height in Meters × Height in Meters)) is a measurement of body fat based on height and weight and applied to both men and women from 18 to 65 years. The WTO regards a BMI of less than 18.5 as being underweight and may indicate malnutrition, an eating disorder, or other health problems, while a BMI equal to or greater than 25 is considered overweight and above 30 is considered obese. The range of BMI values is valid only as statistical categories.

Based on the information, we can define fat-thin as four levels: Y1: underweight, Y2: normal, Y3: overweight, and Y4: obese. Therefore, all kinds of body shapes can be described using one of the 5×4 fuzzy values ($m = 20$).

The proposed recommendation system permits to generate of two outputs:

▪ Fitting of a Garment Style

The fitting of a garment style can be perceived using several frequently used emotional keywords. In this paper, we just extract those from the H&M shopping guide: Skinny, Slim, Straight, Loose. However, for different brands, there are different fashion rules on garment style fitting. To solve this problem, we make a unified neutral description of garment fitting by defining a fuzzy variable of five values: tight, a little tight, moderate, a little loose, and loose ($h = 5$).

▪ Details

Based on the design or shopping experts' knowledge, we take three details: waist, foot and ornamental. And we formalize them according to the same principle as the garment style fitting. The three defined fuzzy variables describing the details are given below.

1. Low-waist, Regular-waist, High-waist
2. Pencil Pants, Regular, Bell-bottom
3. Ornamental, without ornamental

Next, we formalize the proposed system as well as the concerned data:

Category 1: Let $BS = \{bs_1, \ldots, bs_m\}$ be a set of m (m = 20) body shapes, representing all the combinations of the 5 standard tall-low types and 4 fat-thin types obtained from the Chinese National Standard GB/T 1335.2-1997, i.e. "X1Y1", "X2Y1", "X3Y1", "X4Y1", "X5Y1", "X1Y2", "X2Y2", "X3Y2", "X4Y2", "X5Y2", "X1Y3", "X2Y3", "X3Y3", "X4Y3", "X5Y3", "X1Y4", "X2Y4", "X3Y4", "X4Y4", "X5Y4".

Category 2: Let $S = \{s_1, \ldots, s_n\}$ be a set of n style keywords (n = 8), including "Elegant", "Feminine", "Young", "Sexy", "Classic", "Romantic", "Folk" and "Sport".

Category 3: Let $C = \{c_1, \ldots, c_k\}$ be a set of k visual images (k = 6).

Let N be the total number of input variables (Categories 1, 2, and 3). We have $N = m + n + k$ because, for each specific consumer, her body shape (all the body shapes correspond to m inputs), desired style keyword (all the style keywords correspond to n inputs) and visual image (all the visual images correspond to k inputs) constitute the complete consumer profile.

Category 4: Let $I = \{I_1, \ldots, I_q\}$ be a set of q weights (q = 3) corresponding to the three input parts BS, S and C. They are obtained by human evaluations using the Fuzzy AHP method [7].

Category 5: Let CP be a profile of a specific consumer including her body shape and desired style keywords and visual images. It is expressed by a N-dimensional weighted vector denoted as

$CP = (I_1 \times bs_1, \ldots, I_1 \times bs_m, I_2 \times s_1, \ldots, I_2 \times s_n, I_3 \times c_1, \ldots, I_3 \times c_k)$.

Category 6: Let $G = \{g_1, \ldots, g_h\}$ be a set of h fitting levels (h = 5), including "fitting-loose", "fitting-a little loose", "fitting-moderate", "fitting-a little tight" and "fitting-tight".

Category 7: Let $DW = \{dw_1, \ldots, dw_x\}$ be a set of x details of the waist (x = 3), including "waist-high", "waist-moderate", and "waist-low".

Category 8: Let $DF = \{df_1, \ldots, df_y\}$ be a set of y details of leg opening (y = 3), including "Bell-bottom", "Regular", and "Pencil Pants".

Category 9: Let $DO = \{do_1, \ldots, do_z\}$ be a set of z details of ornamentals (z = 2), including "Ornamental-more", "Ornamental-little".

The above M variables (Categories 6, 7, 8, 9) describing garments constitute the profile of a recommended product with $M = h + x + y + z$.

A real case of consumer profile

A real case is given here to illustrate the performance of the proposed method. For a given consumer whose data include the following three parts:

(1) Body shapes: $b1 = 163$ cm, $b2 = 104$ cm, $b3 = 92$ cm, $b4 = 50$ kg.

(2) Style keywords: $w1$ (elegant).

(3) Preferred image: $p1$.

We can calculate from the body data the corresponding fuzzy sets describing the criteria of (tall-low) and (fat-thin), i.e. ($X1$, $X2$, $X3$, $X4$, $X5$) = (0,0,0.65,0.35,0) and ($Y1$, $Y2$, $Y3$, $Y4$) = (0,0.98,0.02,0).

Next, we calculate the BS, S and C, based on the three parts of the input data.

(1) BS = {0,0,0,0,0,0,0,0.64,0.34,0, 0,0,0.01,0.01,0, 0,0,0,0,0}, representing m (m = 20) body shapes, formed by the combinations by multiplication of all the elements "XiYj" (i =1, …, 5 and j = 1, …, 4) in "tall-low" and "fat-thin".

(2) S = {0.5,0,0,0.5,0,0,0,0}, representing that the consumer selects the 1st and 4th style elements at the same time from all the n styles keywords (n = 8). The selected keywords are "Elegant" and "Sexy" respectively. The 1st and 4th elements of S are 0.5 and the others 0 so that the sum of all elements in S is 1. If only "Elegant" is selected, we have S = {1,0,0,0,0,0,0,0}. For simplicity, we just suppose that this consumer selects "Elegant".

The elements of S can be defined by the consumer herself. For example, we can give S = {0.4,0.3,0,0.1, 0,0.2,0,0}, showing that 40% for "Elegant", 30% for "Feminine", 10% for "Sexy" and 20% for "Romantic".

(3) C = {1,0,0,0,0,0}, representing that the consumer selects "Picture 1" from all the k visual images (k = 6).

The elements of C can be defined by the consumer herself.

As we have $(I_1,I_2,I_3) = (0.48,0.31,0.21)$ by fuzzy AHP, then we can calculate the consumer profile by

$CP = (I_1 \times bs_1, \ldots, I_1 \times bs_m, I_2 \times s_1, \ldots, I_2 \times s_n, I_3 \times c_1, \ldots, I_3 \times c_k) = (0,0,0,0,0,0,0,0.31,0.16,0, 0,0,0.005,0.005,0, 0,0,0,0,0, 0.31,0,0,0,0,0,0,0, 0.21,0,0,0,0,0)$.

SUCCESSFUL CASES RECOMMENDATION SYSTEM

Successful cases are very helpful for increasing the relevancy and accuracy of the recommendation system. After each successful recommendation is satisfied by the consumer, the corresponding couple of <consumer profile, recommended product profile> will be added to the database of successful cases. When a new consumer arrives, her/his profile will be first compared with the existing successful cases. If the similarity of this new consumer profile and an existing consumer's profile is higher than a predefined threshold ε ($\varepsilon \in [0.5,1]$), then this recommendation system will recommend the corresponding successful product to the consumer. The computation of this system is realized using case-based reasoning technology.

Case-based reasoning

Case-based reasoning is the process of solving new problems based on the solutions of similar past problems [8]. For example, a doctor who cures a patient by recalling another patient who exhibited similar symptoms is using case-based reasoning. A lawyer who advocates a particular result in a trial based on legal precedents and a judge who creates case law using case-based reasoning. Case-based reasoning is a prominent kind of analogy-making [9].

Case-based reasoning is not only a powerful way for computer reasoning but also a pervasive behaviour in everyday human problem-solving. More radically, all reasoning is based on past cases personally experienced. This view is related to prototype theory, which is most deeply explored in cognitive science [10].

As shown in figure 3, Case-based reasoning is described using a cyclic process as follows.

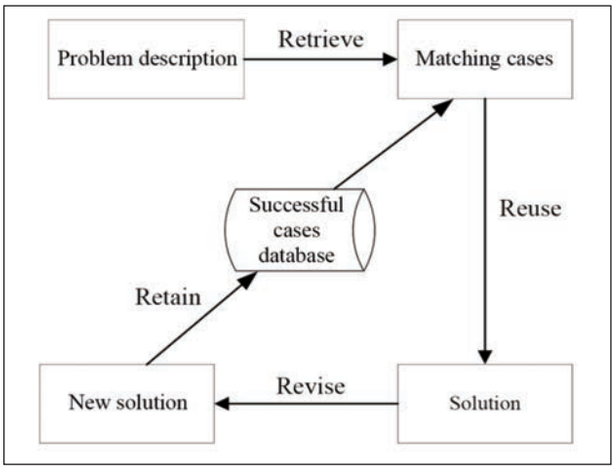

Fig. 3. Cyclic process of Case-based reasoning

(1) Retrieve the most similar cases or cases.
(2) Re-use the knowledge in that case to solve the problem.
(3) Revise the proposed solution.
(4) Retain the experience for the next problem-solving.

Similarity degree of fuzzy sets

The similarity degree of two fuzzy sets can be defined as below.

Let X be the universe.

Let $F(X)$ be the set of all the fuzzy sets on X.

Assuming that A, B, and C are three fuzzy sets defined on $F(X)$, i.e. $\mathbf{A}, \mathbf{B}, \mathbf{C} \in \mathbf{F}(\mathbf{X})$ and N is a mapping function with $\mathbf{F}(\mathbf{X}) \times \mathbf{F}(\mathbf{X}) \rightarrow [\mathbf{0,1}]$.

$\mathbf{N}(\mathbf{A},\mathbf{B})$ is called the similarity degree of any two fuzzy sets A and B if the following conditions are satisfied:

① $\mathbf{N}(\mathbf{A},\mathbf{B}) = \mathbf{N}(\mathbf{B},\mathbf{A})$

② $\mathbf{N}(\mathbf{A},\mathbf{A}) = 1$, $\mathbf{N}(\mathbf{X},\varnothing) = 0$

③ if $\mathbf{A} \subseteq \mathbf{B} \subseteq \mathbf{C}$, then $\mathbf{N}(\mathbf{A},\mathbf{C}) \leq \mathbf{N}(\mathbf{A},\mathbf{B}) \wedge \mathbf{N}(\mathbf{B},\mathbf{C})$

This definition just gives the guidelines for defining a similarity degree, and it can cover several specific definitions given in different contexts. The most used definitions are summarized below.

1. Hamming similarity degree

If $\mathbf{X} = \{\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_n}\}$, then

$$\boldsymbol{N_1(A,B)} = \mathbf{1} - \frac{\mathbf{1}}{\boldsymbol{n}} \sum_{i=1}^{n} |\boldsymbol{A(x_i)} - \boldsymbol{B(x_i)}| \qquad (1)$$

If $\mathbf{X} = [\boldsymbol{a,b}] \subseteq \boldsymbol{R}$, then

$$\boldsymbol{N_1(A,B)} = \mathbf{1} - \frac{\mathbf{1}}{\boldsymbol{b-a}} \int_a^b |\boldsymbol{A(x)} - \boldsymbol{B(x)}| \mathbf{d}\boldsymbol{x} \qquad (2)$$

We give below one example of the Hamming similarity degree of two fuzzy sets A and B. If $A = \{(x1, 0.4), (x2, 0.8), (x3, 1), (x4, 0)\}$ and $B = \{(x1, 0.4), (x2, 0.3), (x3, 0), (x4, 0.2)\}$, the Hamming similarity degree is:

$$\boldsymbol{N_1(A,B)} = \mathbf{1} - (\mathbf{0} + \mathbf{0.5} + \mathbf{1} + \mathbf{0.2})/\mathbf{4} = 0.575 \qquad (3)$$

2. Euclidean similarity degree

If $\mathbf{X} = \{\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_n}\}$, then

$$\boldsymbol{N_2(A,B)} = \mathbf{1} - \frac{\mathbf{1}}{\sqrt{\boldsymbol{n}}} \left(\sum_{i=1}^{n} (\boldsymbol{A(x_i)} - \boldsymbol{B(x_i)})^2\right)^{1/2} \qquad (4)$$

If $\mathbf{X} = [\mathbf{a}, \mathbf{b}] \subseteq \boldsymbol{R}$, then

$$\boldsymbol{N_2(A,B)} = \mathbf{1} - \frac{\mathbf{1}}{\boldsymbol{b-a}} \left(\int_a^b (\boldsymbol{A(x)} - \boldsymbol{B(x)})^2 \mathbf{d}\boldsymbol{x}\right)^{1/2} \qquad (5)$$

For the same fuzzy sets A and B defined previously, the Euclidean similarity degree is

$$\boldsymbol{N_2(A,B)} = \mathbf{1} - \mathbf{0.5} \cdot \sqrt{(\mathbf{0} + \mathbf{0.25} + \mathbf{1} + \mathbf{0.04})} = 0.43 \qquad (6)$$

3. Max-min similarity degree

If $\mathbf{X} = \{\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_n}\}$, then

$$\boldsymbol{N_3(A,B)} = \frac{\sum_{i=1}^{n} (\boldsymbol{A(x_i)} \wedge \boldsymbol{B(x_i)})}{\sum_{i=1}^{n} (\boldsymbol{A(x_i)} \vee \boldsymbol{B(x_i)})} \qquad (7)$$

For the same fuzzy sets A and B, the max-min similarity degree is

$$\boldsymbol{N_3(A,B)} = 0.4 + 0.3 + 0 + 0 / 0.4 + 0.8 + 1 + 0.2 = 0.29 \qquad (8)$$

4. Arithmetic averaged similarity degree

$$N_4(A,B) = \frac{2\sum_{i=1}^{n}(A(x_i) \wedge B(x_i))}{\sum_{i=1}^{n}A(x_i) + \sum_{i=1}^{n}B(x_i)} \quad (9)$$

For the same fuzzy sets A and B, the arithmetic averaged similarity degree is

$$N_4(A,B) = 2\cdot(0.4+0.3+0+0)/3.1 = 0.45 \quad (10)$$

Formalization, similarity and reasoning

The database of successful cases *DB_SC* is composed of all the *w* past successful recommended consumer profiles, the corresponding consumer profiles and frequencies of being used.
It is formalised by

$$DB\_SC = \{<CP_i, \{<SRPP_i^{(k)}, T_i^{(k)}> \mid k = 1, \ldots, p(i)\} > \mid i = 1, \ldots, w\} \quad (11)$$

where CP_i is the *i*-th consumer profile in *DB_SC*, and $SRPP_i^{(k)}$– the *k*-th product profile successfully recommended to CP_i, and $T_i^{(k)}$ – the frequency with which this product profile has been used.
In real shopping experience, several different products may have been accepted by consumers having the same profile.
According to the previous formalization of *CP*, each consumer profile CP_i of *DB_SC* is expressed by a *N*-dimensional weighted vector ($N=m+n+k$), denoted as

$$CP_i = (I_1\times bs_{1i}, \ldots, I_1\times bs_{mi}, I_2\times s_{1i}, \ldots, I_2\times s_{ni}, I_3\times c_{1i}, \ldots, I_3\times c_{ki}) \quad (12)$$

where $bs_{1i}, \ldots, bs_{mi}$ are the elements of CP_i corresponding to the *m* ($m=20$) body shapes, $s_{1i}, \ldots, s_{ni}$ are the elements of CP_i corresponding to the *n* style keywords ($n=8$), $c_{1i}, \ldots, c_{ki}$ are the elements of CP_i corresponding to the *k* visual images ($k=6$).
The similarity degree between a new consumer profile *CP* and the successful cases database *DB_SC*, denoted as *Similarity*(*CP, DB_SC*), is defined as the maximal value of the similarity degrees of *CP* related to all the consumer profiles CP_i ($i=1, \ldots, w$) in the database *DB_SC*. The similarity of *CP* related to CP_i, denoted as *Similarity*(*CP, CP*$_i$) is defined using the fuzzy sets and Hamming similarity degree. We have

$$Similarity(CP, CP_i) = 1 - \frac{1}{2} \times \left[I_1\times\left(\sum_{j=1}^{m}|bs_j - bs_{ji}|\right) + I_2\times\left(\sum_{j=1}^{n}|s_j - s_{ji}|\right) + I_3\times\left(\sum_{j=1}^{k}|c_j - c_{ji}|\right)\right]$$

This similarity degree varies between 0 and 1. The closer the new consumer profile *CP* is to the existing consumer profile CP_i, the closer their similarity degree is to 1.

According to these similarity degrees, we try to select the most relevant product profiles to be recommended to the new consumer *CP* by using the Case-based reasoning method. Case-based reasoning is basically based on the *k*-Nearest Neighbours algorithm. Its reasoning is composed of the three following rules:
Rule 1: If $Similarity(CP, CP_i) \le \varepsilon$ for all $i=1, \ldots, w$, then there is no similar consumer profile in the database *DB_SC* and the system will start the other recommendation modules for *CP*.
Rule 2: If there exists only one CP_i ($i \in \{1, 2, \ldots, w\}$ so that $Similarity(CP, CP_i) > \varepsilon$, then we select the product profile $SRPP_i^{k*}$ with $T_i^{k*} = \max\{T_i^{(k)} \mid k = 1,\ldots, p(i)\}$ for recommendation to the consumer *CP*. If $SRPP_i^{k*}$ is not accepted by the consumer, the system will successively recommend the other product profiles from $\{SRPP_i^{(k)}\}$ according to the descending order of $T_i^{(k)}$s.
Rule 3: If there exist several CP_j's ($j=1,2, \ldots, g$ and $1<g\le w$) so that $Similarity(CP, CP_j) > \varepsilon$, then we will select a consumer profile CP_i meeting $Similarity(CP, CP_i) = \max\{Similarity(CP, CP_j) \mid j=1, \ldots, g\}$ and apply Rule 2 for successively recommending relevant product profiles. If the product profiles of CP_i cannot be accepted by the consumer, we will select the consumer profile from $\{CP_j \mid j=1, \ldots, g\}$ corresponding to the second biggest similarity degree and recommend its concerned product profiles, and so on.

VALIDATION OF THE RECOMMENDATION SYSTEM

In this example, we define $\varepsilon = 0.8$. With this threshold, we search for the product profiles corresponding to a new consumer profile from the successful cases database. A garment e-shop is created with two successful cases in the database DB_SC. It is represented by CP_1=(0,0,0,0,0,0,0,0.17,0.3,0, 0,0,0.005, 0.005,0, 0,0,0,0,0, 0.31,0,0,0,0,0,0,0, 0.21,0,0,0,0,0), $SRPP_1^{(1)}$ = (0.8,0.7,0.4,0.4,0.3,0.1,0.2,0.4,0.9,0.5, 0.2,0.8,0.4) and $T_1^{(1)} = 1$. $SRPP_1^{(2)}$ = (0.1,0.3,0.4,0.7, 0.5,0.1,0.3,0.8,0.5,0.7,0.6,0.1,0.7) and $T_1^{(2)} = 3$.
A female consumer is visiting the e-shop. Her profile CP is (0,0,0,0,0,0,0,0.28,0.19,0, 0,0,0.005,0.005,0, 0,0,0,0,0, 0.31,0,0,0,0,0,0,0, 0.21,0,0,0,0,0).
From the computation, we find that the similarity degree of *CP* related to CP_1 is 0.89 (> the threshold 0.8). However, the frequency of the recommended product $T_1^{(2)}$ is 3 (larger than $T_1^{(1)} = 1$). Therefore, this system will recommend the product $SRPP_1^{(2)}$ to the consumer *CP*. From $SRPP_1^{(2)}$ = (*loose* 0.1 , *a little loose* 0.3 , *moderate* 0.4 , *a little tight* 0.7 , *tight* 0.5 , *waist-high* 0.1 , *waist-moderate* 0.3 , *waist-low* 0.8 , *Bell-bottom* 0.5 , *Regular* 0.7 , *Pencil Pants* 0.6 , *Ornamental-more* 0.1 , *Ornamental-little* 0.7), we can see that the garment fitting level of this product is “a little tight” since 0.7 is the biggest one of the garment fitting levels. In the same way, details of the waist are “low”, details of the leg

opening are “regular” and details of ornamental are “little”.
The virtual try-on is given in figure 4, and this consume\r is satisfied with the recommendation product. It shows that the database of successful cases is helpful for this consumer.

Fig. 4. Virtual fitting effects by the consumer

CONCLUSIONS AND FUTURE WORK

In this garment recommendation system, we use Case-based reasoning technology to recommend relevant garments to each consumer by comparing her consumer profile and the successful cases database. If the similarity value between the consumer profile and the successful cases database is higher than a predefined threshold ε ($\varepsilon \in [0.5,1]$), this recommendation system will be applied to the consumers. Its principle is to use the experience of successfully recommended products for making new recommendations to consumers having similar profiles. In practice, this module will enable to propose more satisfactory products to consumers because it is closer to a successful real shopping experience. In this context, the comparison between the consumer profile and the successful cases database is particularly important.
Compared with other existing methods, the proposed system is more robust and interpretable owing to its capacity to treat human perception. This work can be further extended to support other fashion-oriented products such as suits, dresses, coats and so on.
Due to the time limitation, the current work is still far from being perfect. In future work, more effort should be dedicated to the following aspects:
1. In the future, to obtain more generalized and concrete information about successful recommendation cases, it is imperative to integrate deep learning technology into the system.
2. In the future, fashion trend forecast strategies can be introduced to make the recommendation system more accurate and intelligent.

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Research on thermal comfort and moisture management properties of drapery fabrics produced with polyester yarns having different fibre cross-sectional shapes and TiO_2 amount

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ABSTRACT – REZUMAT

Research on thermal comfort and moisture management properties of drapery fabrics produced with polyester yarns having different fibre cross-sectional shapes and TiO_2 amount

This study aims to provide an investigation regarding the effect of fibre cross-sectional shape, incorporated TiO_2 amount (%) during polyester yarn production, and the weft density parameters respectively, on thermal comfort, moisture management, water vapour permeability, and air permeability properties of polyester drapery fabrics. Completely randomized three-factor analysis of variance (ANOVA) was conducted at the significance level of 0.05. SNK tests were also performed to observe the means of each parameter. Some of the weft yarn production parameters and the weft density (picks/cm) factors were found as significant factors in some thermal comfort and moisture management, water vapour, and air permeability properties of drapery samples.

Keywords: *fibre cross-sectional shape, drapery fabrics, thermal comfort properties, MMT, water vapour permeability, air permeability*

Studiu privind confortul termic și proprietățile de gestionare a umidității țesăturilor pentru draperii produse cu fire din poliester având diferite forme de secțiune transversală a fibrelor și cantități de TiO_2

Acest studiu își propune să ofere o analiză privind influența formei secțiunii transversale a fibrei, a cantității de TiO_2 încorporate (%) în timpul obținerii firelor din poliester și a desimii firelor de bătătură asupra confortului termic, proprietăţilor de gestionare a umidității, permeabilității la vapori de apă și permeabilităţii la aer ale ţesăturilor din poliester pentru draperii. Analiza de varianță cu trei factori complet randomizată (ANOVA) a fost efectuată la un nivel de semnificație de 0,05. Au fost efectuate și teste SNK pentru observarea mediilor fiecărui parametru. Unii dintre parametrii de producție a firului de bătătură și factorii de desime a bătăturii (fire de bătătură/cm) au fost identificaţi ca factori semnificativi pentru unele proprietăți de confort termic și de gestionare a umidităţii, permeabilitate la vapori de apă și permeabilitatea la aer ale mostrelor de draperii.

Cuvinte-cheie*: forma secțiunii transversale a fibrelor, țesături pentru draperii, proprietăți de confort termic, MMT, permeabilitate la vapori de apă, permeabilitate la aer*

INTRODUCTION

Drapery fabrics are the main furnishing textile groups which can be produced with different weave patterns by using different natural and man-made fibres like cotton, linen, rayon, polyester, or blends of those fibres. Although drapery fabrics are generally used to provide a decorative aspect, some additional properties have also been considered as the required features in recent years besides the aesthetic properties. Innovations related to drapery fabrics, light and UV resistant (black-out), thermal insulation and energy saving, protective effect against electromagnetic waves (EMI), and noise (sound) insulation are still progressing. For example, black-out curtains generally block the light, and these products are used in various fields to protect from light and UV radiation and personal privacy. Some antibacterial curtains are utilized in common public areas such as hotels, restaurants, or trains where such types of fabrics are highly demanded [1, 2].

Polyester is the most common fibre utilized as the raw material for drapery fabrics owing to its high mechanical properties in wet and dry state. Other synthetic and regenerated cellulosic fibres may be also utilized as the raw materials for these products. When the energy-saving properties are considered for these products, thermal comfort properties should also be evaluated in addition to mechanical and dimensional properties. The thermal comfort of fabric may be described by the movement of heat, moisture, and air. Non-sensorial comfort can be obtained from test equipment such as Alambeta, sweating guard hot plate moisture management tester (MMT) etc. Static thermal properties may be characterised by thermal conductivity, thermal resistance, and thermal absorption. Moisture management has the function of weight control of cloth by preventing moisture

increase on the fabric. Water vapour permeability and air permeability are the other parameters that influence fabric comfort. Water vapour permeability indicates the vapour transmitted from the body which may be influenced mainly by fibre content, thickness, and fabric geometry. etc. Water vapor resistance which mainly depends on the air permeability is mentioned as the most important parameter for determining thermal comfort in many studies [3–16]. There are numerous studies evaluating the effect of fibre, yarn, and fabric structural properties on the comfort properties of fabrics. With the manner of thermal properties, many researchers have emphasized that the porosity and thickness of fabrics influence the thermal resistance of fabrics [17–22]. Matusiak and Sikorski [23] investigated the influence of the structure of woven fabrics on their thermal insulation properties. It was concluded in the study that weave and linear density of weft yarn significantly influenced the thermal properties of woven fabrics. Synthetic fibres can be engineered to provide a high level of thermal insulation, not only by bulking or texturing the yarn but also by introducing a modified fibre cross-section. The thermal properties of textile fabrics are influenced by many factors at microscopic (chemical composition, morphological characteristics, fineness, cross-section, porosity and water content of fibre components), mesoscopic (yarn structure and properties) and macroscopic levels (fabric physical and structural properties and finishing treatments). The fibre's cross-sectional shape and its related results, affect the thermal properties of yarns and fabrics which are produced from them. Considering the cross-sectional shape of fibres, heat flow between or inside the fibres will vary regarding the contact surface areas of fibres and the current porosity. Until recent years, the fibres were mostly produced as round cross-sections. But nowadays, instead of the round cross-section new versions of fibres are preferred to improve and develop fibre properties. As it is known in the melt spinning method, continuous filaments are obtained by passing the melt through the holes on the spinneret. The cross-section shapes of polyester fibres can be easily changed by the shape or size of the nozzle holes [24, 25].

Some synthetic fibres have been produced with a hollow core or channel. Hollow fibres have many unique properties and have found numerous applications as well. For example, hollow fibres can provide great bulkiness with less weight and are often used to make insulated clothing materials. Pac et al. [26] studied the effect of fibre morphology, yarn and fabric structure on the thermal comfort properties of the fabric. Ramakrishnan et al. [27] explained the effect of fibre fineness on the thermal resistance of fabrics. According to them, the microdenier fibre gives low thermal conductivity and higher thermal resistance. A total of eight woven fabrics were produced in two different weave patterns (plain and twill) from polyester yarns of four different fibre cross-sectional shapes (round, hollow round, trilobal and hollow trilobal) in Karaca et al.'s study [16]. Varshney et al. [28] investigated the effect of profiles of polyester fibres of four different cross-sectional shapes (circular, scalloped oval, tetrakelion and trilobal) on the physiological properties of their fabric. Tyagi et al. [29] studied the thermal comfort properties produced from polyester/viscose and polyester/cotton ring and air jet yarns where circular and trilobal cross-sectional polyester fibres were utilized. Manish et al. [30] determined the effect of using a tetra channel cross-section polyester fibre in place of cotton in a polyester/cotton blended yarn on various handle and thermal properties. Utilizing TiO_2 during the yarn extrusion of synthetic fabrics has also been one of the popular ways to apply some extra features to textile products. Titanium dioxide has high performance in many applications due to its many electrical, optical, and chemical properties. It is also used in the constituting yarns of drapery fabric owing to its high solar reflectivity [31, 32]. Apart from the investigation of fibre, yarn and fabric structure effect on comfort properties, some studies investigated the effect of utilising varying ratios of TiO_2 amount (% 0, 0.3, 0.6, 1, 1.4, 2.0, 2.4) during the melt spinning process of polyester yarn on thermal properties of fabric samples produced from those yarns [33]. Different ratios of TiO_2 during yarn extrusion were also utilized within our study to investigate the effect of this substance amount (%) on thermal comfort and moisture management properties of drapery fabrics which are estimated to have high solar absorbance at the same time.

From the literature investigated, it may be understood that thermal comfort and moisture management properties of polyester drapery fabrics have become a serious research area recently. It has also been discovered that there are not many studies related to the effect of fibre cross-sectional type, and the incorporated TiO_2 (%) amount during yarn spinning on drapery fabrics' some thermal comfort properties produced at different weft densities. The scope of this work is aimed to produce drapery fabrics with satisfying thermal comfort and moisture management properties. Hence woven fabrics of different structural parameters such as weft density, and weft yarn type where different polyester yarn production parameters were selected such as different fibre cross-sectional shapes, and the different incorporated amounts of TiO_2 (%) during extrusion were utilized to explore the effects of above-mentioned parameters on thermal comfort and moisture management properties of drapery fabrics.

EXPERIMENTAL

Materials and preparation

18 different drapery fabrics were produced by using 334/192 denier/fil draw textured polyester weft yarns produced with different fibre cross-sectional shapes (round, w, hollow) and different amounts of incorporated TiO_2 (0.3%, 1.2%, 1.8%) and with the same

50 denier polyester warp yarns at two different weft densities (24 and 28 threads/cm). The polyester multifilament weft yarns (334dtex/194 fil) utilized in this study were produced from semi dull polyester (PET) polymer via the melt spinning process. Only the spinneret cross-sectional shape and the incorporated TiO_2 amount (%) were altered. BARMAG FDY 21 Multifilament spinning machine was utilised for the process. 18 different polyester multifilament yarns of 334 dtex and 192 filaments with round, hollow round, trilobal sectional shapes were manufactured as the weft yarns. Details of the production parameters of carbon black - TiO_2 added pre-oriented polyester yarns were indicated in table 1. Carbon black and Titanium Oxide (TiO_2) added Pre (Partially) Oriented yarns were directed to a false twisting machine (Oerlikon Barmag). The drawn texturized (DTY) polyester yarn samples' images captured by OLYMPUS SC30 20X/0.40∞/0/FN22 microscope are revealed below in figure 1. The experimental design of 18 different drapery fabrics produced from these 334/192 denier/fil DTY polyester weft yarns is revealed in table 2.

Method

Before all tests, all fabrics were conditioned for 24 h in standard atmospheric conditions (at the temperature of 20±2°C and relative humidity of 65±2%). Drapery fabrics' thermal comfort performance and moisture management properties should also be evaluated considering that they may be utilized in hot and cold climates in front of the windows. Their windproof performance should also be considered

Table 1

POLYESTER WEFT YARN SPINNING CONDITIONS					
Extruder temperature (°C)	**1st region**	**2nd region**	**3rd region**	**4th region**	**difil**
	286 (°C)	**286 (°C)**	**286 (°C)**	**286 (°C)**	**286 (°C)**
Winder speed (mpm)	3000				
1st Godet speed (m/min)	2800				
2nd Godet speed (m/min)	2970				
Melting pomp (rpm)	11.55				
Oil pomp (rpm/oil type)	40/mineral oil				
Nozzle pressure (bar)	135				

Table 2

EXPERIMENTAL DESIGN OF FABRICS PRODUCED FROM PARTIALLY ORIENTED YARNS WITH DIFFERENT PRODUCTION PARAMETERS								
Fabric code	**Fibre cross-sectional shape**	**Incorporated TiO_2 (%)**	**Incorporated carbon black (%)**	**Weft yarn type (denier/fil)**	**Texturing type**	**Weft density (picks/cm)**	**Warp yarn type (denier)**	**Warp density (picks/cm)**
A1	round	0.3	1.05	334/192 PES DTY	Draw	24	50	112
A2	round	0.3				28		
A3	round	1.2				24		
A4	round	1.2				28		
A5	round	1.8				24		
A6	round	1.8				28		
A7	w	0.3				24		
A8	w	0.3				28		
A9	w	1.2				24		
A10	w	1.2				28		
A11	w	1.8				24		
A12	w	1.8				28		
A13	hollow	0.3				24		
A14	hollow	0.3				28		
A15	hollow	1.2				24		
A16	hollow	1.2				28		
A17	hollow	1.8				24		
A18	hollow	1.8				28		

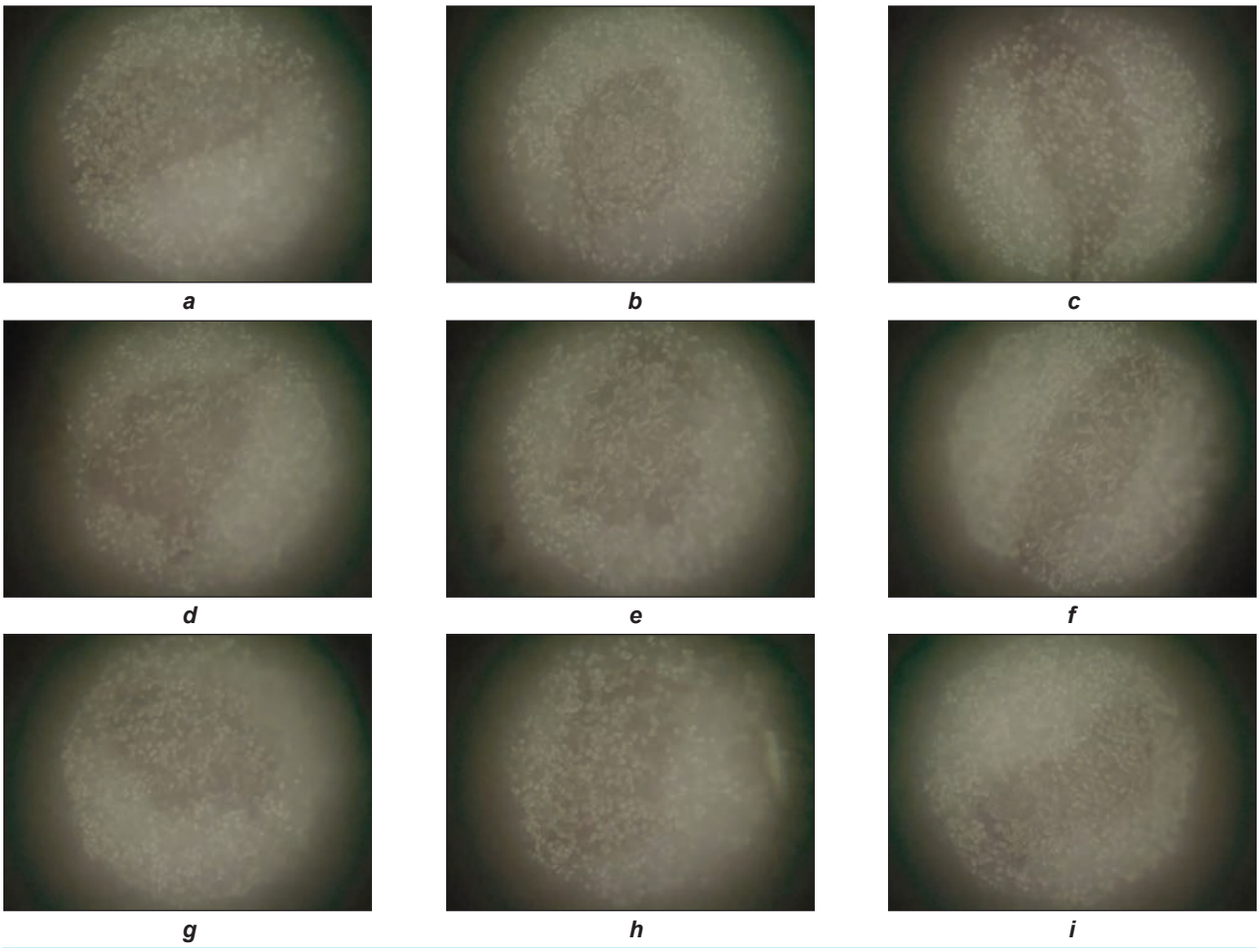

Fig. 1. Fibre cross-sectional shape of polyester yarns utilized for drapery fabrics: *a* – round cross-sectional fibres with 0.3 TiO_2 (%); *b* – round cross-sectional fibres with 1.2 TiO_2 (%); *c* – round cross-sectional fibres with 1.8 TiO_2 (%); *d* – "W" cross-sectional fibres with 0.3 TiO_2 (%); *e* – "W" cross-sectional fibres with 1.2 TiO_2 (%); *f* – "W" cross-sectional fibres with 1.8 TiO_2 (%); *g* – hollow cross-sectional fibres with 0.3 TiO_2 (%); *h* – hollow cross-sectional fibres with 1.2 TiO_2 (%); *i* – hollow cross-sectional fibres with 1.8 TiO_2 (%)

associated with the fabrics' structural properties. Hence thermal comfort, moisture management, water vapour permeability and air permeability properties were evaluated by using the Alambeta device, Moisture management tester, Permetest device and SDL Atlas Digital Air Permeability Tester Model M021 A devices respectively which are placed in the laboratory of Textile Engineering Department, Bursa Uludağ University. Each measurement was performed according to the related standard indicated in table 3 below.

Table 3

TEST TYPE AND THE STANDARDS	
Measurement	**Device and standard**
Thermal comfort properties	Alambeta
Moisture management	SDL ATLAS, AATCC 195-2009
Water vapour permeability	Permetest, TS EN ISO 11092
Air permeability	SDL ATLAS, TS 391 EN ISO 9237

Thermal comfort properties were evaluated in terms of Thermal conductivity (λ), Thermal diffusivity (*a*), Thermal absorptivity (*b*), and Thermal resistance *(r)* results of samples. A moisture Management Tester (MMT, SDL Atlas) was utilized to measure the moisture management properties of fabrics based on the AATCC 195-2009 standard [34]. The results were expressed in terms of the wetting time for top and bottom surfaces (WTT, WTB), the absorption rate for top and bottom surfaces (ABST, ABSB), spreading speed (SST, SSB) and maximum wetted radius for top and bottom surfaces (MWRT, MWRB), accumulative one-way transport index (AOTI), and overall moisture management capability (OMMC). Additionally, table 4 reveals the grading of moisture management terms indices where the indices are graded and converted from value to grades of five levels: **1 – Poor, 2 – Fair, 3 – Good, 4 – Very good, and 5 – Excellent.** Relative water vapour permeability (RWP %) and absolute water vapour permeability (AWP) of drapery samples were measured via the PERMETEST device in the unit of m^2Pa/W. This instrument can determine non-destructive measurement of the samples according to ISO 11092 standard and it works on

Table 4

GRADING OF MMT INDICES [34]						
Index	**Grade**					
	Surfaces	**1**	**2**	**3**	**4**	**5**
Wetting time	Top	≥120	20–119	5–19	3–5	<3
		No wetting	Slow	Medium	Fast	Very Fast
	Bottom	≥120	20–119	5–19	3–5	<3
		No wetting	Slow	Medium	Fast	Very Fast
Absorption rate	Top	0–10	10–30	30–50	50–100	>100
		Very slow	Slow	Medium	Fast	Very Fast
	Bottom	0–10	10–30	30–50	50–100	>100
		Very slow	Slow	Medium	Fast	Very Fast
Max. wetted radius	Top	0–7	7–12	12–17	17–22	>22
		No wetting	Small	Medium	Large	Very large
	Bottom	0–7	7–12	12–17	17–22	>22
		No wetting	Small	Medium	Large	Very large
Spreading speed	Top	0–1	1–2	2–3	3–4	>4
		Very slow	Slow	Medium	Fast	Very Fast
	Bottom	0–1	1–2	2–3	3–4	>4
		Very slow	Slow	Medium	Fast	Very Fast
AOTI	Top	<–50	–50 to 100	100–200	200–400	>400
		Poor	Fair	Good	Very good	Excellent
OMMC	Bottom	0.0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	>0.8
		Poor	Fair	Good	Very good	Excellent

the principle of heat flux sensing. The relative water vapour permeability (RWP) of the sample is calculated by the ratio of heat loss from the measuring head with fabric (q_s) and heat loss from the measuring head without fabric (q_o) as below equation [35, 36].

$$RWP = (q_s / q_o) \times 100\ \% \quad (1)$$

Air permeability of fabrics was measured based on EN ISO 9237 standard using SDL Atlas Digital Air Permeability Tester Model M 021 A. Measurements were performed by application under 100 Pa air pressure per 20 cm^2 fabric surface. Averages of measurements from 10 Averages of measurements from 10 different areas of fabrics were calculated [37].

Statistical analysis

A completely randomized three-factor analysis of variance (ANOVA) was performed to determine the effect of fibre cross-sectional shape, incorporated TiO_2 amount (%) of weft yarns and the weft density on drapery fabrics' thermal comfort, moisture management, water vapour permeability and air permeability properties. The means were compared using SNK tests. The treatment levels were marked by the mean values, and levels marked by a different letter (a, b, c) reveal that they were significantly different. The statistical evaluations were done by using the SPSS 23 Statistical software package.

RESULTS AND DISCUSSIONS

Thermal properties

Thermal properties were evaluated in terms of bar graphs and statistical results. Figures 2 to 5 indicate the bar charts of thermal conductivity, thermal absorptivity, thermal resistivity, and fabric thickness respectively. According to figure 2, thermal conductivity results do not fluctuate prominently regarding to fibre cross-sectional type. Maximum thermal conductivity value was obtained from A8 coded fabric samples while minimum value was found among A17 coded fabric samples. Figure 3 indicates thermal absorptivity values where the maximum value was obtained from A6 coded fabrics and the minimum value was found among A9 samples. Concerning fibre cross-sectional shape, samples of yarns having hollow fibres display slightly higher thermal absorptivity results compared to those having round and W cross-sectional fibres. Thermal resistance results (figure 4) reveal a fluctuating trend among the fabric samples. Samples of yarns having "w" cross-sectional fibre reveal higher thermal resistance values compared to those having round and hollow fibres. There is not a prominent trend for the fabric thickness results (h) regarding fibre cross-sectional shape according to figure 5. Additionally, it is observed that although fabric thickness results are expected to be directly parallel with the thermal resistance results,

the graphs may differ slightly due to the varying thermal conductivity results.

Three-Way ANOVA was utilized to investigate the significant effect of weft density, fibre cross-sectional shape and TiO_2 (%) amount on the thermal properties of the produced drapery fabrics at a significant ratio of 0.05 (table 5). Besides ANOVA results, Student-Newman-Keuls (SNK) multi-comparison tests (to evaluate the significance different of subgroups regarding TiO_2 (%) amount and fibre cross-sectional shape) were also conducted for the comparison of means of thermal properties (table 6). Regarding to ANOVA results; fibre cross-sectional shape and weft density were significant factors in thermal conductivity at a significance level of 0.05. The interaction of TiO_2 and fibre cross-sectional shape was also a significant factor in thermal conductivity at a significance level of 0.05. When thermal diffusivity is considered; it can be observed that fibre cross-sectional shape and weft density had a significant effect on this parameter at a significant level of 0.05. Thermal absorptivity was significantly influenced by fibre cross-sectional shape and the weft density at a significance level of 0.05. Fibre cross-sectional shape, weft density and the interaction of TiO_2 and fibre cross-sectional shape parameters had significant effect on the thermal resistivity of fabrics. Sample thickness was significantly influenced by fibre cross-sectional shape, weft density and the interaction of fibre cross-sectional shape and weft density at a significance level of 0.05. The peak heat flow density ratio (p) and peak heat flow density (q) were significantly influenced only by the fibre cross-sectional shape. Since TiO_2 (%) was not a significant factor for thermal comfort results according to ANOVA tests, SNK tests were performed only for fibre cross-sectional shape parameters (table 6). According to SNK results, minimum thermal conductivity was obtained from samples with hollow pet yarns while maximum value was found among the samples with W cross-section PET yarns. This may be attributed to the high insulation properties of hollow pet yarns. It is mentioned in Karaca et al.'s study [14] that when it is geometrically considered, the pore volume in the yarns produced from hollow fibres will be greater than that in yarns produced from solid fibres of the same fibre count because of the greater outer dimension of the hollow fibres which will lead to a higher unit weight and thicker fabric structure hence higher insulation in the fabrics produced from these fibres. Considering thermal diffusivity, the minimum value was obtained from samples of hollow yarns while the maximum value was obtained from w section yarns. Thermal absorptivity values of samples from yarns of hollow fibres were higher than samples from yarns of round and w sectional fibres which were observed under the same subset at a significance level of 0.05. This means that samples made of hollow fibres will give a cool feeling while samples made of round and w sectional fibres will give a warmer feeling. Thermal resistivity results of the samples made of hollow and round fibres were observed under the same subset at a significance level of 0.05 and lower than those with "w" fibres. Normally since samples with "w" cross-sectional

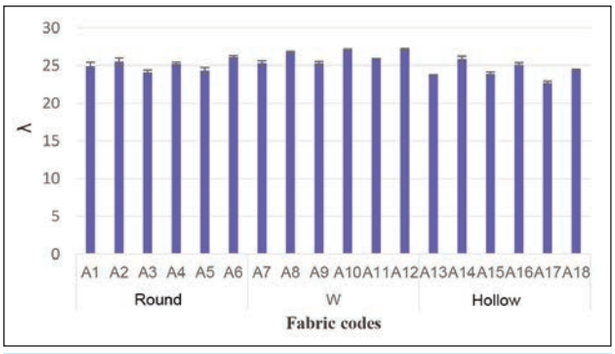

Fig. 2. Thermal conductivity $(W \cdot m^{-1} \cdot K^{-1}) \cdot 10^{-3}$

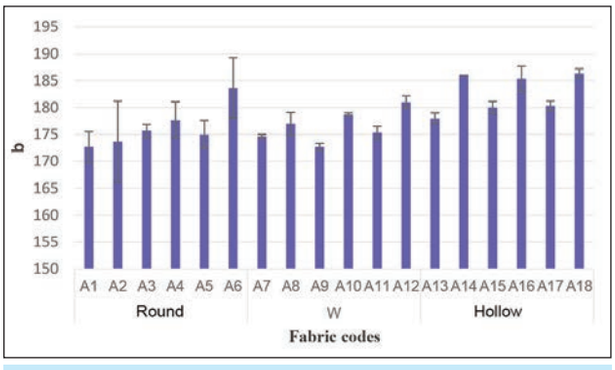

Fig. 3. Thermal absorptivity $(W \cdot s^{1/2})/m^2 \cdot K$

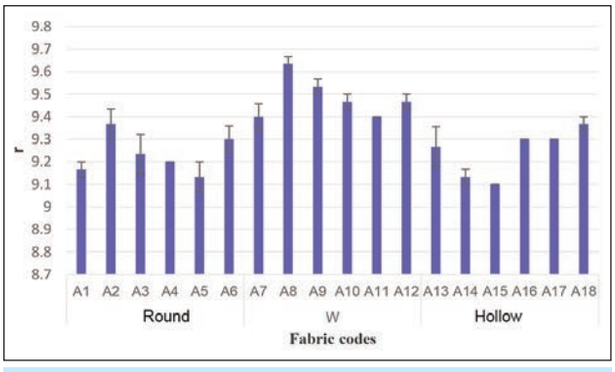

Fig. 4. Thermal resistivity $(m^2 \cdot K)/W \cdot 10^{-3}$

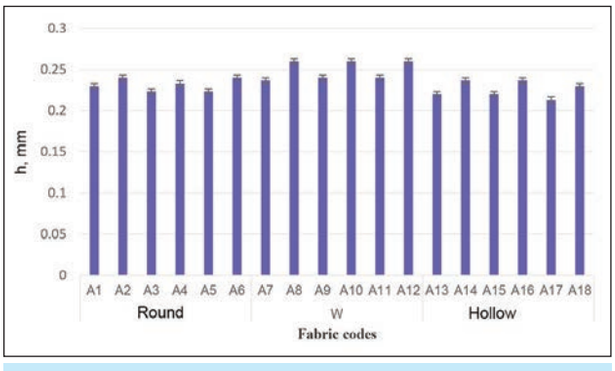

Fig. 5. Fabric thickness (mm)

shaped fibres had the maximum thermal conductivity, these samples are expected to reveal the minimum thermal resistivity. However, the result is not as expected. This may be due to the fabric thickness value. Regarding fabric thickness, the Fabric thickness of samples with yarns of hollow fibres indicated higher values compared to their counterparts with yarns of round and "w" sectional fibres. Considering the peak heat flow density ratio; samples of yarns made of "w" cross-sectional fibres indicated the lowest value while samples with yarns made of hollow fibres revealed the maximum value. Additionally, samples with yarns made of round fibres were not statistically different from their counterparts with "w" and "hollow" fibres at a significance level of 0.05. Regarding peak heat flow density, samples of pet yarns with "w" section fibre revealed the lowest value while samples of pet yarns with "hollow" and "round" cross-sectional fibres indicated the maximum value which was observed under the same subset at a significance level of 0.05.

Moisture management properties

It has been observed in many studies that moisture management properties of the fabrics are influenced by fabric structure, yarn structure and fibre structure. Synthetic fibres such as polyester are hydrophobic, which means that their surface has few bonding sites for molecules. Hence they are expected to remain dry, with good moisture transportation and release [36]. The moisture management performance of the fabrics was evaluated in terms of wetting time (s), absorption rate (%/s), the spreading spread (mm/s) for the top (SS_t) and bottom surfaces (SS_b), the accumulative one-way transport index (AOTI) and overall moisture management capacity (OMMC) using bar graphics. Additionally, a completely randomised three way-ANOVA test was performed to investigate the significant effect of TiO_2 (%) amount, fibre cross-sectional shape and weft density on moisture management properties of drapery fabrics (table 7). SNK tests were also evaluated for the comparison of means (table 8). Each result was discussed within each related part.

Wetting time (WT_t, WT_b)

According to figure 6, Maximum top wetting time and bottom wetting time results were obtained from A3 coded samples while minimum top wetting time was found among A2 coded samples and minimum bottom

Table 5

ANOVA RESULTS FOR THERMAL PROPERTIES

Main source	λ $(W·m^{-1}·K^{-1})·10^{-3}$	α $(m^2·s^{-1})·10^{-6}$	b $(W·s^{1/2})/m^2·K$	r $(m^2·K)/W·10^{-3}$	h (mm)	p	q $(W/m^2)·10^3$
TiO_2 (%)	0.25	0.06	0.12	0.63	0.24	0.61	0.50
Fibre cross-sectional shape	**0.00***	**0.00***	**0.00***	**0.00***	**0.00***	**0.04***	**0.00***
Weft density	**0.00***	**0.00***	**0.00***	**0.00***	**0.00***	0.66	0.61
TiO_2 * Fibre cross-sectional shape	**0.00***	0.09	0.72	**0.01***	0.05	0.26	0.57
TiO_2 * weft density	0.78	0.86	0.60	0.36	0.79	0.85	0.91
Fibre cross-sectional shape * weft density	0.23	0.89	0.70	0.47	**0.03**	0.86	0.76
TiO_2 * fibre cross-sectional shape * weft density	0.10	0.86	0.70	**0.00***	0.76	0.62	0.78

Note: * significantly important.

Table 6

SNK RESULTS FOR THERMAL PROPERTIES

Parameter: Fibre cross sectional shape	λ $(W·m^{-1}·K^{-1})·10^{-3}$	α $(m^2·s^{-1})·10^{-6}$	b $(W·s^{1/2})/m^2·K$	r $(m^2·K)/W·10^{-3}$	h (mm)	p	q $(W/m^2)·10^3$
Hollow	24.27 a	0.17 a	182.66 b	9.24 a	0.22 a	1.44b	0.59 b
Round	25.03 b	0.20 b	176.38 a	9.23 a	0.23 b	1.42 ab	0.58 b
W	26.22 c	0.22 c	176.55 a	9.48 b	0.24 c	1.40 a	0.56 a
Parameter: Weft density	λ $(W·m^{-1}·K^{-1})·10^{-3}$	α $(m^2·s^{-1})·10^{-6}$	b $(W·s^{1/2})/m^2·K$	r $(m^2·K)/W·10^{-3}$	h (mm)	p	q $(W/m^2)·10^3$
24	24.44 a	0.01 a	176.03 a	9.28 a	0.22 a	1.43 a	0.59 a
28	25.90 a	0.02 a	181.03 a	9.35 a	0.24 a	1.44 a	0.58 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

Table 7

ANOVA RESULTS FOR MMT PROPERTIES								
Main source	**WT_t**	**WT_b**	**Abs_t**	**Abs_b**	**SS_t**	**SS_b**	**Accumulative Transfer Index**	**OMMC**
TiO_2 (%)	**0.02***	0.06	0.06	0.96	0.17	0.58	0.06	0.61
Fibre cross-sectional shape	**0.04***	**0.00***	0.37	0.91	**0.01***	0.73	**0.00***	0.07
Weft density	0.14	**0.02***	**0.00***	0.77	**0.04***	0.31	0.70	**0.02***
TiO_2 * Fibre cross-sectional shape	**0.02***	0.18	**0.00***	0.73	0.13	0.72	**0.00***	0.37
TiO_2 * weft density	0.32	0.30	0.12	0.58	0.21	0.63	**0.01***	0.79
Fibre cross-sectional shape * weft density	**0.02***	**0.00***	0.49	0.16	**0.01***	0.35	**0.01***	0.91
TiO_2 * Fibre cross-sectional shape * weft density	0.31	0.65	**0.00***	0.27	0.20	0.23	0.07	0.62

Note: * significantly important.

Table 8

SNK RESULTS FOR TOP WETTING TIME, BOTTOM WETTING TIME, TOP SPREADING SPEED AND ACCUMULATIVE TRANSFER INDEX OF DRAPERY SAMPLES						
Parameter		**WT_t**	**WT_b**	**SS_t**	**AOTI**	**OMMC**
TiO_2	0.3	1.5 a	4.01a	4.37a	1774.09 a	0.72 a
	1.2	1.80 b	5.72a	3.22a	1768.76 a	0.72 a
	1.8	1.73 b	4.70 a	2.60 a	1857.93 a	0.71 a
Fibre cross sectional shape	Round	1.52 a	6.28 b	5.04 b	1542.60 a	0.70 a
	W	1.81 b	4.23 a	2.51 a	1910 b	0.72 a
	Hollow	1.70 ab	4.01 a	2.65 a	1947 b	0.73 a
Weft density	24	1.75 b	5.53 b	2.60 a	1793.82 a	0.70 a
	28	1.61 a	4.15 a	4.20 b	1806.61 a	0.73 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05

wetting time was found among A7 coded samples. Wetting time results of top surfaces are generally close to each other however there is a fluctuating trend for bottom wetting results regarding fibre cross-sectional shape. Fabric samples of yarns with round cross-sectional fibres revealed higher wetting time for bottom surfaces compared to their counterparts with hollow and w cross-section fibres. This may indicate that samples of yarns with hollow and w cross-sectional fibres have an easy drying advantage. *SNK* results (table 8) also reveal that fabric samples of polyester yarns added with different TiO_2 (%) amounts and fabric samples of yarns with different fibre cross-sectional shapes possessed different WT_t and WT_b results at a significance level of 0.05. Considering the TiO_2 (%) amount, samples of yarns with 1.2 % TiO_2 and 1.8 % TiO_2 substance revealed the same WT_t results which were higher than the result of samples with 0.3 % TiO_2. Regarding to fibre cross-sectional shape, fabrics of weft yarns with round fibre sectional shape indicated the lowest WT_t value while fabrics of yarns with "w" cross-sectional shape indicated the highest WT_t value. Additionally, fabrics of yarns with round fibres revealed higher WT_b values compared to those with "w" and "hollow" fibres at a significance level of 0.05.

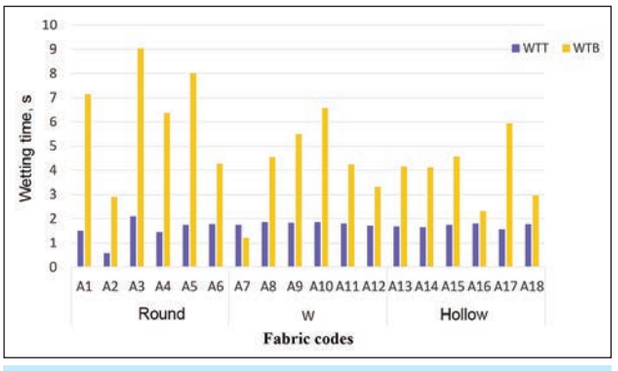

Fig. 6. Wetting time

Absorption rate (%/s)

The absorption rate (%/*s*) values reveal the average moisture absorption ability of the top and bottom surfaces of fabric in the pulp time. According to figure 7, the maximum top absorption rate was found among A1 coded fabrics whereas the minimum value was obtained from A3 coded fabrics. Bottom absorption rate (%/*s*) values do not fluctuate prominently among

the samples. Additionally, there is not a clear trend of top absorption rate results regarding fibre cross-sectional shape. As it is observed, since top absorption rate values are higher than bottom absorption rate values, it may be anticipated that there is not so much liquid diffusion from next-wet surfaces to the opposite side. Hence the liquid may accumulate on the top of the fabric instead of the bottom side. Since the fibre cross-sectional shape, TiO_2 amount (%) and the weft density factors were non-significant on top and bottom absorption rate values, *SNK* tests were not performed.

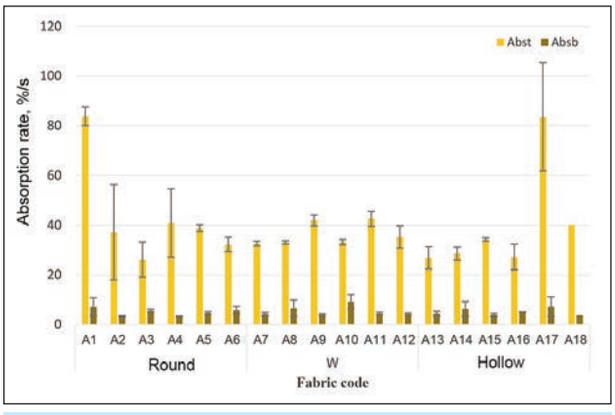

Fig. 7. Absorption rate (%/s)

Spreading Speed (SS_t, SS_b)

Figure 8 indicates the spreading speed of the drapery sample. According to figure 8, minimum SS_t was obtained from A3 coded fabrics of yarns with round fibres as 2.21 mm/s and minimum SS_b was obtained from A9 coded fabrics of yarns with hollow fibres as 3.02 mm/s. According to MMT grade indices displayed in table 4, these two fabrics have medium SS_t and SS_b values. On the other hand, maximum SS_t was obtained from A2 coded fabrics of yarns with round fibre as 12.88 mm/ss and SS_b value was obtained from A7 coded fabrics of yarns with "w" cross-sectional fibres as 9.50 mm/sec which means the fabrics have very fast SS_t and SS_b according to MMT grade indices. Additionally, it is generally observed that SS_b results of fabrics are higher than

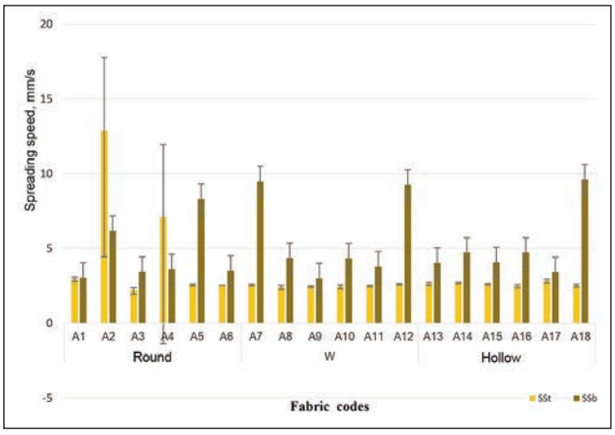

Fig. 8. Spreading speed (mm/s)

SS_t results. *SNK* test results (table 8) also revealed that fabrics of yarns with different fibre cross-sectional shapes possessed different SS_t results. Fabrics of yarns with round cross-sectional fibres indicated higher SS_t results compared to samples made of yarns with "W" and hollow cross-sectional fibres which were observed under the same subset at a significance level of 0.05.

Accumulative One-Way Transport Index (AOTI)

One way transportation capability may also be described as one-way liquid moisture transfer from the fabric's inner surface to the outer surface. This parameter describes how easily a fabric can transport moisture absorbed from its conducting surface to the other side by providing a moisture feel reduction which is a sign of fabric comfort. It was mentioned in the literature that polyester fibres can pass moisture from the inner to the outer surface due to its tendency to transport moisture instead of absorbing it. Figure 9 indicates the accumulative one-way transport index of drapery samples. According to figure 9, the highest value was found among A15 coded fabrics whereas the minimum value was obtained from A4 coded fabrics. Although the *AOTI* results of fabrics with round fibres were generally lower than their counterparts with "w" cross-sectional and hollow fibres, it may be observed that whole samples have *AOTI* above 400 value which means the fabrics have excellent *AOTI* according to MMT grade indices (table 4). Fibre cross-sectional shape factor, the interaction of fibre cross-sectional shape and TiO_2 amount (%), the interaction of fibre cross-sectional shape and weft density and the interaction of TiO_2 amount (%) and the weft density factors had a significant effect on *AOTI* results at a significance level of 0.05. *SNK* results (table 8) also possessed those fabrics with different fibre cross-sectional shapes that possessed different *AOTI* at a significance level of 0.05. Minimum *AOTI* was obtained from fabrics with round fibres while maximum value was obtained from samples with hollow and w section fibres which were observed under the same subset at a significance level of 0.05.

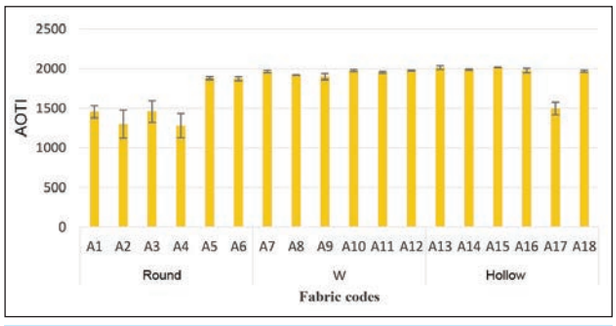

Fig. 9. Accumulative One-way Transport Index

Overall Moisture Management Capacity (OMMC)

Figure 10 reveals the *OMMC* results of fabric samples. There is not a prominent trend for *OMMC* results of the samples regarding to fibre cross-sectional

shape of weft yarns. The highest *OMMC* value was obtained from A8 coded samples as 0.75 whereas the minimum *OMMC* value was obtained from A9 coded sample as 0.66. Since all the samples have *OMMC* values between 0.6 and 0.8, they are in the very good grade according to MMT grade indices (table 4). According to the ANOVA test, *OMMC* values were significantly influenced only by the weft density factor (table 7).

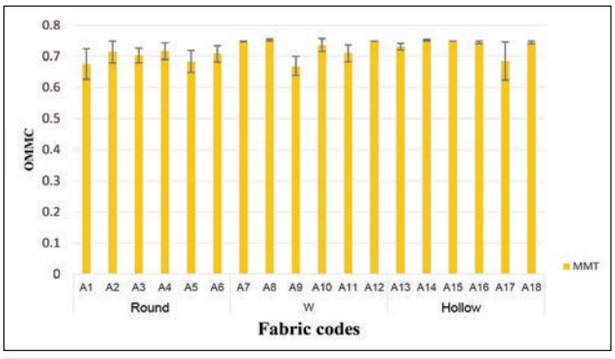

Fig. 10. OMMC results

Air permeability

Figure 11 indicates the air permeability results of the drapery samples. The highest air permeability was obtained from A3 coded fabrics at 335 mm/sec while minimum air permeability was found among A12 coded fabrics at 92.36 mm/sec. As a general evaluation, there is not a prominent trend for the air permeability results concerning the fibre cross-sectional shape of drapery samples. However, the samples of yarns with a "w" cross-sectional shape reveal slightly lower results compared to their counterparts with hollow and round fibres. Another remarkable result about the bar graph, when the results are related to the weft densities of the samples (table 2), it is understood that owing to the high number of interlacements among the fabric, drapery samples with 28 weft density indicated lower air permeability results which do not allow air to pass through freely and easily. Three-way ANOVA test (table 9) was conducted to investigate the effect of fibre cross-sectional shape, amount of TiO_2 (%) and the weft density on air permeability results of samples. According to the results, all three main factors and the interactions of these main sources were significant parameters on the air permeability properties of the samples at a significance level of 0.05. SNK results (table 10) also indicated that samples of yarns produced with different TiO_2 (%) amounts and samples of yarns with different fibre cross-sectional shapes possessed different air permeability results. Regarding to amount of TiO_2 (%) in the yarns of the samples, minimum air permeability was obtained from the samples with the amount of 0.3 and 1.8 TiO_2 (%) which were observed under the same subset at a significant level of 0.05. On the other hand, the highest air permeability was obtained from the samples of yarns with the amount of 1.2 TiO_2 (%). When the fibre cross-sectional shape is taken into consideration, it is observed that samples having "W" cross-sectional shape fibres have the lowest air permeability value while samples having round and hollow cross-sectional shape fibres which were observed under the same subset provided the maximum air permeability value at significant level of 0.05.

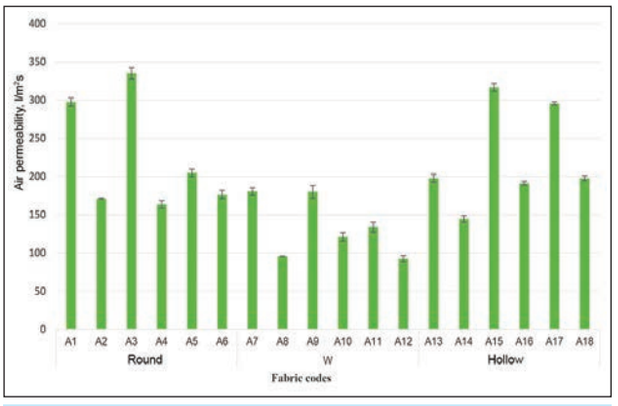

Fig. 11. Air permeability

Table 9

ANOVA RESULTS FOR AIR PERMEABILITY	
Main source	**Air permeability**
TiO_2 (%)	0.00*
Fibre cross-sectional shape	0.00*
Weft density	0.00*
TiO_2 * Fibre cross-sectional shape	0.00*
TiO_2 * weft density	0.00*
Fibre cross-sectional shape * weft density	0.00*
TiO_2 * Fibre cross-sectional shape * weft density	0.00*

Note: * Significantly important.

Table 10

SNK RESULTS FOR AIR PERMEABILITY		
Parameter		**Air permeability**
TiO_2	0.3	181.11 a
	1.2	217.20 b
	1.8	183.24 a
Fibre cross sectional shape	Round	226.30 b
	W	134.55 a
	Hollow	221.43 b
Weft density	24	239.42 a
	28	148.96 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

Relative water vapour permeability (RWP), absolute water vapour permeability (AWP)

Water vapour permeability results were evaluated in terms of relative water vapour permeability (*RWP*)

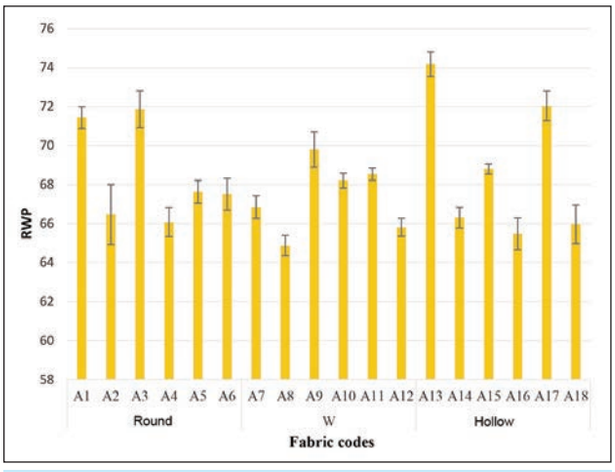

Fig. 12. Relative water vapour permeability (%)

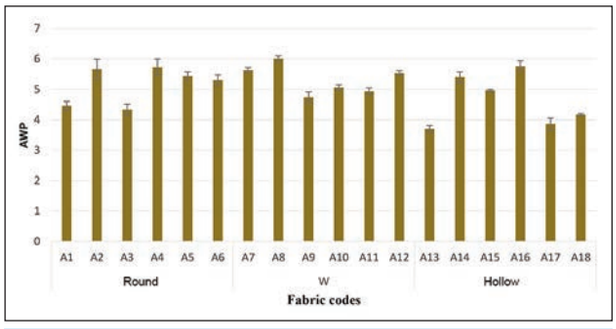

Fig. 13. Absolute water vapour permeability ($Pa \cdot m^2 \cdot w^{-1}$)

and absolute water vapour permeability (*AWP*) which were obtained from the Permetest device. Figure 12 reveals the relative water vapour permeability results of the samples. According to figure 12: the highest relative water vapour permeability result (%) was obtained from A13 coded samples, while the minimum value (%) was obtained from A8 coded samples. There is not a prominent trend for *RWP* results regarding to fibre cross-sectional shape of drapery samples however when the weft densities are considered, it is understood that samples with higher weft density (28 thread/cm) indicated lower *RWP* (%) compared to their counterpart with lower weft density (24 thread/cm) as an expected result. When the absolute water vapour permeability (figure 13) is considered, A8 coded samples revealed the maximum and A13 coded samples revealed the minimum absolute water vapour permeability ($Pa.m^2/w$) contrary to the relative water vapour permeability results. Additionally, there is not a prominent difference between the absolute water vapour permeability of the samples produced from yarns of fibres with different fibre cross-sectional shapes. Three-way ANOVA was conducted to investigate the effect of fibre cross-sectional shape, incorporated TiO_2 amount (%) and weft density parameters on the relative (%) and absolute water vapour permeability ($Pa \cdot m^2/w$) values of the samples. According to the ANOVA table (table 11), the incorporated TiO_2 (%) amount was a significant factor in *AWP* but a non-significant factor in the *RWP* value of the samples. Fibre cross-sectional shape and weft density were significant factors in the *RWP* and *AWP* values of the samples. All interactions of these three factors except the interaction of TiO_2 (%) and weft density factors were also significant on *RWP* and *AWP* results. Samples made of yarns with different fibre cross-sectional shapes revealed different *RWP*, and *AWP* results at a significant level of 0.05 (table 12). The minimum *RWP* value was obtained from samples with "w" cross-sectional-shaped fibres. The *RWP* values of samples with "round" and "hollow" fibres which were observed under the same subset at a significance level of 0.05 were higher than those with "w" cross-sectional shaped fibres. *AWP* value of samples with hollow cross-sectional shaped fibres was lower than those with "w" and round cross-sectional shaped fibres which were observed under the same subset at a significance level of 0.05. *SNK* results also indicated that samples of yarns with different TiO_2 amounts (%) possessed different *AWP* results at a significance level of 0.05 (table 12). Fabric samples of yarns with 1.8 TiO_2 (%) revealed lower *AWP* results than those of yarns with 0.3 and 1.2 TiO_2 (%) at a significance level of 0.05.

Table 11

ANOVA RESULTS FOR WATER VAPOR PERMEABILITY		
Main source	**RWP**	**AWP**
TiO_2 (%)	0.49	**0.01***
Fibre cross-sectional shape	**0.00***	**0.00***
Weft density	**0.00***	**0.00***
TiO_2 * Fibre cross-sectional shape	**0.00***	**0.00***
TiO_2 * weft density	0.08	**0.00***
Fibre cross-sectional shape * weft density	**0.00***	**0.02***
TiO_2 * Fibre cross-sectional shape * weft density	**0.00***	**0.00***

Note: * Significantly important.

Table 12

SNK RESULTS FOR WATER VAPOR PERMEABILITY			
Parameter		**RWP**	**AWP**
TiO_2	0.3	68.34 a	5.14 b
	1.2	68.36 a	5.10 b
	1.8	67.91a	4.87a
Fibre cross sectional shape	Round	68.49 b	5.15 b
	W	67.33 a	5.31 b
	Hollow	68.78 b	4.64 a
Weft density	24	70.12 a	4.67 a
	28	66.29 a	5.40 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

CONCLUSION

This study has been conducted to investigate the effect of fibre cross-sectional shape and the utilized

TiO_2 (%) amount during yarn extrusion on some thermal comfort, moisture management, air permeability and water vapour permeability of drapery fabrics produced at different weft densities. As all yarn and drapery fabric production conditions were kept the same, a difference in fabric comfort properties of drapery fabrics was attributed to fibre characteristics, utilized TiO_2 and the fabric weft density. According to ANOVA results, fibre cross-sectional shape and weft density were significant factors in thermal conductivity at a significance level of 0.05. TiO_2 (%) was not a significant factor for thermal properties. Considering all thermal properties, the difference in the number of contact points of samples with different fibre cross-sectional shapes revealed different results. Fabric samples with round fibres revealed higher wetting time for bottom surfaces compared to their counterparts with hollow and w cross-sectional shape fibres. This may indicate that samples of yarns with hollow and w cross-sectional shape fibre have an easier drying advantage compared to those with round shape fibres. Whole samples have an accumulative one-way transport index above 400 value which means the fabrics have excellent accumulative one-way transport index according to MMT grade indices. All the samples have OMMC value between 0.6 and 0.8 which mean they are in a very good grade according to MMT grade indices (table 4). OMMC values were significantly influenced only by the weft density factor according to the ANOVA test. All three main factors; the effect of fibre type, amount of TiO_2 (%) and weft density and the interactions of these main sources were significant parameters on air permeability properties of the samples. The incorporated TiO_2 (%) amount was a significant factor in AWP but a non-significant factor in the RWP value of the samples. Fibre cross-sectional shape and weft density were significant factors in the RWP and AWP values of the samples. As a general evaluation of the study, considering all test results including thermal properties, MMT, water vapour and air permeability of drapery fabrics, it is observed that the amount of TiO_2 (%) does not have a prominent influence on the above-mentioned comfort properties. However, the fibre cross-sectional shape' effect is generally significant in most of the thermal and comfort properties of drapery fabrics. Hence new fibre designs to be used as warp or weft yarns of drapery fabrics may be improved by considering fibre additive materials in further studies for satisfying comfort properties.

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Colour prediction as a weaving design selection help tool in Jacquard CAD

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ABSTRACT – REZUMAT

Colour prediction as a weaving design selection help tool in Jacquard CAD

The final colour prediction of a weave design made of dyed yarns is a difficult problem. This study shows how a geometric model can be developed to obtain the final colour prediction objectively. For this purpose, a woven material was divided into weft, warp and pores. Then, all parameters needed for the calculation of each colour contribution were identified. A geometrical model based on construction parameters was developed to predict the surface colour contribution of each coloured yarn in a weave surface. To validate the predicted colorimetric data, a visual assessment experiment was conducted. Then, the difference between the predicted and actual colour appearance of the weave pattern was evaluated and analysed in function of weaving structures, and weft yarns colours. For this purpose, simple woven structures (plain, twill 1/3, basket 2/2 and satin Turc) with four coloured weft yarns were used. Results show that the proposed model could correctly predict the final colour of weave designs. Therefore, the model has the potential to eliminate subjective evaluations and reduce prototype sample production by automating the process of weave/colour simulation, thereby reducing the cost and time for product development. The methods of utilization of colour in woven textiles depend upon the composition of the weave design to be woven and the structure parameters of the cloth.

Keywords: *weave design, colour prediction, Jacquard CAD, dyed yarns*

Predicția culorilor ca instrument suport pentru selecția designului legăturii în Jacquard CAD

Predicția finală a culorii unui design al legăturii realizat din fire vopsite este o problemă dificilă. Acest studiu arată cum poate fi dezvoltat un model geometric pentru a obține predicția finală a culorii în mod obiectiv. În acest scop, un material țesut a fost împărțit în bătătură, urzeală și pori. Apoi, au fost identificați toți parametrii necesari pentru calculul fiecărei contribuții de culoare. A fost dezvoltat un model geometric bazat pe parametrii de construcție pentru a preconiza contribuția culorii suprafeței fiecărui fir colorat într-o legătură. Pentru a valida datele colorimetrice preconizate, a fost efectuat un experiment de evaluare vizuală. Apoi, diferența dintre aspectul de culoare preconizat și cel real al modelului de legătură a fost evaluată și analizată în funcție de structurile de legătură și de culorile firelor de bătătură. În acest scop s-au folosit structuri simple țesute (pânză, diagonal 1/3, panama 2/2 și atlas turc) cu patru fire de bătătură colorate. Rezultatele arată că modelul propus ar putea preconiza corect culoarea finală a modelelor de legătură. Prin urmare, modelul are potențialul de a elimina evaluările subiective și reduce producția de probe prototip prin automatizarea procesului de simulare a legăturii/culorii, reducând astfel costul și timpul de dezvoltare a produsului. Metodele de utilizare a culorii în materialele țesute depind de compoziția design-ului legăturii care urmează să fie țesută și de parametrii de structură ai ţesăturii.

Cuvinte-cheie*: design de legătură, predicție de culoare, Jacquard CAD, fire vopsite*

INTRODUCTION

Visual inspection is the conventional method of assessing colour and still is practised widely, colour instrumental measurement is an important alternative because it eliminates the human factor [1].

Instrumental methods can be categorized into quality control procedures and formulation methods. Consequently, the use of digital instruments to determine or to specify colours by comparison with visual standards is becoming a necessity for many industries including computer colour-matching formulation, paints, printing and plastics colouration. The primary objective of colourimetry is the numerical description of colour using physical measurements. Each colour can be positioned in so-called a colour space. The CIELAB system, recommended by the CIE 1976 is the most adopted in the textile industry case. The principle consists of using the theories of primary colours and optical colour mixing of knitted or woven samples [2–9]. For dyed and printed textile materials, the intensity of the colour is proportional to the concentration of the adsorbed/absorbed dyes. Another proportionality must be considered with big interest. In woven designs from coloured threads, a coloured pattern is a consequence of two possible arrangements where the warp is over the weft or vice versa. Thus, the primary elements of woven fabric design are combination ways of weaves and blending of colours using such weaves. That being said, most Dobby and Jacquard fabrics producer's facilities are now equipped with Computer Aided Textile Design systems [9]. In the pre-computer era, the designing

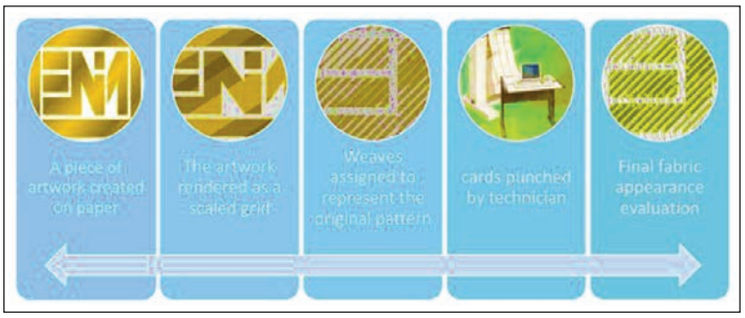


Fig. 1. Jacquard weaving design process in the pre-computer era

process was done in the following flow chart as follow (figure 1):

– A piece of artwork was created on paper.
– The artwork was then rendered as a scaled grid (known as squared paper or design paper), whose columns and rows represented warp and weft yarns, respectively.
– Weaves were then assigned to specific areas to represent the original pattern.
– A technician then punched cards, direct from this technical design layout, in which each card represents one pick of the actual fabric.
– Finally, the weaving structure aspect is evaluated on a final woven fabric.

Modern CAD systems provide a variety of design tools that are supported by standardized colour and weaving structure databases that allow the simulation of weave structures on the computer monitor that could be printed on paper. In figure 2, we illustrate the Nedgraphics® Jacquard weaving design from different technical views: design view, card view, weaves view and 3D simulation view a CAD weaving software.

As illustrated in figure 2, for each colour in the design view, a weaving structure is selected then the card view is generated. Weaving designers can use a 3D simulation to check the weaving layout.

However, deviations in the colour values of these simulations still occur. Also, the colour on fully flat fabric simulations on paper or computer screens is 2D which differs from the real three-dimensional nature of fabrics and yarns [9].

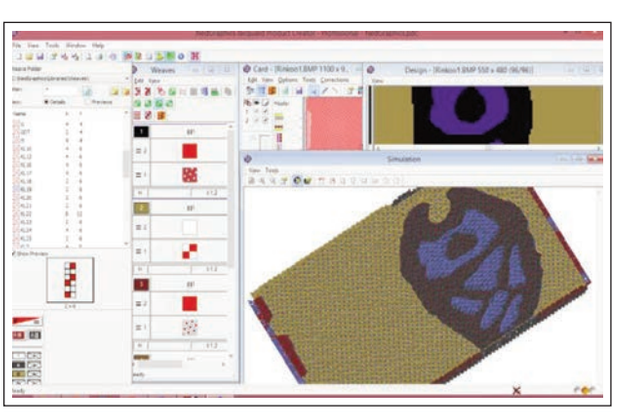


Fig. 1. Jacquard weaving design using CAD system (NedGraphics®)

The colorimetric result in the thread-based assay is also not easy to interpret with bare eyes [10]. This is because colour changes happen in small spaces, and a camera or scanner is required to quantify them. Some researchers provided a model that involves colorimetric measurements for colour prediction. However, a colorimetric tool is less used when fabrics are made from coloured yarns [11]. Among the literature review presented in this introduction, there is a lack of scientific methods to help designers choose weaving structures in Jacquard to highlight patterns.

This study aims to explore the colour difference prediction of simple weaving structures as a help tool in the Jacquard weave design selection. Coloured weft yarns used in the developed model are compared to measured results to evaluate the prediction of the final shade. Consequently, this prediction will offer more reproducibility and accuracy in the shade matching of fabrics made from coloured yarns which is hard to obtain. Colour simulation of a weaving design prediction could be used as a help tool to select a weaving structure related to a weaving design colour.

MATERIALS AND METHODS

Fabrics weaving designs

Experiments were carried out employing 16 samples: 4 simple weaving designs (plain weave, 1/3 right twill, basket 2/2 and satin Turc) and for each structure, 4 coloured yarns were used (undyed, blue, green and red). Weave design and flat view of the used samples and basic metrological parameters are presented in table 1. For all samples, the warp density is 30 ends/cm. The 50% cotton/50% polyester yarns are used as warp and weft yarns and have a count number of 33.5 tex. Samples were woven using a flexible rapier weaving machine: Picanol Gam Max with an electronic dobby as a shedding mechanism a denting plan of 14×2 was used.

The final fabric colour depends on each component colour and the compacity of the structure. All samples were relaxed using a RelaxLab according to the NFG 07-102 test standard (AFNOR).

Coloured yarn colour strength

The weft threads were red, blue, green and undyed. The warp threads were only undyed. The colour resulting from these samples is not an intrinsic property of the object and its perception may vary depending on the wavelength or the colour distribution of the light source which is also depending on the textile reflectance. For each coloured yarn, colour coordinates (L, a, b) were measured with the help of a colorimetric SPECTRAFLASH FF6000 using a D65 light source at, a 10° viewing angle.

Yarns and pores contribution

Woven fabrics are formed by interlacing yarns as a binary system (warp and weft yarns). Each yarn gives it contributes to the geometrical shape and affects predicting the final colour. This contribution is not the only function of warp and weft density but also a function of the pattern.

Each component contribution calculation is based on the constructional parameters of each yarn in the fabric. By using fabric design illustration, as an example of the satin Turc (presented in figure 3), the fractions of individual colour components in a colour repeat according to the flow chart are used according to the CIELAB colour space to calculate colour difference tolerance.

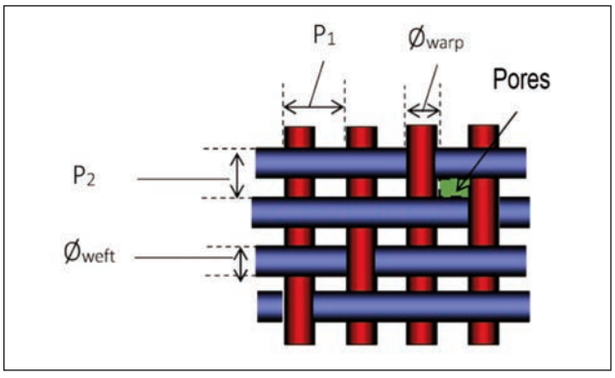


Fig. 3. Schematic presentation of a satin Turc structure and interlacing point made up of three components warp, weft and pores (P_1: distance between two warp yarns, P_2: distance between two warp yarns, $Ø_{warp}$: warp yarn diameter and $Ø_{weft}$: weft yarn diameter)

According to figure 3, the surface proportion of each component according to the fabric's total surface is calculated (all dimensions were expressed in centimetres).

The warp yarn surface contribution to the fabric is:

Warp-Contribution =

$$= 100\,\frac{4Ø_{Warp}Ø_{Weft} + 20Ø_{Warp}(P_2 - Ø_{Weft})}{16P_1P_2} \quad (1)$$

The weft yarn contribution on the fabric surface:

Weft-Contribution =

$$= 100\,\frac{4Ø_{Weft}Ø_{Warp} + 20Ø_{Weft}(P_2 - Ø_{Warp})}{16P_1P_2} \quad (2)$$

And the pore's contribution to the fabric surface:

$$Pores\text{-}Contribution = 100\,\frac{8(P_1 - Ø_{Warp})(P_2 - Ø_{Weft})}{16P_1P_2} \quad (3)$$

RESULTS AND DISCUSSION

Component geometrical contribution

Based on equations 1, 2 and 3, each component's geometrical contributions to the weaving fabric are presented in figure 4.

According to figure 4, it is noticed that the component contribution is a function of the weft densities. The more the structure is compact, the less the pores contribution percentage. This is due to the surface partition layout of each component.

Colour prediction model

To determine the most appropriate colour model to use with different structures, several Kubelka-Munk theory-based approaches were employed [9, 12]. An assumption was made that a yarn colour on the fabric surface was independent of the other yarn colours [13, 14] and this assumption leads to the K/S model described below:

$$\log(K/S)_{mixing} = C_i \log(K/S)_i \quad (4)$$

where (C_i) is the concentration of each coloured yarn (each component contribution percentage), K – the light absorption coefficient and S – the light scattering coefficient.

The flow chart of figure 5 illustrates the steps used to calculate the final colour attributes for any given weave structure using a colour mixing model. This schema is developed to design the database tool, to make the colour information accessible and easy to use.

This theory can be also used to model the colour of various forms of textile materials. In this case, the colour contributions of dyes will be replaced by the colour contribution of each coloured yarn.

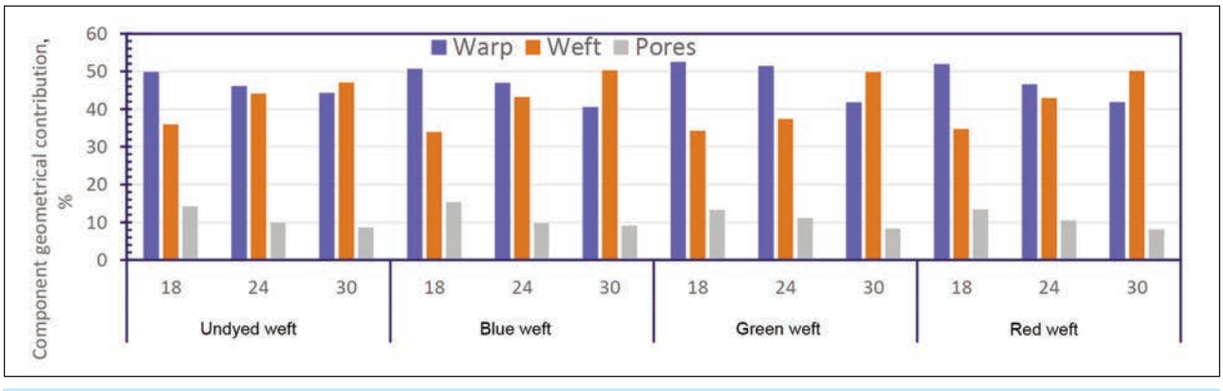


Fig. 4. Geometrical contribution of tested yarns in the case of plain weave (undyed warp, warp density = 30 ends/cm)

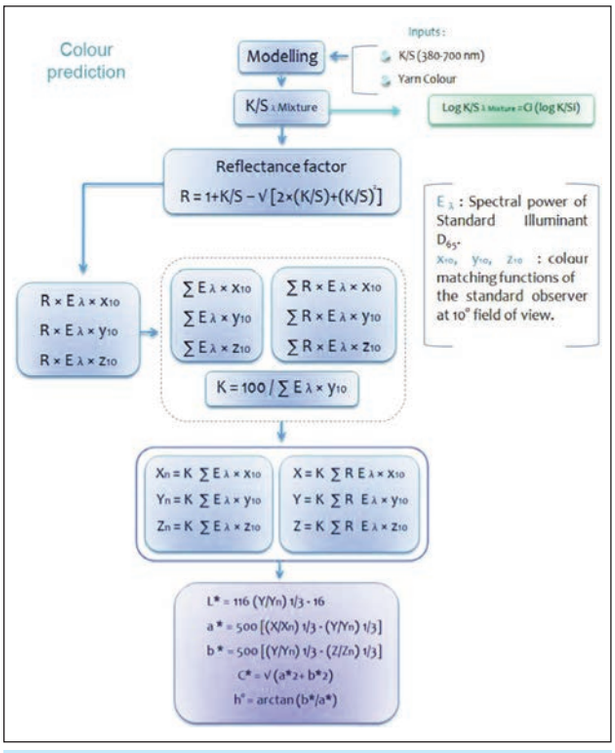


Fig. 5. Colorimetric calculation flow chart

The colour proportions for the mixing model have a near relationship with the component contribution fraction. We calculate this parameter for each tested weave design.

Model validation

The results of all 16 samples were used in the prediction of the final colour values and then compared with the measured colour values of the actual fabric samples. As described in table 1, four different colours of weft threads were used, red, blue, green and undyed. These colours were chosen because they are located in different parts of the CIE L*a*b* colour system. Red has a very high positive value of colour parameter a* whereas green is located at the opposite end of the colour system; blue is also located at the end of the system but with a very negative value.

The distance in colour space was calculated using the law of Pythagoras. It can be calculated by the following equation:

$$\Delta E_{CMC} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (5)$$

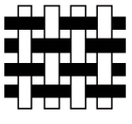
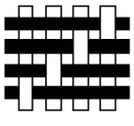
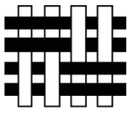
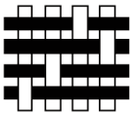
The predicted and measured colorimetric values of all 16 samples are shown in table 1.

In table 1, it can be deduced that the fraction of single-colour components (warp and weft) changes with the change in the contexture of woven material. It is also dependent on constructional parameters such as thread fineness, and density.

The colour difference ΔE_{CMC} described in equation 5 is the distance between the points for reference and standard respective coordinates in the CIELAB colour space. Such a measurement of colour difference is very useful for establishing whether a coloured sample (reference) is an acceptable match to the target (when compared with a standard). It is the only scientific evaluation of the similarity of two dyed samples and the best until now. In our case, the purpose is to evaluate how much two woven fabrics are similar. By comparing the colour difference values calculated between measured and predicted colour values, it was seen that, although each set

Table 1

COMPARISON BETWEEN PREDICTED AND MEASURED COLORIMETRIC DATA USING LOG K/S COLOR MIXING MODEL (WARP DENSITY = 30 ENDS/CM AND WEFT DENSITY = 30 PICKS/CM)

Structure	Flat View	Weft colour	Measured values			Predicted values			ΔE*
			L*	a*	b*	L*	a*	b*	
Plain weave		Undyed	87.73	1.49	12.62	86.46	–0.28	22.52	10.14
		Blue	65.04	–13.98	–16.73	74.58	–11.28	–13.72	10.36
		Green	86.88	–6.12	22.90	85.23	–5.13	41.80	19.00
		Red	55.26	16.28	3.94	68.40	11.76	24.11	24.49
Twill1/3 right		Undyed	88.73	1.33	13.50	86.38	–0.25	22.69	9.62
		Blue	56.84	–20.10	–25.17	74.80	–11.49	–14.45	22.62
		Green	86.66	–7.63	27.62	86.18	–4.61	38.02	10.84
		Red	39.93	27.45	6.95	70.46	10.39	24.21	39.00
Basket 2/2		Undyed	88.57	1.26	12.30	86.43	–0.27	22.57	10.60
		Blue	64.39	–14.08	–16.97	74.70	–11.40	–14.11	11.03
		Green	86.83	–6.01	23.04	85.84	–4.66	38.93	15.98
		Red	51.27	18.77	5.07	69.17	11.18	24.17	27.25
Satin Turc		Undyed	89.01	1.31	13.43	87.00	–0.36	21.81	8.78
		Blue	56.73	–20.60	–25.65	72.84	–12.90	–18.60	19.20
		Green	86.75	–7.47	27.76	85.37	–5.27	42.16	14.63
		Red	39.93	28.04	7.08	69.92	10.62	24.23	38.69

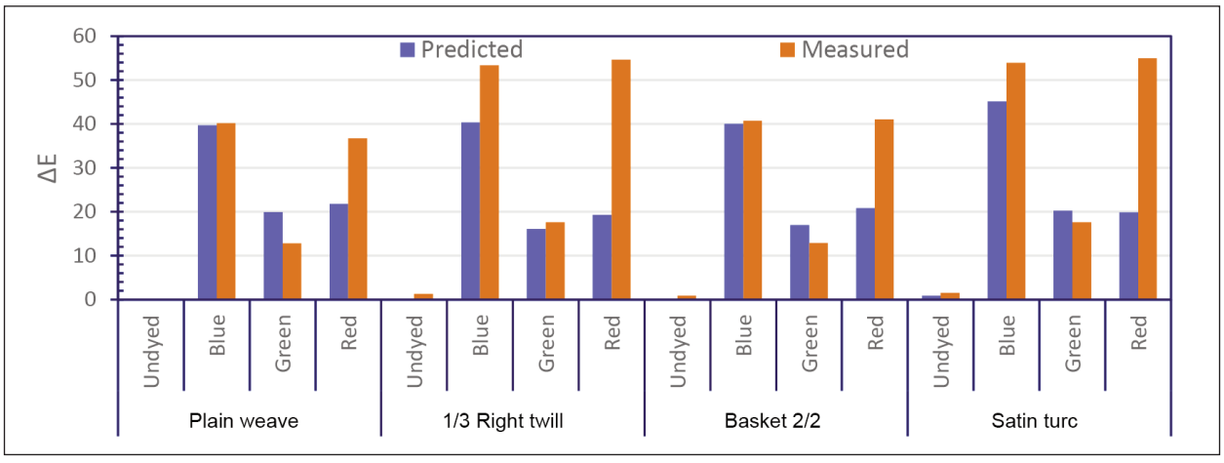


Fig. 6. Distance in colour space: plain weave structure with undyed warp and weft as reference (warp density = 30 ends/cm and weft density = 30 picks/cm)

contains the same weave structures, the log *K/S* prediction varied for each filling yarn colour. The results from the colour measurements show that there is a significant difference in colorimetric data obtained by the two different methods (colorimetric and geometrical predictions). This is due to the choice of the geometrical model and especially for the pores estimation distribution.

Table 1 suggests also that a solid colour could be produced by employing the same colour in warp and weft. However, different colours may be combined to produce either a mixed or intermingled colour effect in which the composite hue appears as a solid colour. According to table 1, the colorimetric coordinates depend considerably on the weave structure. The overall error, represented by ΔE_{CMC}, between the actual fabric measurements and the predicted, was significantly high. This is due to the close weft pick (30 picks/cm), which leads to a false estimation of the geometrical models. Alternatively, colorimetric tools cannot give good sensitivity to the overall error because they do not consider all the cited parameters. Geometry modelling could be reliable for loose density [15]. But, to estimate pores proportion for close density it is advised to use air permeability to evaluate porosity, pores size and proportion [16].

For the used patterns with multi-Color, the final colour is strategically placed in the pattern by merely using the binary system of warp and weft interlacing. The desired colour of a weave appears when the yarn is over the crossing yarns for the desired length and a small or large area if several yarns are used. Moreover, numerous mixtures of colours (such as our case) to produce other colours can be obtained from a few colours of the warp and weft yarns through proper weave interlacing. For dark shades, colour space is more sensible to metrological parameters. Table 1 suggests that the color difference is higher for dark shades (Blue & Red) compared to lighter shades (undyed & green). This makes it harder the colour simulation by the described geometrical method. Figure 6 presents the distance in colour space ΔE where plain weave with undyed warp and weft is considered as a reference.

Undyed yarns could not highlight the colour of the weaving fabric using a small weave ratio, whereas for coloured weft yarns is indeed a difference in colours and subsequently a good appearance of the patterns on the Jacquard fabrics. Also, the differences in the distance in colour space between measured and predicted are essentially caused by the 3D shape of the fabric.

As known, all weave structures are created from a binary system. The warp yarn can be either over or under a weft yarn at the crossover areas. In this study, we used basic weaves. We also varied the colour and density of weft yarns. An infinite number of weaves have been formed and explored. Colorimetric coordinates were compared with those obtained by the proposed geometric model. For all experiments, we obtained almost the same decisions. The geometrical model gives samples that are slightly darker, yellowish and greenest. For lighter samples with lower weft density, the prediction was found to be better.

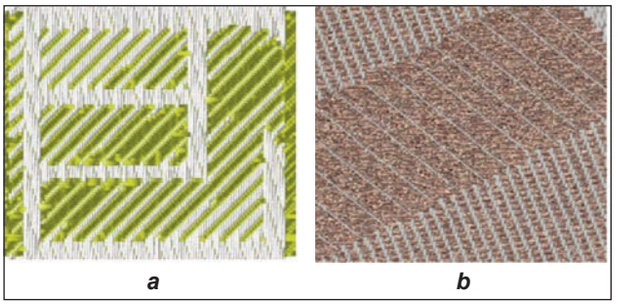


Fig. 7. Weaving design in Jacquard: *a* – without the decision tool, floats default in warp and weft direction; *b* – using colorimetric prediction for weaving structures

As a result of this study, this method could be useful as a help tool to automatically select weaving structures in a Jacquard pattern. As seen in figure 7, *a*, the Jacquard fabric design without a decision tool we can see floats and the pattern colour transition is not

clear. This leads to a Jacquard fabric default in design. But in figure 7, *b*, for each pattern colour, we selected different weaving structures having an important difference in colour space, with the same yarn colours. It is seen the Jacquard fabric visual aspect is more reliable and the pattern transition is more visible.

CONCLUSIONS

The resulting colour of woven structures made of different coloured threads in the warp and weft system depends on the colour values of the threads and the constructional parameters. This research aimed to explore the possibility of predicting colour even though constructional parameters were varied.

Based on the obtained results the following conclusions can be drawn:

The final colour is a function of the constructional parameters that manifest changes in the area of each yarn on the surface.

The colorimetric data of the weave structures can be calculated by using the combined effect of the two aspects of fabric covering power, the optical (reflectance) and the geometric aspect.

Theoretically predicted ΔE colour differences can be compared with those which have been determined by a colorimetric tool. It depends on the thread's colour.

The plain weave and the basket 2/2 have almost the same colour difference (between predicted and measured values). For example, in the case of the undyed weft yarn, the colour difference is 10.14 for the plain weave and 10.60 for the basket weave.

Changes to constructional parameters in one thread system can be substituted with changes to density or fineness in another system to achieve a similar colour effect on the woven surface. This study is not fully reliable in predicting the weave's final colour with accuracy. However, it could be used as a basic decision tool to help Jacquard's CAD designer select the weave design for each colour in the outline and background design.

The automation weaving structure selection in the Jacquard pattern is a very complex problem. It depends not only on the design's weaving structure choice for each pattern colour but also on weaving structure compatibility, yarn type and shade.

Nevertheless, this research attempts to gain insight into this area and construct a framework for further study. Weave design's final colour prediction in structures that are more complicated and using different types of Fancy yarn will form the subject of subsequent research.

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An online blockchain based sustainable logistics management system (OBSLMS) enabled by the Internet of Things for the textile industry

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ABSTRACT – REZUMAT

An online blockchain based sustainable logistics management system (OBSLMS) enabled by the Internet of Things for the textile industry

Blockchain technology and IoT have been beneficial for information sharing, supply-chain management, product tracking and device control in multiple fields. Now, their combined potential has become an emerging concept, one that can be implemented in the textile industry. In most cases, textile industries are the backbone of the economy of a country. The major textile fibres are cotton, jute, wool, silk, bamboo, linen, etc. In theory, the fibre producers' profit and their products' market price may vary depending on the fibre's demand, aggregate supply and the current market structure. But, in real-life textile markets, intermediaries between the producers and buyers lead to significant decreases in the producers' profit. This results in the producer incurring losses and not being able to get back their initial investments as revenue. This research paper aims to provide a solution to the above-stated critical issue. In this paper, we have proposed an Online Blockchain-based Sustainable Logistics Management System (OBSLMS) for textile businesses. The implementation mechanism of the OBSLMS consists of blockchain based business transactions, an IoT based GPS tracking system and a unique QR (Quick Response) code verification for the endpoint delivery of textile fibres from producers to buyers. This sustainable solution also has a bidding feature. Moreover, OBSLMS has been programmed, implemented and tested. The OBSLMS uses the availability and efficiency of the openly available online platform, blockchain technology and IoT to help both the textile fibre producers and the buyers gain a fair profit.

Keywords: *bidding, blockchain, business transaction, online platform, tracking, verification*

Un sistem online de management al logisticii durabile bazat pe blockchain (OBSLMS) disponibil prin internetul obiectelor (IoT) pentru industria textilă

Tehnologia blockchain și IoT au fost foarte utile pentru partajarea informațiilor, managementul lanțului de aprovizionare, urmărirea produselor și controlul dispozitivelor în mai multe domenii. Acum, potențialul lor combinat a devenit un concept în curs de dezvoltare, unul care poate fi implementat în industria textilă. În cele mai multe cazuri, industria textilă reprezintă coloana vertebrală a economiei unei țări. Principalele fibre textile sunt bumbacul, iuta, lâna, mătasea, bambusul, inul etc. În teorie, profitul producătorilor de fibre și prețul de piață al produselor lor pot varia în funcție de cererea de fibre, de oferta agregată și de structura actuală a pieței. Dar, pe piețele textile reale, intermediarii dintre producători și cumpărători duc la scăderi semnificative ale profitului producătorilor. Astfel, producătorul înregistrează pierderi și nu își poate recupera investițiile inițiale ca venituri. Această lucrare de cercetare își propune să ofere o soluție la problema critică menționată mai sus. În această lucrare, am propus un sistem online de management al logisticii durabile bazat pe blockchain (OBSLMS) pentru întreprinderile textile. Mecanismul de implementare al OBSLMS constă dintr-o tranzacție comercială bazată pe blockchain, un sistem de urmărire GPS bazat pe IoT și o verificare unică cu cod QR (răspuns rapid) pentru livrarea de fibre textile de la producători la cumpărători. Această soluție durabilă are și o funcție de licitare. Mai mult, OBSLMS a fost programat, implementat și testat. OBSLMS folosește eficiența platformei online disponibile în mod deschis, tehnologia blockchain și IoT pentru a ajuta atât producătorii de fibre textile, cât și cumpărătorii să obțină un profit echitabil.

Cuvinte-cheie*: licitare, blockchain, tranzacție comercială, platformă online, urmărire, verificare*

INTRODUCTION

As stated in the abstract, the textile industry is vital for the world to function. Factually speaking, it is the traditional occupation for many people from all around the world. The textile fibre producers provide raw materials such as cotton, jute, wool, silk, bamboo, linen, etc., to many textile industries. Depending on the hard work of the producers, the profit they gain from selling their products to buyers might vary. One of the major limitations of the existing textile business system is the lack of transparency in business transactions. With intermediaries involved in a majority of the business dealings, it can be difficult for producers and buyers to know the original price of fibre products. As mentioned earlier, intermediaries often take a significant part of the profits on the fibre products as commission, which results in higher costs for buyers and lower profits for producers. This might create a financial burden for producers and may demotivate them from expanding production. Another limitation of the existing system is the tracking and proof of endpoint delivery of textile fibre products.

The textile sector may experience a transformation to blockchain technology. Producers and buyers can communicate directly with one another utilizing blockchain technology, eliminating the presence of intermediaries. Additionally, it can increase efficiency, lessen fraud, reinforce security, and promote producer-to-buyer transparency. According to Hakius and Petersen, the significant features of blockchain are distributed, verified, immutable and provide peer-to-peer system services with no dependency on centralized authority. The transactions between peer-end systems are also secured with public-private key cryptography and are maintained in immutable blocks [1]. The blocks are not easily tampered with because of the 51% attack rule [2]. The Internet of Things [IoT] is used to integrate the Global Positioning System (GPS) with Google API [3] and to generate a unique Quick Response (QR) code for allocating a unique identity for fibre products based on the transaction.

The OBSLMS aims to impart sustainable supply chain processes ranging from raw materials supply to transformation processes like storing, bidding, transaction, packing, distribution and management. The data of producers and buyers, as well as their communication details, are maintained in this sustainable system. The business transactions are maintained under the Ethereum public blockchain. This system also enables tracking through GPS and provides proof of endpoint delivery through a QR code, thus helping to improve fibre product safety and legitimacy. This proposed approach will be beneficial to the large community of producers & buyers, and will also provide a more user-friendly interface for interactions between them, through an online platform that runs based on the blockchain and IoT.

RELATED WORK

Recently, it has been widely agreed that the applications of blockchain and IoT in textile industries reduce the burden of business transactions and logistics management. The potential benefit of blockchain and IoT has previously been reaped in various domains such as agriculture, healthcare, production engineering, and education. Logistics management in the textile industry is a very tedious process in terms of business transactions and endpoint delivery. Currently, many large-scale textile producers or businesses establish their trademarks to sell their fibre products to respective buyers on an agreement basis to ensure that they earn more return on investment. However ordinary fibre producers are forced to rely upon centralized or government-based regulatory bodies and intermediaries to sell their products. This kind of logistics management is not transparent, not secure and not profitable. It negatively impacts the producers' profit. This research paper mainly focuses on addressing these issues to provide transparency, security and faithful endpoint delivery through the OBSLMS.

The results of Nosirova [4] highlighted the application of blockchain in the textile industry by integrating information sharing and supply chain traceability with production and marketing activities. Agrawal et al. [5] mentioned the challenges and limitations of blockchain based traceability systems. ElMessiry et al. [6] proposed a blockchain-based framework for textile quality improvement and supply chain management. Agrawal et al. [7] gave the operational mode of blockchain based framework for supply chain traceability in the textile and clothing industry. They explained how information is exchanged between supply chain stakeholders. Tripathi et al. [8] discussed briefly the opportunities and challenges of blockchain technology in the fashion industry.

Ülkü et al. [9] gave the system dynamics modelling for the textile industry for sustainable cotton production logistics. They investigated the likelihood of environmental and operational risks and their impacts in four aspects such as variable costs, fixed costs, quality performance, and yield. Zimon and Domingues [10] have provided the guidelines for sustainable supply chain management in the textile industry in terms of internal decision-making, external decision-making, choice of strategy and resource allocation. The results of Rajagopal et al. [11] indicated that by following the capabilities of logistics such as organizational flexibility and customer service rather than cost leadership and organizational performance, a positive impact is acquired.

Helo & Hao [12] presented the blockchain model and implementation architecture for supply chain management. However, they have not clearly explained the step-by-step implementation process of the application with the list of required software in an online platform. Saberi et al. [13] discussed about sustainable supply chain management through blockchain technology and its relationships. Narayanan et al. [14] gave an introduction to the technical and economic aspects of cryptocurrencies. They also covered topics such as cryptography, mining, transaction processing, and blockchain governance. Zohar [15] discussed an in-depth technical overview of the Bitcoin protocol, including its peer-to-peer network, consensus mechanism, and transaction processing.

Kshetri [16] discussed a systematic review of the integration of blockchain and IoT in supply chain management. The author discussed the potential benefits and challenges of using blockchain and IoT together in the supply chain process. They also identified the current research gaps and future research directions. Buterin [17] introduced Ethereum, a decentralized platform for building smart contracts and decentralized applications. He also described the technical features of Ethereum, including its virtual machine, programming language, and consensus mechanism. Xu et al. [18] provided blockchain solutions for green technology in the coordination of a supply chain with an online platform. Faridi et al. [19] proposed a product traceability system with blockchain and IoT. This system could facilitate all stakeholders involved in the supply chain. Pal [20] proposed a solution for transaction services in apparel business supply chain networks with blockchain-based architecture and IoT.

ARCHITECTURE OF THE OBSLMS

The purpose of the OBSLMS is to reduce the reliance on intermediaries and to improve the efficiency of logistics management. It provides a sustainable architecture for textile businesses with verified endpoint delivery of fibre products between producers and buyers. The significant features of the OBSLMS are: the implementation of bidding activity for selling fibre products without any intermediaries; GPS-based tracking facility and conversion of business transaction details into QR codes that can be scanned by buyers, providing them with proof of endpoint delivery of fibre products. Figure 1 illustrates the block diagram of the OBSLMS. The producers produce textile fibres and store them in the warehouse. Then they register their personal and business details on the OBSLMS website. The buyers also register their details on the same website.

The producers auction their textile fibres to the buyers through the bidding activity. The winner of the bidding is selected through an automated target CPA algorithm. Then, the business transactions between producers and the chosen buyer could occur transparently in the blockchain network through smart contracts. The business transactions are stored in a block under the blockchain network securely. After the completion of the business transaction, the textile fibre product can be delivered to the buyer with GPS tracking and QR code verification features of IoT.

Scope and objectives

- Eliminate the intervention of intermediaries
- Provide transparency in business activities
- Increase the profit of producers
- Enable security for the private data of producers and buyers
- User-friendly online system and verified endpoint delivery
- Increase the ease of maintenance for inventory details about textile fibres.

EXPERIMENTAL

Experimental setup

The technical architecture of OBSLMS was designed, developed and implemented through an online platform and open-source software. The blockchain network used in the OBSLMS is permissionless. It is used to develop a decentralized system at commodity prices. This architecture is comprised of four layers as shown in figure 2. This layered architecture is more compatible with the sustainable logistics management system. The layers are as follows:

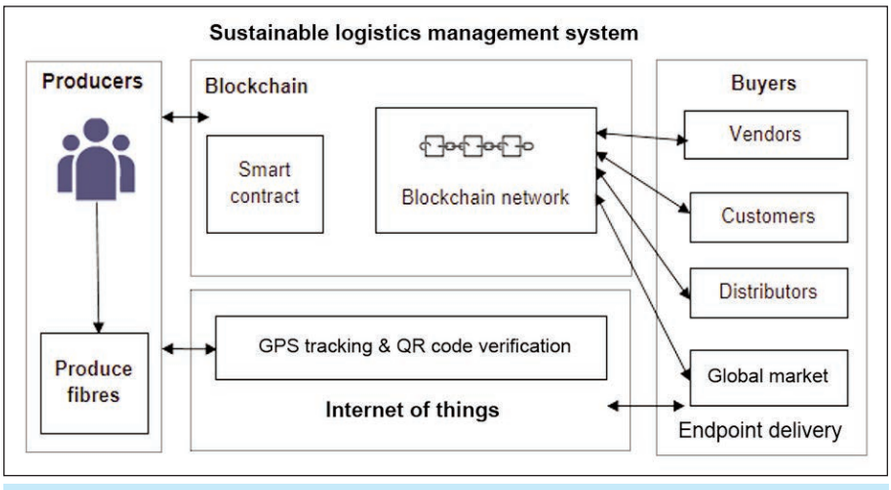

Fig. 1. Block diagram of the OBSLMS

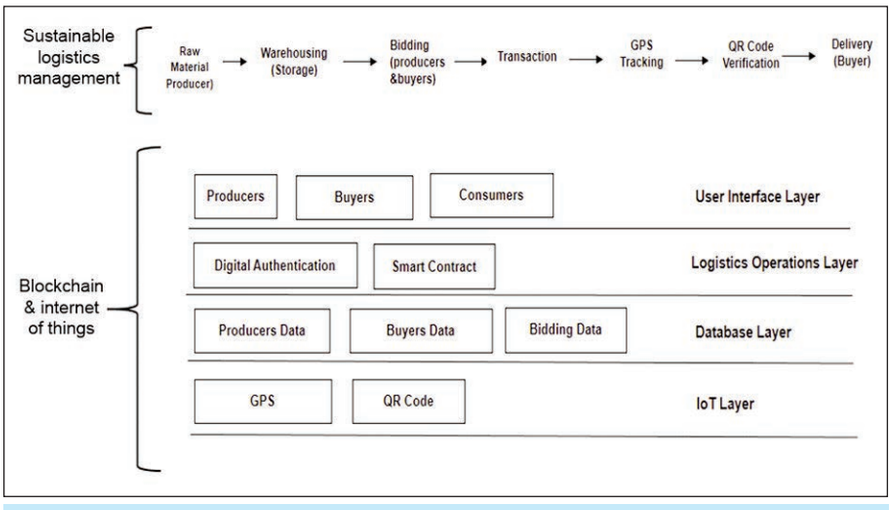

Fig. 2. Layered architecture of the OBSLMS

- **User interface layer** – The top layer is the user interface layer. This layer includes various logistics operators like producers, buyers and customers. Each operator can perform various logistics operations transparently. It is a front end.
- **Logistics operations layer** – The second layer is the logistics operations layer. The cryptography-based digital identity is used to verify the authorities involved in the transaction. The smart contract is a solidity program that can define the business logic and assess the buyers involved in the transaction. It is also used to connect the front end with the back end.
- **Database layer** – The third layer is the database layer. It is used to store producers' data, buyers'

data, bidding data and logistics management information. The data in this layer is processed to improve the efficiency of the sustainable logistics management system and acts as an inventory system for fibre products. The business transaction details are stored in a block that is immutable under the Ethereum public blockchain network. It acts as a back end for the OBSLMS.

- **IoT layer** – The bottommost layer is the IoT layer. The IoT devices enable the tracking of textile fibre products with verified endpoint delivery to provide safety and authorized delivery.

Software, tools and framework used for implementation of OBSLMS

- **Ganache** – Ganache CLI in OBSLMS is a local public blockchain environment for testing and developing smart contracts before deploying them to the Ethereum main net.
- **Django** – Django, a web framework written in Python, is widely used for building web applications. It follows the Model-View-Template (MVT) architecture, which separates the business logic, user interface, user input and output management, making it easy to build complex applications.
- **Solidity programming** – Solidity and solc are powerful tools for developing smart contracts on the Ethereum blockchain. The solc compiler generates an Application Binary Interface (ABI) and a byte code (BIN) file that is used to deploy the contract to the blockchain. It then uses these files to deploy the contract to the blockchain using a tool like Web3.py.
- **Web 3** – Web3.py is a Python library used for interacting with the Ethereum blockchain. It allows developers to build applications that can read data from and send transactions to the Ethereum network.
- **Python 3** – In the OBSLMS, python was used to create the backend server to handle HTTP requests and responses. Python's smtplib was used to send emails. Overall, Python has been a crucial component of the OBSLMS, enabling the creation of a robust and scalable backend server that interacts with the Ethereum blockchain.
- **AJAX** – It is a powerful technique used in web development, and to send data from the HTML frontend to the Python backend without the need for a page refresh.
- **FireBase** – Firebase is a cloud-based platform that provides a suite of tools and services for building web and mobile applications. It offers real-time database, authentication, hosting, cloud storage, and many other features.
- **HTML & CSS** – HTML (Hypertext Markup Language) is the standard markup language used to create web pages. CSS (Cascading Style Sheets) is a style sheet language used to add style and layout to web pages. It provides a visual appearance of HTML elements.

IMPLEMENTATION DETAILS

Web page design details of OBSLMS

The homepage of OBSLMS has quick navigation for all the mandatory links and it mainly contains the newsroom. The producer and buyer registration page collects details such as name, password, email, business ID, location and Aadhar number. The registration data of both the producer and the buyer are stored in FireBase. The producer and buyer login pages are validated from already stored authentication information in the database with Django and FireBase. The producer dashboard is the main interface for the registered producers to manage their accounts, inventory and orders received from buyers. It provides the producers with analytics on their business sales and revenue trends. The buyer dashboard is used to view the available fibre products and to participate in the bidding process. After logging in, the buyer is presented with the list of currently available fibre products with their descriptions and the minimum bid price set by the producers. The bidding page is designed to operate in full-screen mode, which allows users to focus solely on the bidding process without any distractions. One of the key features of OBSLMS is its live updating functionality, which allows users to view real-time updates on the bidding process. The bidding is automated with a target CPA algorithm which is a smart bidding strategy that delivers the best results at every auction. This is implemented using Python's Google APIs. The transaction page is deployed in the Ethereum public blockchain network through Ganache CLI. Application Binary Interface and Byte codes will be generated in the solidity compiler. They are connected through the Web3 module, through which the transaction is performed. It has modules such as the mail module, QR code generation module and GPS location tracking module. In the mail module, the transaction links and the QR codes are being shared through email. The QR code generation module generates a QR code based on each business transaction hash value. This contains information such as the amount, quantity, buyer name, and producer name and business transaction address. This QR code is used to verify the authenticity of the buyer and the fibre products during endpoint delivery.

Procedural steps for technical implementation architecture of the OBSLMS

The technical implementation architecture of the OBSLMS is shown in figure 3.

Sustainable Logistics Management

1. Create HTML files for the following: registration pages, login pages, dashboard pages for both producer and buyer and then a bidding page.
2. Now configure the Django server with the HTML files
3. Configure FireBase with the requirements
4. Configure FireBase with the Django server
5. Configure the settings file for the server and set the debugging options as False

6. Create the appropriate function for each HTML file in the views.py file and alter the urls.py with the corresponding namespace
   6.1. For data on the registration Page: Get data from the page and upload it to FireBase
   6.2. For data in Login Page: Validate the credentials by data==data in FireBase
   6.3. For adding an action in the producer Dashboard: Upload the data of the item in FireBase, in Nosql format
   6.4. For each product in "Items of Producer": Display to the buyer for bidding with necessary actions
   6.5. For each action on the bidding page: Update the values in the database and also display them in HTML
   6.6. For data on the verify page, decode the data using the decryption algorithm
7. Configure the mail server with the Django views function to send a mail to the buyer
8. Create the QR code display function using the QR code module for each bid winner in the bidding list, mail sent to the buyer with a link for the transaction and after successful completion of payment.

Blockchain

1. Start the blockchain server in the (Ganache-CLI)
2. Configure the blockchain server with Django views.py using the web3 module
3. Wait for the invoking of payment from the buyer
   3.1. If paymentInvoked () ==True:
   If amount < walletAmount:
   ProceedTransaction () else: Throws Error
   3.2. If paymentSuccess () ==True: Create, and store the block in the blockchain network
   else: Return "Error in payment"
   3.3. Return the transaction hash to the Django server and display it on the webpage

Internet of Things

1. Once the transaction is complete, Invoke genQR()
2. Copy the text scanned from the QR code using a scanning application and verify through the webpage
3. Manage the order through the GPS tracking (link attached in QR).

Workflow of the OBSLMS

The workflow of OBSLMS is illustrated in figure 4. The textile fibre producers could register their data on the OBSLMS textile business website, likewise, buyers also register their data on the same website. All of the data will be stored in the database. The producers produce fibres and then publish the details of those fibres on this system.

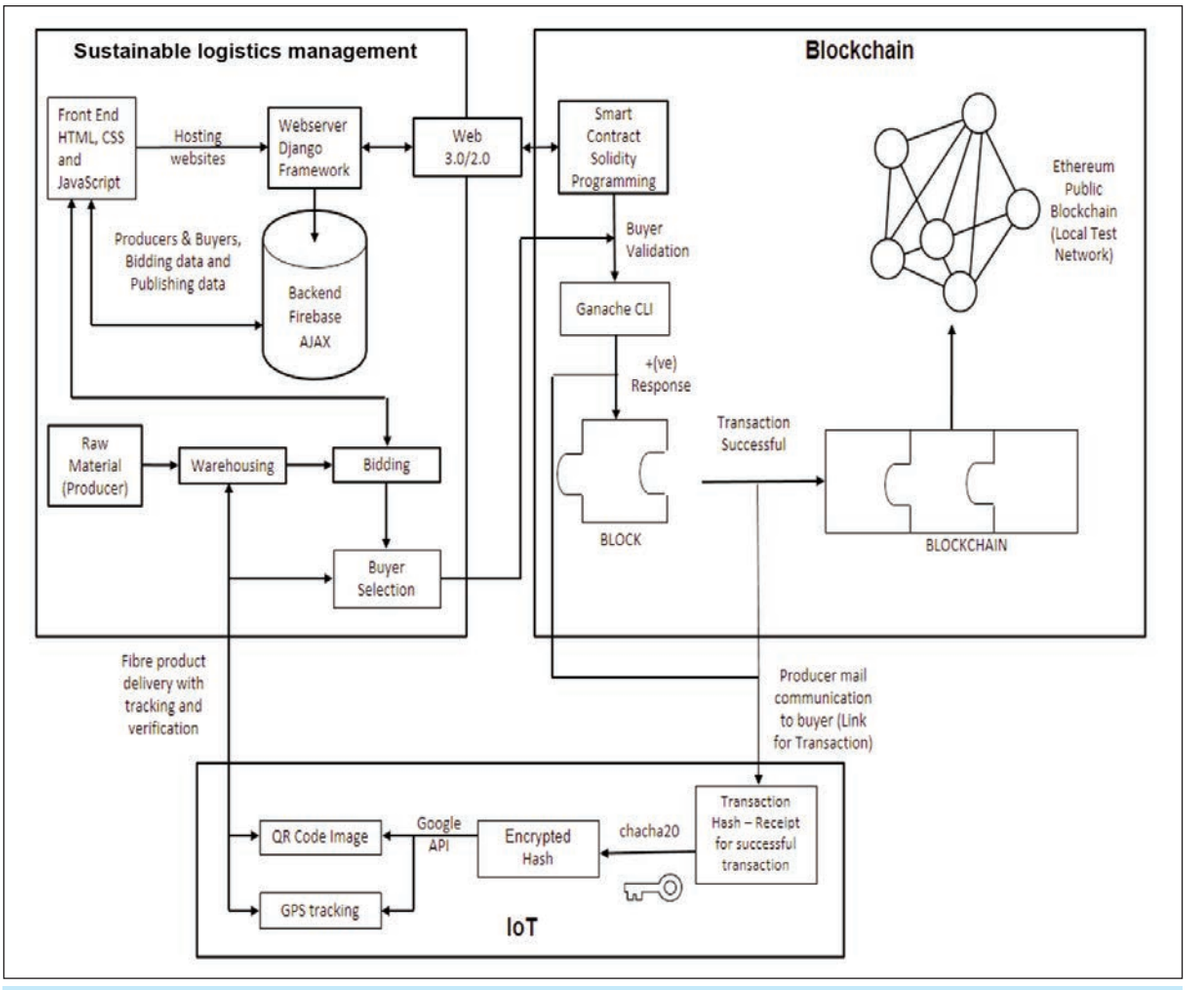

Fig. 3. Technical implementation architecture of the OBSLMS

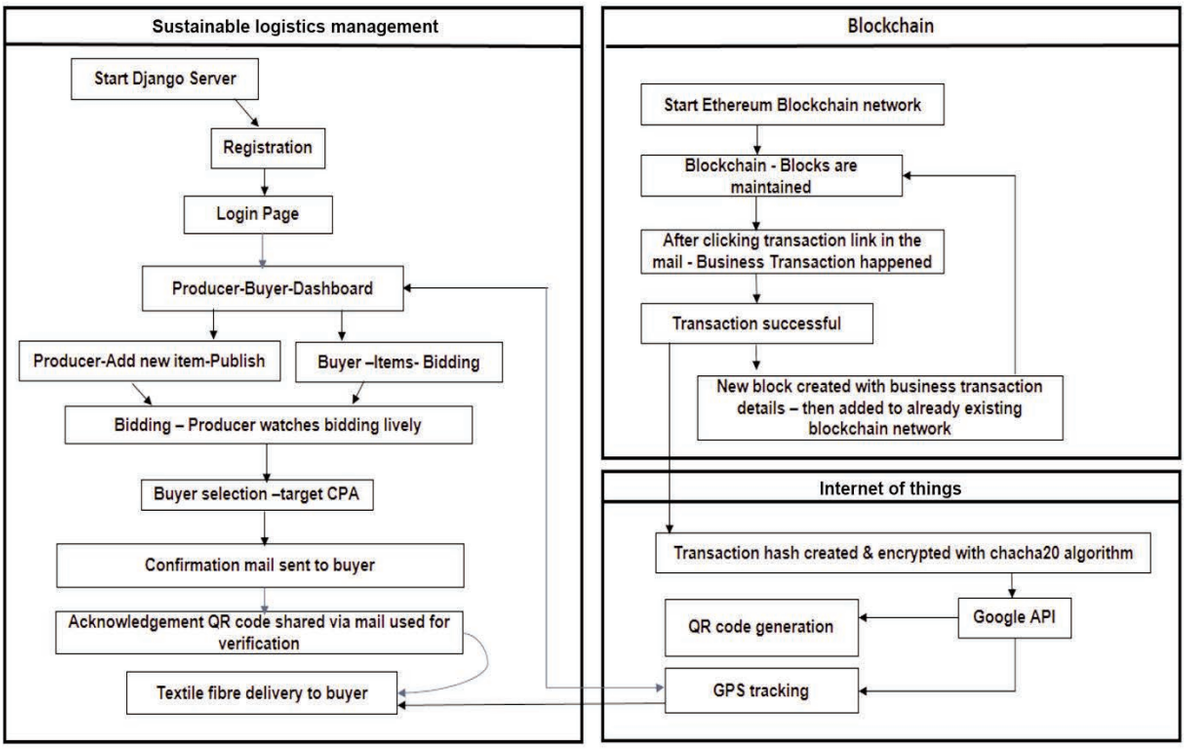

Fig. 4. Workflow of the OBSLMS

On the buyer's side, the buyer initiates the bidding based on their fibre demand or requirements. Once the producers publish their fibre product, the bidding activity is initiated. The notification messages about the bidding with the specified time slot are sent to the buyers who have requested it. The bidding is automated with a target CPA (Cost per Action) algorithm. Once the bidding time slot is over, the producer selects and declares the buyer who won the bid, with the help of this algorithm. Then the auto-generated electronic mail will be sent to the buyer to complete the business transaction with the producer. This business transaction will be carried out by the smart contract in blockchain technology. Once the transaction is completed a new block is created with the block number, previous hash, current hash, and business transaction details. After the successful completion of the business transaction and a positive response from the server, the block gets added to the pre-existing blockchain network. The transaction hash is created and it is encrypted with the chacha20 algorithm. Then, the order confirmation mail is sent to the buyer which contains the GPS tracking information and QR code generated based on encrypted transaction hash, which has all the data such as transaction hash, producer details, and buyer details of the fibre that has been ordered. Also, during the delivery of the textile fibre products, the QR code can be used for verification of the buyer as well as the fibre product, using the link provided in the order confirmation mail.

CONCLUSION AND FUTURE ENHANCEMENTS

Using blockchain, GPS tracking, and QR code verification with IoT, this research paper describes the implementation of OBSLMS for textile businesses that promote direct market dealing between producers and buyers, without intermediaries. As this is the first digital sustainable logistics solution for transaction management, it has to be improved. Some potential future work includes integrating additional payment methods such as other cryptocurrencies and credit card transactions to expand the user base and provide more flexibility to the users. Secondly, adding a reputation system based on feedback from customers can enable trust between producers and buyers, motivating producers to provide high-quality products. Thirdly, implementing a shipment and delivery system can provide a seamless experience for customers and producers. Additionally, expanding the scope of the application beyond a local market is also crucial. Finally, developing a mobile application that can provide more accessibility to end users and enhance the user experience, especially for customers who may want to place bids on products on the go will dramatically improve the accessibility of this system. Overall, the possibilities for future work on the application are vast, and continued development can help enhance the online platform's capabilities, further establishing it as a dependable and effective marketplace for textile fibre producers and buyers.

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Investigating the effects of Information and Communication Technology (ICT) on capital market uncertainty by considering its impact on the textile industry: a case study for Iran

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ABSTRACT – REZUMAT

Anvestigating the effects of Information and Communication Technology (ICT) on capital market uncertainty by considering its impact on the textile industry: a case study for Iran

Information and Communication Technology (ICT) plays a vital role in sharing information and greater participation in exchanges and trading of investors' shares. Because the use of information and communication technology in financial markets reduces marketing costs, it has a significant role. Therefore, the primary purpose of this research article is to investigate the impact of ICT on capital market uncertainty in Iran. In this study, the GARCH model has been used to estimate the capital market uncertainty index. The results of ARDL model estimation using quarterly data in the period 2011: 1 to 2020: 4 in the short and long term showed the effect of the ratio of online transactions to the total volume of transactions as an ICT indicator on capital market uncertainty in the short term. Long-term are different. In the short run, increasing the ratio of online transactions to the total volume of transactions has increased capital market uncertainty. It has reduced capital market uncertainty in the long run. Other model results showed that inflation, economic growth, and exchange rate significantly affect the performance uncertainty of the total stock exchange index as an indicator of capital market uncertainty. And it takes about 7.5 seasons on average to completely offset the imbalance in capital market uncertainty.

Keywords: *financial time-series, Information and Communication Technology (ICT), computational financial mathematics, capital market Uncertainty, asset pricing models, vector autoregression model with distributed intervals (ARDL), ICT indicator, online trading system, developing countries, stock exchange index*

Investigarea efectelor tehnologiei informației și comunicațiilor (TIC) asupra incertitudinii pieței de capital, luând în considerare impactul acesteia asupra industriei textile: un studiu de caz pentru Iran

Tehnologia informației și comunicațiilor (TIC) joacă un rol vital în schimbul de informații și facilitează o participare mai mare la schimburile și tranzacționarea acțiunilor investitorilor. Deoarece utilizarea tehnologiei informației și comunicațiilor pe piețele financiare reduce costurile de marketing, are un rol semnificativ. Prin urmare, scopul principal al acestui articol de cercetare este de a investiga impactul TIC asupra incertitudinii pieței de capital din Iran. În acest studiu, modelul GARCH a fost utilizat pentru a estima indicele de incertitudine al pieței de capital. Rezultatele estimării modelului ARDL folosind date trimestriale în perioada 2011: 1 până în 2020: 4 pe termen scurt și lung au evidențiat efectul raportului tranzacțiilor online față de volumul total al tranzacțiilor ca indicator TIC asupra incertitudinii pieței de capital pe termen scurt. Pe termen lung rezultatele sunt diferite. Pe termen scurt, creșterea raportului dintre tranzacțiile online și volumul total de tranzacții a crescut incertitudinea pieței de capital. Însă a redus incertitudinea pieței de capital pe termen lung. Alte rezultate ale modelului au arătat că inflația, creșterea economică și cursul de schimb afectează în mod semnificativ incertitudinea privind performanța totală a indicelui bursier ca indicator al incertitudinii pieței de capital. Și este nevoie de aproximativ 7,5 sezoane în medie pentru a compensa complet dezechilibrul în ceea ce privește incertitudinea pieței de capital.

Cuvinte cheie: *serii temporale financiare, Tehnologia Informației și Comunicațiilor (TIC), matematică financiară computațională, incertitudinea pieței de capital, modele de stabilire a prețurilor activelor, model de autoregresie vectorială cu intervale distribuite (ARDL), indicator TIC, sistem de tranzacționare online, tari in curs de dezvoltare, indice bursier*

INTRODUCTION

Following the spread of the coronavirus at the beginning of 2020, the social and economic situation of the world has entered a crisis at an incredible speed [1–3]. According to the forecasts of the International Monetary Fund, world economic growth is expected to be 4.9%, which is 7.6% lower than the previous year's forecast. It is expected that 170 countries will face a decrease in per capita income [4]. In 2020 and 2021, most countries' economies were affected by the Coronavirus pandemic (COVID-19). As a result, economic activity contracted sharply in the first half of 2020 due to containment measures and increased risk aversion, and the setback continued. However, unlike the COVID-19 pandemic, the root causes of

one of the most intense extreme financial events of the last centuries, such as the GFC of 2007–2008 (global financial crisis), were more profound and more severe implications, both macroeconomic and microeconomic [5]. COVID-19 changed the context for Information and Communication Technology (ICT) use globally [6]. Information and Communication Technology has undoubtedly led to far-reaching changes in all social and economic spheres of humanity. Its impact on human societies is such that today's world rapidly becoming an information society [7]. ICT is a set of tools and methods computers, and communication networks use to produce, publish, store, organize, exchange, access, retrieve and disseminate information [8, 9]. ICT includes two aspects of hardware and software, each of which includes a variety of appropriate methods, tools, and standards [10]. In general, ICT, through the growth of productivity of all factors in the productive sectors of ICT, capital deepening, and productivity growth of all aspects through the reorganization and application of ICT, can influence economic growth [11].

In recent years, the environment has fundamentally changed in various social, cultural, and economic fields [12, 13]. According to most researchers, these fundamental changes result in ICT [14–16]. Today, the national economy has given way to the world economy. In this area, countries will be prosperous if they do not limit job opportunities only to their geographical framework and have an expansive worldwide workspace in mind [17]. One of the essential facilities provided by ICT is its effect on the production process of products and services that a new business offers [10, 18]. For example, ICT can help produce products with a broader range of information or add a new service to a product [19, 20]. Depending on the progress of a business's flow, ICT can help create, change or destroy activities and connections in the value chain of a business, or it can reorganize the current business process [21]. The availability and quality of ICT infrastructure determine the efficiency and feasibility of using these tools for business. ICT can provide an effective tool to support economic activity [22, 23]. ICT, especially mobile phones, computers, and the Internet, has become essential for business development and increasing competition [24]. The high penetration rate of mobile phones in developing countries and the cost-effectiveness of Internet services have provided unique opportunities for different people to take advantage of these technologies and start or expand new businesses [25].

Many economists attribute the slow economic growth of financial markets in developing countries to the inefficiency and underdevelopment of the ICT sector and recommend systematic reforms to achieve faster economic growth [26, 27]. After various studies on the developments in the ICT industry, attention was turned to the capital markets and the interaction between ICT and the stock market [28–30]. These studies showed that capital markets, which are very important in the economy of any country and have been mentioned as one of the tools to control the economy, are affected by ICT tools, and gradually and with the strength of this industry, the ICT industry enters the market Capital has been smooth and welcomed by many investors [28, 31, 32]. In this regard, Cheng et al. [33] found that ICT development has increased economic growth and financial development by increasing the number of people using the Internet and securing Internet platforms. In their research, Brown et al. [34] found that the trading volume and frequency of capital market transactions decreased by about 5% on days when mobile Internet systems were slowing down. In other words, ICT has played an influential role in online transactions. Bahraini and Qafas [35], in their study on the impact of ICT on the economic growth of selected developing countries in the Middle East and North Africa (MENA) and sub-Saharan Africa (SSA), found that except for landlines, Other information and communication technologies such as mobile phones, Internet use, and bandwidth acceptance are the main drivers of economic growth in the developing countries MENA and SSA in the recent period 2007–2016. In addition, their findings confirm the superiority of MENA countries over SSA countries in terms of Internet use and bandwidth acceptance. Therefore, a group of researchers found that internal factors, including structural, financial, marketing, and managerial variables, and external factors, including economic, political, and cultural variables affect the stock price index in the stock market [36–40]. Sepehrdoost and Sadri [41] showed that tools and equipment related to information technology had a positive effect on the growth of the capital market of the Iranian Stock Exchange. Therefore, one of the primary and vital functions of ICT is the wide impact that it can have on financial markets [31]. Other research study used Capital Adequacy, Asset Quality, Management, Earnings, Liquidity, and Sensitivity or CAMELS rating system in the context of information reliability in the financial field [42].

Studies show that the introduction and improvement of ICT tools have led to increased trading volume and speed and better dissemination of information on the stock exchanges [30, 43, 44]. The importance of this industry has caused attention to be paid to the ICT industry and its developments in the stock market. In the capital market, the primary basis of transactions is the existence of relevant information, which is why communication is considered the most expensive asset in the capital market [45, 46]. Usually, when new information about the situation of companies in the market is published, this information is analyzed by analysts, investors, and other users. Based on this, a decision is made to buy or sell stocks [47, 48]. This information and how to react to it affect users' behaviour, especially actual and potential shareholders, and increases or decreases the price and volume of stock exchanges. Because how people respond to new information shapes price fluctuations. Therefore, in the case of confidential and heterogeneous dissemination of information, we will see different reactions from investors in the capital market,

leading to incorrect and misleading analyses of the current market situation.

Regardless of the various definitions and the wide range of ICT applications in different parts of human life, it is essential to state that the development of ICT is necessary for the growth and development of countries' economies for several reasons. First, this technology increases the speed of information transfer, and thus information is disseminated to more people. Second, ICT reduces the cost of production because access to the knowledge produced is possible at the lowest cost. Also, reducing transaction costs reduces the degree of inefficiency and uncertainty. Third, ICT overcomes time and space constraints, resulting in increased information transfer between buyers and sellers, and the production process transcends national boundaries. This technology enables everyone to recognize their superiority over others in a market economy, Which leads to a broader market and increased access to the global supply of goods. Fourth, it makes the market more transparent and increases demand. The importance and necessity of ICT are such that in the present age, having the comparative advantage of natural resources and reserves specific to developing countries has lost its value compared to the competitive advantage of technology specific to developed countries. Therefore, investing in this sector, while the high added value will follow, significantly improves processes [49].

In situations where access to information is costly, investors are forced to formulate their analysis of the company's future profitability, cash flows, etc., through subjective estimates. As a result, people in a better position than others in terms of information will be able to make better estimates because of this information position. It will affect market supply and demand and lead to fluctuations in stock prices. Many empirical studies have shown that active financial markets in the face of information asymmetry can induce trade fluctuations and help them expand. In this regard, the main purpose of this article is to investigate the impact of ICT on stock market uncertainty in Iran in the period 2011–2020 using seasonal data. In this regard, it is hypothesized that the ratio of online transactions to the total volume of transactions and the number of published announcements significantly impact capital market uncertainty in Iran. The remaining sections are organized as follows: 2nd section is the Literature review and hypothesis, followed by the data and methods in 3rd section. The findings and discussion are presented in 4th section and 5th section concludes the research.

LITERATURE REVIEW

Information and Communications Technology

Life in the present age, although it has created new needs, questions and problems, has also presented him with solutions and ways of answering questions and satisfying human needs. Although direct communication and the use of traditional methods of information are a vital necessity today, they alone do not meet the growing thirst of today's complex societies. Humans are thirsty to know, analyze, and process information and news, but the erratic spread of knowledge prevents them from making informed choices. For this reason, communications and communication tools have entered the arena to remove existing barriers [50, 51]. In the present age, ICT has overshadowed all aspects of human life, including a change in all production and distribution methods to education, exchanges, and human relations [52, 53]. The importance of communication as the cornerstone of human societies and the basis for the interaction of cultures and ideas is such that it has changed even the security borders of countries [51].

Information technology was probably coined in the late 1970s to refer to computer technology to work with information [54, 55]. Regardless of the various definitions and the wide range of ICT applications in different parts of human life, it is essential to state that the development of ICT is necessary for the growth and development of countries' economies for several reasons [56, 57]. First, this technology increases the speed of information transfer, and thus information is disseminated to more people [58, 59]. Second, ICT reduces the cost of production because access to the knowledge produced is possible at the lowest price. Also, reducing transaction costs minimizes the degree of inefficiency and uncertainty [53]. Third, ICT overcomes time and space constraints, resulting in increased information transfer between buyers and sellers, and the production process transcends national boundaries. This technology enables everyone to recognize their superiority over others in a market economy, Which leads to a wider market and increased access to the global supply of goods [20, 21]. Fourth, it makes the market more transparent and increases demand [10, 60]. The importance and necessity of ICT are such that in the present age, having the comparative advantage of natural resources and reserves specific to developing countries has lost its value compared to the competitive advantage of technology specific to developed countries [21, 61]. Therefore, investing in this sector and the high-added value will significantly improve processes [21].

Adebisi and Babatunde [62] investigated the implementation of green information and communication technology in the textile industry using a multi-criteria approach for the most preferred ICT alternative in the textile industry. The criteria they considered were green ICT implementation cost (IC), operation and maintenance cost (OMC), environmental impact (EI), improved system performance and utilization (ISPU), supply chain management (SCM), and job opportunities. (EO). Their results show that the most preferred ICT alternative is power management, with an overall coefficient of 0.60, and the least preferred is software optimization, with a coefficient of 0.23. This allows for a clean industrial process in the textile industry and also promotes sustainable cities and communities through responsible consumption and

production, as highlighted in Sustainable Development Goals (SDG) 11 and 12. In their research, Vankevich et al. [63] studied ICT skills in Belarus for the textile industry. They state that investment in ICT skills training is needed to improve the situation. Avadanei et al. in their research [64] reviewed new ICT tools for the sustainable textile and apparel industry. They state that the textile and clothing industry of the European Union needs a flexible workforce that can respond to the development and globalization of the market and the need for sustainable design and manufacturing to meet the sustainable global demand for innovative products. Suitable for training employees, preparing them to face the importance of these new challenges, improving their knowledge, and developing new skills and competencies for this new type of business.

The effect of ICT on economic growth and development can be examined from both supply and demand sides. On the supply side, the growth of ICT and its skills leads to increased productivity of ICT agents in economic activities. The demand side leads to increased demand for new products and services. ICT has undoubtedly led to extensive changes in all social and economic areas of humanity. Its impact on human societies is such that today's world is rapidly becoming an information society. A community in which knowledge and the level of access and practical use of knowledge have a pivotal and decisive role. The scope of its application and effects in various aspects of human societies' present and future life have become essential topics worldwide. It has attracted the attention of many countries. Still, in the definition of ICT, it can be said that it is the collection, organization, storage, and dissemination of information, including audio, video, text, or number, done using computer tools and telecommunications [65].

Capital market uncertainty

The capital market is one of the important financial markets in every country, which equips and allocates financial resources to the economy [66, 67]. The capital market gives a large part of the country's financial resources, and how financial resources are allocated directly affects the performance of the real sector of the economy [68, 69]. On the other hand, considering the variety and dispersion of information in the field of accounting and financial affairs and the extent of information in this field, to choose the best information needed by each user to make a decision, a system is needed that intelligent features and can also analyze the information Anticipate the need [70]. Forecasting is a crucial element for managerial decision-making because most decisions at all levels of the organization directly or indirectly depend on some form of future forecasting [71]. The purpose of forecasting is to reduce risk in decision-making, nowadays, many forecasts in accounting and finance are done by intelligent and expert systems, and the essential application of intelligent systems in accounting, management, and economics is the prediction of these variables [72]. Traders in financial markets, such as the stock market, use technical analysis tools to make the right decision about buying or selling stocks [73]. Uncertainty is a space in which the decisions of economic actors, including households, businesses, and the public sector in various fields, are accompanied by uncertainty [74, 75]. The unpredictable nature of shocks and unawareness of the market structure cause one to remain confident under any circumstances. Several definitions of uncertainty can be presented [76, 77]. Therefore, the continuation of the process of growth and development in the economy, first of all, requires attention to the factors that create them [78–80]. Many countries, especially developing countries, work hard to develop and adopt economic policies to ensure full employment and sustainable economic growth through investment [81, 82]. By encouraging investment and granting special privileges, such countries seek to create a favourable environment for investment and attract foreign and domestic investment [82, 83].

The government's economic and sometimes non-economic policies are among the most important causes of economic uncertainty [84, 85]. These policies, along with changes in resources, preferences, and technology, obscure the outcome of the decisions of economic agents [86]. Accordingly, identifying the effects of uncertainty on the real activities of the economy is of particular importance. Uncertainty is a situation in which either possible events that occur in the future are unknown or, if these events are known and known, the probabilities of these events are not available and when either or both of these events occur. Decisions about the future are complex and difficult; hence the atmosphere of uncertainty prevails over decisions [87–89]. Economic decisions, including investment demand, are largely based on information from decision-makers about how variables move, but when these changes are unstable and irregular, they create uncertain conditions under which economic decisions will have more risks and costs [90, 91]. Instability and uncertainty in these variables cause distrust in the economic environment, so investors do not easily make investment decisions. Hence, investment is one of the most volatile macroeconomic variables [92–94]. A high degree of economic uncertainty can increase opportunity costs for the investor [95, 96]. These costs include delaying and waiting for new information before making an investment decision, which results in a favourable investment reduction [93, 97].

Therefore, the impact of macroeconomic uncertainties on investment is of particular importance, and extensive studies in economics today are devoted to the issue of uncertainty. Despite much debate, the effects of uncertainty on investment are still theoretically weak, and the results are inconsistent. Therefore, knowing how and to what extent these uncertainties affect investment can provide appropriate recommendations and help policymakers achieve the desired economic goals.

Various theories have been proposed to explain investment theories. The most important are internal investment theory, investment acceleration theory,

neoclassical investment theory, and the Tobin theory, which are called traditional investment theories [98]. The general feature of these theories called traditional investment theories, is that they are interrelated with past and present variables, such as sales, profits, prices, interest rates, and capital stock; this means that rationalizing the role of prices in determining the desired long-term capital stock, and also with the help of a hypothesis of static maximization, they find the optimal way to reach the desired level of capital stock in terms of confidence. In other words, profit-maximizing firms determine the optimal investment amount in terms of complete and risk-free information in these theories. In practice, however, it is difficult for firms to determine the optimal amount of investment, and they are usually, in fact, higher or lower than the optimal amount. This could be due to a lack of complete information [99, 100].

Traditional models often ignore three essential features of investment costs; first, these costs are largely irreversible, and the prices are not recoverable after the investment is made [101]. This means that investments are costs incurred and cannot be repaid. Second, there is always certainty about future investment returns [94]. The best thing to do here is to evaluate each investment opportunity's return probabilities [82]. Third, the investment can be delayed until you receive new information on prices, costs, and other market conditions [100]. This ability to defer irreversible investment costs influences investment decisions; in other words, these characteristics cause the investment to react to different types of risks, such as uncertainty, future prices and costs of production, interest rates, cash flow, and the time of investment [48,99]. These three cases show the profound impact of uncertainty issues on investment and make investors sensitive to the uncertainties of macroeconomic variables. According to the contents of this study, we consider two hypotheses:

H1: The ratio of online transactions to the total volume of transactions significantly affects capital market uncertainty in Iran.

H2: The number of published announcements significantly affects capital market uncertainty in Iran.

RESEARCH METHODOLOGY

Data

Considering that the method used in this dissertation is data processing using data published by institutions such as the Statistics Center of Iran, the Central Bank of the Islamic Republic of Iran, the stock exchange site, the main stock deposit site, the comprehensive information system of publishers, The site of the Ministry of Economy and Finance and the Tehran Stock Exchange Technology Management Company is referred to certain individuals or groups are not parties to the question. No questionnaire is used, so the statistical community is not discussed in this study, but time and place. The online trading system was implemented and available in Iran in January 2010. For this reason, statistical data related to Iran have been used quarterly from 2011 to 2020. Excel software has been used to prepare the necessary variables for use in the model related to the hypothesis. For this purpose, the information collected in the worksheets created in this software environment was entered. Then the necessary calculations (for example, the ratio of online or online transactions to the total volume of transactions) were performed to obtain the variables of this study. Necessary for use in this research model entered version 10 of Eviews software. First, the uncertainty of the total return index of the stock market was calculated, and then the model was estimated by the ARDL method.

Model

Model 1 has been used to test the research hypotheses using theoretical foundations and experimental studies.

$$FD_t = C + \beta_1 LRGDP_t + \beta_2 INF_t + \beta_3 FREERATE_t + \\ + \beta_4 GOV_t + \beta_5 FIN_t + U_t \quad (1)$$

where:

FD is Stock Market Index Returns Uncertainty As a capital market uncertainty index, first extract the stock market index returns from the Tehran Stock Exchange site and then use the GARCH model to estimate the return of the stock market index.

GOV is the ratio of online or offline trades to the total volume of trades. The indicators of the number of users of online transactions, the number of published announcements, the ratio of capital market participants to capital market users, and the ratio of online or online transactions to the total volume of transactions were used as ICT indicators in the model. However, due to inappropriate econometric results (inappropriate results in terms of economic theory and semantics) due to the use of indicators of the number of users of online transactions and the ratio of capital market participants to capital market users, these indicators were removed from the models. The data required for this study for the relevant period through the Statistics Center of Iran, the Central Bank of the Islamic Republic of Iran, information stored in the library of the Tehran Stock Exchange Organization and the websites of the Stock Exchange Organization, the comprehensive information system of publishers, website of the Ministry Economy and Finance and Technology Management Company of Tehran Stock Exchange have been collected.

FIN is the number of notifications published. The number of announcements and advertisements posted to inform the visitors on the site of the comprehensive information system of publishers.

GDP is the GDP is a measure of economic growth the economy. Gross domestic product is the sum of the final value of goods and services produced in a country, usually one year. It is used to measure this variable through the logarithm of GDP in each chapter. **INFLATION** is the Inflation Rate (Percent). **FREE RATE** is the unofficial exchange rate.

The exchange rate is a foreign currency equivalent to a domestic currency. In other words, the exchange rate is the price of buying and selling a foreign currency in the country's currency. *U* is the equation error, and *t* is the time representation.

EMPIRICAL RESULTS

Table 1 presents some of the concepts of descriptive statistics of variables, including mean, median, minimum and maximum observations, standard deviation, skewness, and elongation. The essential central indicator is the average, which indicates the distribution's equilibrium point and centre of gravity and is an excellent indicator to indicate the centrality of the data. The middle is another central indicator that shows the state of society. An important point that can be inferred from comparing the mean and the mean is the issue of the normality of the data. One of the essential parameters of data dispersion is the standard deviation. A vital point to be inferred from the standard deviation of a variable is to include the variable in the regression model. As seen in table 1, the standard deviation of the variables is not zero, so the studied variables can be entered into the model.
The degree of asymmetry of the frequency curve is called skewness. If the skewness coefficient is zero, society is perfectly symmetrical. If the skewness coefficient is positive, there is skewness to the right, and if it is negative, there is skewering to the left. The curve's elongation amount compared to the standard curve is called elongation with elongation. If the elongation is about zero, the frequency curve is balanced and standard in terms of elongation. If this value is positive, the curve is prominent, and if it is negative, the curve is broad. In this study, the elongation of all variables is positive. The skewness is normal to the third torque. Skewness is a measure of the existence or asymmetry of the distribution. For a perfectly symmetric distribution, it is zero; for an asymmetric distribution, it is positively skewed for higher values; and for an asymmetric distribution, it is negatively stretched for smaller values.

Examining the trend of variables

Investigating the trend of the return index of the Tehran Stock Exchange (Dx) as a capital market index (FD)

The return trend of the total stock index as a capital market index shows that: during the period studied in the present study, the highest rate of return on the capital market index is related to the first quarter of 2020, and the lowest rate of return is associated with the winter of 2014 (figure 1).
To better examine this issue, we must first examine some of the drivers of liquidity absorption in the second half of 2019, particularly in 2020. One of the biggest economic problems of governments is the issue of liquidity growth, which causes inflation and

Table 1

DESCRIPTIVE STATISTICS

Variables	Mean	Median	Std. Deviation	Skewness	kurtosis	Minimum	Maximum
FD	0.089115	0.00834	0.344293	5.829267	35.94767	3.810007	2.182516
LRFDP	9.559013	9.544489	0.173883	–0.08054	2.666686	9.186622	9.951641
INF	21.5525	21	11.32687	0.306265	1.804615	6.9	42.7
FREERATE	66937.51	35389.7	68005.91	1.681351	4.812919	11531.5	272626
FIN	5991.15	4940.5	2897.525	0.73499	2.419832	2291	13305
GOV	0.8565	0.9	0.092807	–0.7362	2.26387	0.65	0.96

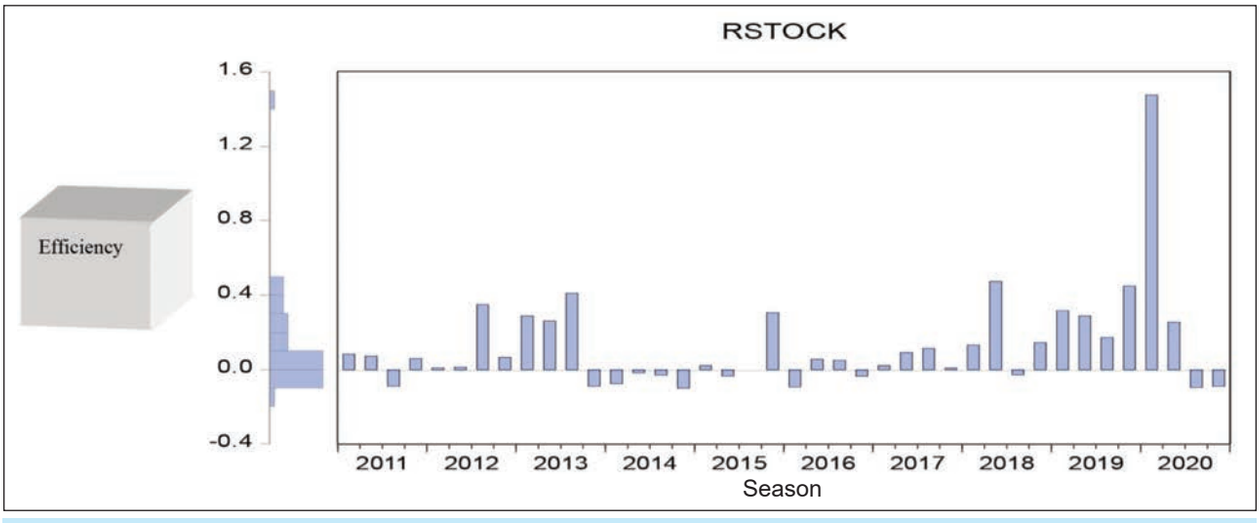

Fig. 1. Return on the total stock index as an indicator of capital market uncertainty

consequently increases commodity prices. Therefore, a mechanism to control liquidity and attract market liquidity is one of the demands of governments. It means that holding money reduces its value, and the desire to turn it into capital goods among investors flourishes. Without a practical and accurate solution, this desire creates speculation in investment markets such as currency, gold, cars, and housing.

On the other hand, the budget deficit and the lack of funding through oil exports due to sanctions doubled the attractiveness of the stock market for the government to cover the budget deficit by divesting its shares in large companies. Government financial and propaganda support for the stock market caused the stock market to turn green, the economic downturn due to the outbreak of coronary heart disease, and business owner's efforts to earn alternative income and compensate for losses. On the other hand, lower bank interest rates caused many capitalists. Due to the attractiveness of the stock market, they should transfer capital from banks to the stock exchange. Other factors that make the stock market attractive to the general public include the ease of access to mobile phone transactions, which is possible even in the most remote areas. The cessation of imports of many goods due to sanctions resulted in the success of domestic goods and the resulting profitability of domestic manufacturing companies due to the growth of demand. Sell at a reasonable and anticipated price by designing and selling ETF funds to support specific shares.

On the other hand, the increasing growth of companies' capital increase this year, which is done to improve financial structures, created increasing attractiveness for its inclusion symbols. To finance the government, the initial public offerings became more intense, and the dream profits that its shareholders received in a short time became an attempt to buy them. It became a daily competition. They were worried about losing attractive daily profits, which added to the excitement of the everyday shopping queue and made the queues heavier.

Examining the trend of real GDP logarithm (LRGDP) as an indicator of economic growth

First, the GDP variable at this year's price was extracted from the Central Bank's website to calculate the economic growth index. To convert current GDP data into real figures, this variable was divided into CPI data for each period, which is quarterly extracted from the website of the Statistics Center of Iran, which results in real GDP. The data were then logarithmized for use in the model. The data trend of this variable is shown in the figure 2.

The highest economic growth rate is related to the second quarter (summer) of 2020 because in this period, in addition to removing a few obstacles to sanctions, such as the release of some money blocked state-owned banks and facilitating exports, while increasing global demand. In the field of oil and gas, due to the discovery of the coronavirus vaccine in the world and the return of factories to the production line, the volume and selling price of oil and gas products increased, which has led to an increase in real production. The lowest rate of economic growth was in the fourth quarter of 2011.

Examining the inflation rate trend

The highest amount of inflation data is related to the second quarter of 2019, which occurred due to the policies of the Central Bank to increase the volume of liquidity. The lowest inflation rate during the period under review is related to Chapter 4 of 2016, which occurred due to the government's contractionary policies using open market operations and bond issuance. In 2016 and 2017, the government and the central bank performed the best performance in controlling the inflation rate during the study period (figure 3).

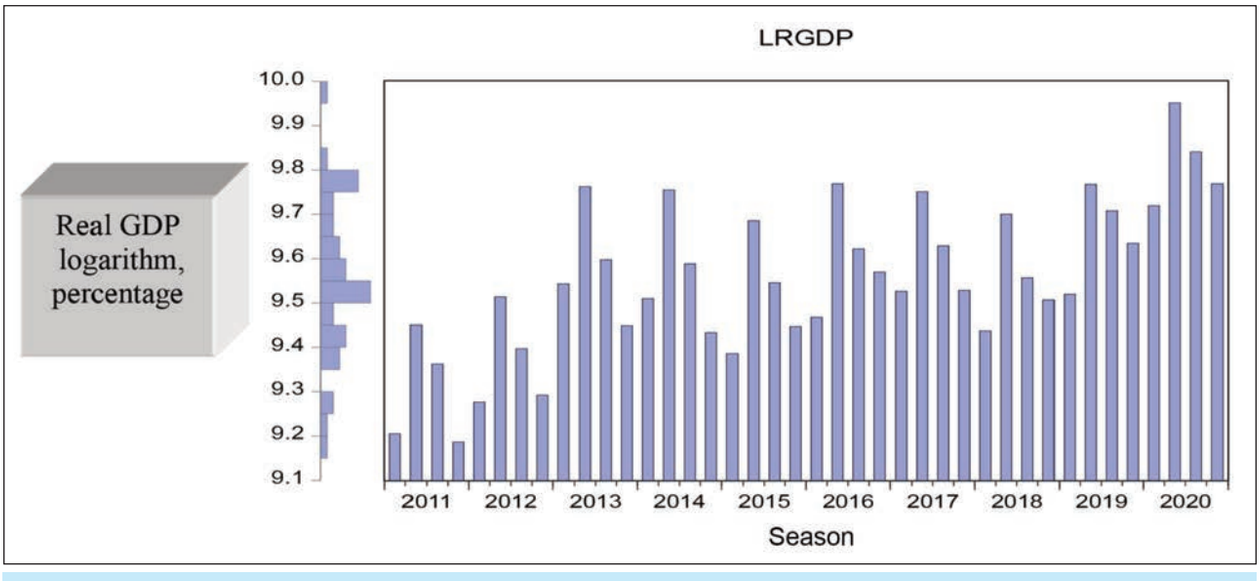

Fig. 2. The logarithm trend of real GDP as an indicator of economic growth
(*Source: Research calculations based on data from the Statistics Center of Iran and the Central Bank and researcher calculations and author's computations*)

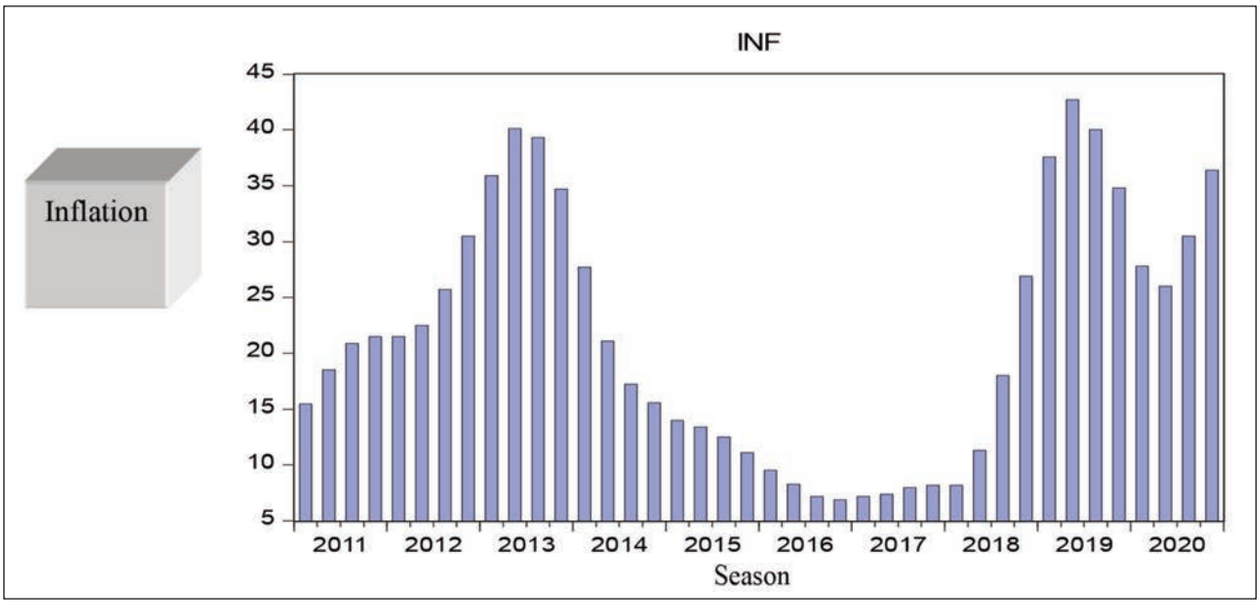

Fig. 3. Inflation rate trend
(*Source: Statistics and Data Center of the Ministry of Economy and Finance and researcher calculations and Author's computations*)

Checking the trend of the free exchange rate (unofficial) (FREERATE)

An examination of the free exchange rate trend shows the national currency's highest exchange rate or devaluation in the third quarter of 2020 and the lowest in the first quarter of 2011 (figure 4).

The ratio of online or total transactions to total transactions (GOV) as an indicator of ICT

This index is the ratio of the number of online transactions that users and capital market participants have registered in their trading platform during the study period. Its data has been extracted through the Tehran Stock Exchange and Securities Organization data centre to the total transactions. (Calculated by trading worksheets + total online sales). Increasing the face of this deduction means increasing the volume of online or offline transactions relative to the denominator of the deduction, which includes the total number of transactions. This means that trading platforms are expanding and improving their mechanism. Users and traders are positioned as good indicators as a variable of the quality of the ICT status to examine its effects on the capital market (figure 5).

Due to the improvement of the structure of Internet technology and efforts to make public use of this

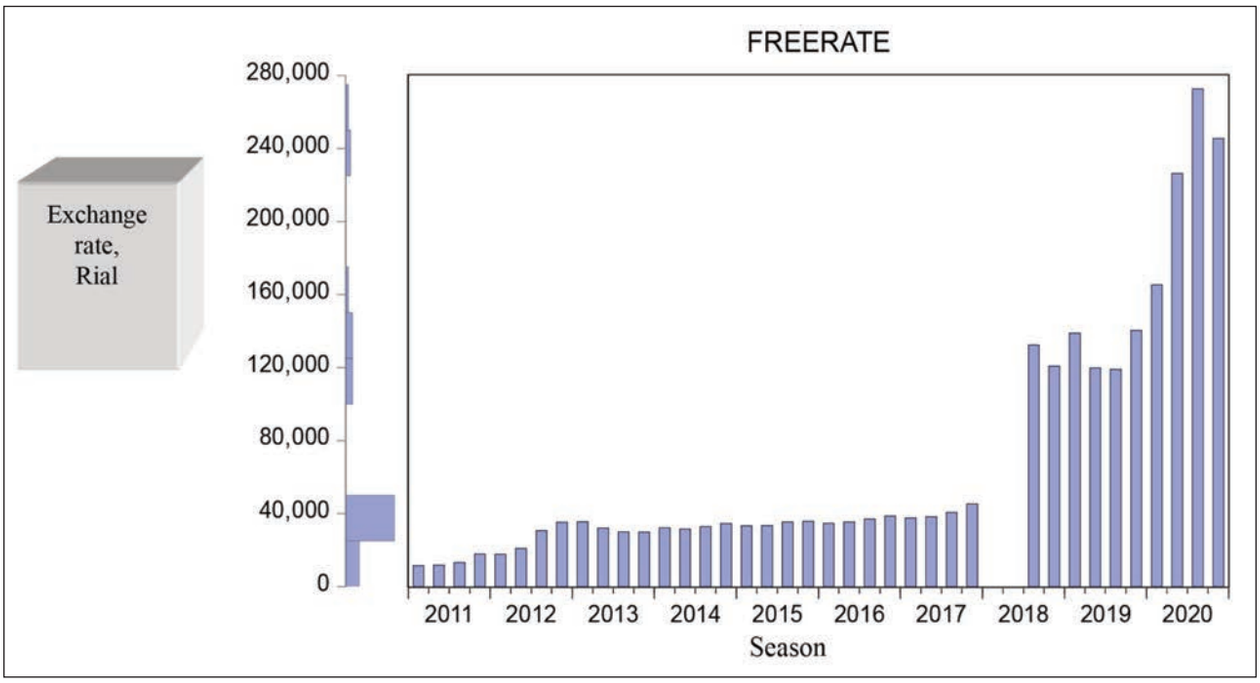

Fig. 4. Free (Informal) Exchange Rate Trend

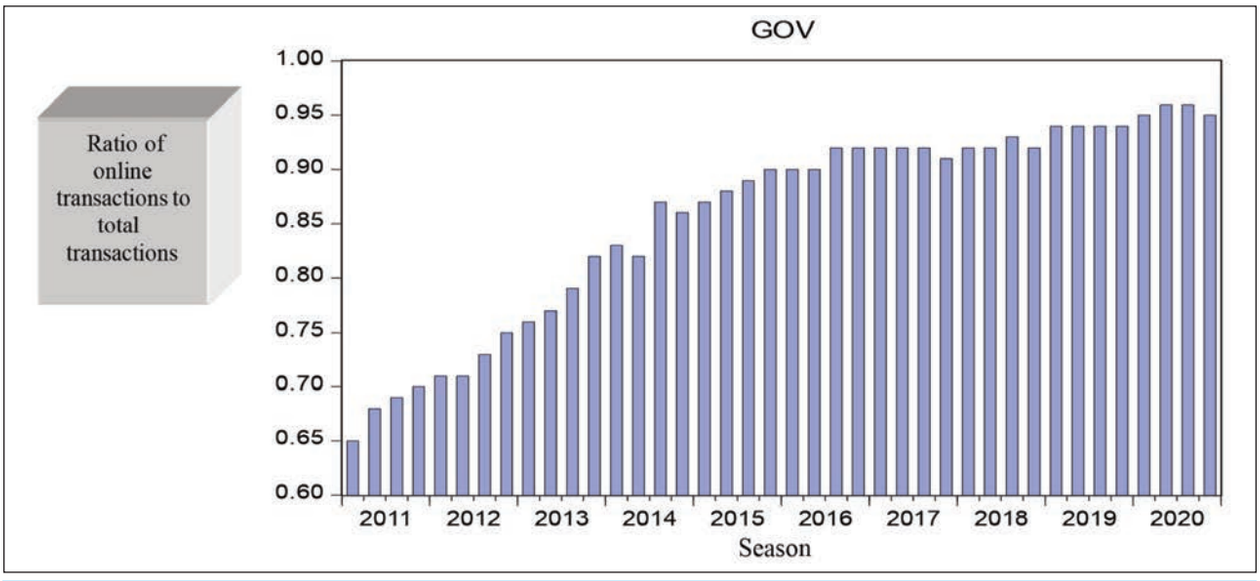

Fig. 5. The trend of the ratio of online transactions to total transactions
(*Source: Tehran Stock Exchange (WWW.TSETMC.COM) and author's computations*)

powerful tool in various fields, significantly improving the quality of trading platforms and easier and more access to this essential infrastructure that is required for online or offline trading, during the period The trend of online trading in relation to the total trading is still increasing, which is a factor for the upward slope of figure 5.

Check the trend of the number of published announcements (FIN)

The number of published announcements is related to the change in the status of trading symbols, capital increase and distribution of profits, and quarterly, six-month, nine-month, and annual financial statements of listed companies, as well as the disclosure of information from groups A and B. Published by the Exchange and Securities Organization (figure 6).:

The highest number of announcements was published in the second quarter of 2020, and the lowest number of reports was published in the fourth quarter of 2011.

The essential central indicator is the average, which indicates the distribution's equilibrium point and centre of gravity and is an excellent indicator to indicate the centrality of the data. The middle is another central indicator that shows the state of society. An important point that can be inferred from comparing the mean and the mean is the issue of the normality of the data. One of the essential parameters of data dispersion is the standard deviation. A vital point inferred from the standard deviation is to include the variable in the regression model. The results showed that the standard deviation of the variables is not zero, so the studied variables can be entered into the

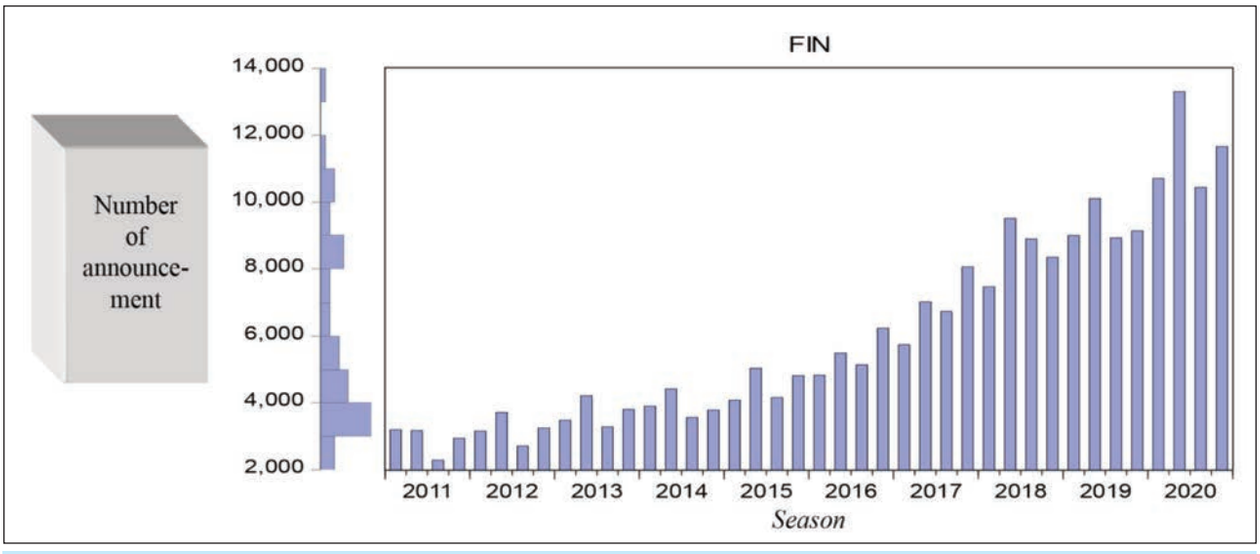

Fig. 6. The trend of the number of announcements published through the CODAL system and Tehran Stock Exchange Technology Management Company
Source: CODAL system (WWW.CODAL.IR) and Author's computations

model. The degree of asymmetry of the frequency curve is called skewness. If the skewness coefficient is zero, society is perfectly symmetrical. If the skewness coefficient is positive, there is skewness to the right, and if it is negative, there is skewness to the left. The curve's elongation amount compared to the standard curve is called elongation with elongation. If the elongation is about zero, the frequency curve is balanced and normal in terms of elongation. If this value is positive, the curve is prominent, and if it is negative, the curve is wide. In this study, the elongation of all variables is positive. The national currency's highest exchange rate or devaluation was in the third quarter of 2020, and the lowest was in the first quarter of 2011. The highest number of announcements was published in the second quarter of 2020, and the lowest number of reports was published in the fourth quarter of 2011. During the study period, the trend of online trading in relation to total trading continued to increase, which is a factor for the upward slope of figure 6. The highest inflation data relates to the second quarter of 2019 due to the central bank's policies to increase liquidity.

The lowest inflation rate during the study period is related to Chapter 4 of 2016, which occurred due to the government's contractionary policies using open market operations and bond issuance. The highest economic growth rate is related to the second quarter (summer) of 2020 because in this period, in addition to removing a few obstacles to sanctions, such as the release of some money blocked state-owned banks and facilitating exports, while increasing global demand. In the field of oil and gas, due to the discovery of the coronavirus vaccine in the world and the return of factories to the production line, the volume and selling price of oil and gas products increased, which has led to an increase in real production. The lowest rate of economic growth was in the fourth quarter of 2011. During the period studied in the present study, the highest rate of return on the capital market index is related to the first quarter of 2020, and the lowest rate of return is associated with the winter of 2014.

Stationary variable

One of the most appropriate tests for seasonal data is the HEGY test, proposed by Parasite, Granger, and Yu as a method that replaces the generalized Dickey-Fuller unit (ADF) test in seasonal data. The results of the HEGY test are given in table 2.

The results of the unit root test in the period 2011: 1 to 2020: 4 in table 3 show that the volatility variables of the return of the total stock index as an index of capital market uncertainty (FD) and the logarithm of real GDP (LRGDP) as an indicator of economic growth with a one-time difference and inflation rate (INF) variables, number of published announcements (FIN) and the ratio of online or offline trades to total trades as an ICT index (GOV) and non-exchange rate Are official (FREERATE) at the Stationary level (I0).

This estimate is only used to calculate the uncertainty and therefore does not need to be interpreted. By estimating the GARCH model (1), RESID can be estimated using the return variable of the total index of the Tehran Stock Exchange. To calculate the uncertainty, it is enough to multiply the residues of the above equation or the so-called RESID by two. In the next step, the main research model is estimated. Regression equation (1) by ARDL method and with default settings of Ives software (in Ordinary mode and according to the number of data in the studied time series, considering that the number of data is less than 80 by Schwartz-Bayesian method) has been estimated (table 4).

The results of the short-term model estimation in table 4 show that: the uncertainty of the return of the total stock exchange index as an index of capital market uncertainty in previous seasons has had a negative and significant effect on capital market uncertainty in the current season. In other words, with a one percent increase in the uncertainty of the return of the total stock index in the previous quarter, assuming other conditions are stable, the uncertainty of the capital market in the current season has decreased by 1.620977 percent. This indicates a lack of transfer of uncertainty between the seasons.

Table 2

RESULTS OF STATIONARY OF THE VARIABLE TEST USING THE HEGY TEST

Result	Hypothesis zero	In level of			Variable
		$F_{\pi_3 \cap \pi_4}$	t_{π_2}	t_{π_1}	
Stationary with one-time differentiation – I(1)	Hypothesis 1. Existence of unit root or non-seasonal unit root at zero frequency Hypothesis 2. Existence of seasonal unit root at six-month frequency. Hypothesis 3. Existence of seasonal unit root in annual frequency	3.65	–2.73	–3.14	FD
Stationary with one-time differentiation Stationary – I(1)		7.32	–1.86	–2.24	LRGDP
Stationary – I(0)		8.78	–1.79	–1.16	INF
Stationary – I(0)		0.07	–2.87	–2.25	GOV
Stationary – I(0)		15.39	–1.53	–2.46	FREERATE
I(0)Stationary		10.76	–2.23	–2.95	FIN

Table 3

RESULTS OF ESTIMATING THE UNCERTAINTY OF RETURN ON THE TOTAL STOCK EXCHANGE INDEX AS AN INDEX OF CAPITAL MARKET UNCERTAINTY				
Dependent Variable: RSTOCK Method: ML ARCH – Normal distribution (BFGS / Marquardt steps) Coefficient covariance computed using the outer product of gradients Presample variance: backcast (parameter = 0.7) GARCH = C(1) + C(2)*RESID(–1)^2 + C(3)*GARCH(–1)				
Variable	**Coefficient**	**Std. Error**	**z-Statistic**	**Prob.**
Variance equation				
C	0.022246	0.006762	3.289914	0.0010***
RESID(–1)^2	1.425018	0.432289	3.296446	0.0010***
GARCH(–1)	–0.033407	0.044931	–0.743508	0.4572*
R-squared	–0.230744	Mean dependent var		0.129258
Adjusted R-squared	–0.199976	S.D. dependent var		0.272514
S.E. of regression	0.298521	Akaike info criterion		–0.073886
Sum squared resid	3.5646	Schwarz criterion		0.05278
Log-likelihood	4.477723	Hannan-Quinn criteria.		–0.028088
Durbin-Watson stat	1.151736			

Note: * 10% error level; ** 5% error level; *** 1% error level.

Table 4

RESULTS OF MODEL ESTIMATION IN SHORT-TERM ARDL (3,2, 0, 3, 0, 0)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.***
FD(–1)	–1.620977	0.129941	–12.47471	0.0000***
INF	–0.140687	0.021635	–6.502782	0.0000***
LRGDP	0.945229	0.226555	4.172179	0.0006***
FREERATE	4.43E-05	4.86E-06	9.120681	0.0000***
GOV	1.912389	0.791275	2.416845	0.0265***
FIN	–8.90E-05	3.85E-05	–2.313415	0.0327***
C	–10.35073	1.942586	–5.328324	0.0000***
R-squared	0.951579	Durbin-Watson stat		2.14146
Adjusted R-squared	0.916608	Prob(F-statistic)		0.0000

Note: * 10% error level; ** 5% error level; *** 1% error level.

Suppose there is an increase in uncertainty in a particular season. In that case, the resulting excitement is discharged in the same season. There is no reason for the cycle of uncertainty to continue into subsequent seasons by changing the circumstances. Market participants are smart and make the necessary adjustments to their investment portfolio in the same season under uncertain conditions. Inflation has a negative and significant effect on the uncertainty of the return of the entire stock exchange index as an indicator of capital market uncertainty. Therefore, the hypothesis about the considerable impact of inflation on capital market uncertainty can not be rejected. With a one percent increase in the average inflation rate, assuming other conditions remain constant, capital market uncertainty has decreased by 0.140687 percent. In inflationary conditions, the average nominal profit of companies increases due to the devaluation of money. This increase is due to compensate for the decrease in real profits. Therefore, with the rise in the inflation rate, companies' dividends will increase, and consequently, the stock price will increase. Also, with growing inflation, the investor is less inclined to hold money due to its high risk. Therefore, they are looking to reduce the liquidity in their portfolio. For this purpose, one of the options is to buy stocks that can act as a shield against inflation.

As a result, the demand for investing in the stock market increases. Increasing the need to buy stocks increases the stock price, consequently increasing the value of transactions and increasing the volume of transactions. Investment in companies can increase. Therefore, companies issue shares to provide the necessary financial resources for future investments. Thus, with the inflation rate increase, companies' shares will also improve. According to what was said, inflation raises the stock market activity index (trading value, trading volume, the number of shares, and stock returns). Also, the liquidity index (ratio of

exchange value to total current value of the stock market, ratio of the number of exchanged shares to the total issued shares of the stock market) can increase. Therefore, the effect of inflation on stock market activity, return, and liquidity indicators is positive in the short run. Since stock market activity and liquidity indicate stock market performance, it can be concluded that the effect of inflation on stock market performance in the short term in Iran is positive. As a result, capital market uncertainty decreases [102].

Fama sought to explain the negative relationship between inflation and stock returns. He showed that the negative relationship between actual stock returns and inflation is due to chain effects. His explanation was contrary to the original Phillips curve, meaning a negative correlation between inflation and economic activity. Increasing persistent inflation reduces actual future activities because steady inflation reflects changes in real future activities and, as a result, decreases stock returns. The negative correlation between actual stock returns and inflation is called the chain effect due to the connection between these two relationships. In general, the real sector of the economy indicates that the relationship between stock returns and the growth rate of actual activities is positive. Fama believed that a positive relationship between stock returns and actual activity due to the real sector is combined with a negative relationship between inflation and actual activity due to the financial industry. A negative relationship between actual stock returns and inflation is inferred. In other words, with rising inflation, stock returns will decrease, and capital market uncertainty will increase.

Economic growth has a positive and significant effect on the performance uncertainty of the total stock index as an indicator of capital market uncertainty. Therefore, the hypothesis about the considerable impact of economic growth on capital market uncertainty can not be rejected. With an average increase of one percent in economic development, assuming other conditions are stable, capital market uncertainty has increased by 0.945229 percent. As economic growth increases, so do the welfare of society and the willingness to invest. As a result, corporate profits increase, their financial statements improve, corporate stocks become more valuable, corporate stock returns increase, and capital market uncertainty decreases. But in the Iranian economy, economic growth has increased capital market uncertainty. Thus, economic growth leads to the demand for financial services and financial market development.

The exchange rate has a positive and significant effect on the performance uncertainty of the total index of the stock exchange as an indicator of capital market uncertainty. Therefore, the hypothesis about the considerable impact of exchange rates on capital market uncertainty can not be rejected. Capital market uncertainty increases by increasing the unit exchange rate on average, assuming other conditions are constant. The ratio of online transactions to the total volume of transactions as an ICT index has a positive and significant effect on the return uncertainty of the total stock exchange index as an indicator of capital market uncertainty. Therefore, the hypothesis of the considerable impact of ICT on capital market uncertainty can not be rejected. With increasing one unit in the ratio of online transactions to the total volume of transactions as an average of ICT, assuming that other conditions are constant, capital market uncertainty has increased by 1.912389% in the short term. The effect of the ratio of online or online transactions to the total volume of transactions on capital market uncertainty in the long and short time is different. Since some capital market participants in Iran do not have stock exchange literacy, they are affected by the actions of other shareholders, especially significant shareholders, and imitate their behaviour. This factor increases the excitement in the market and increases the uncertainty in the capital market in the short run. Increasing trading volume in the long run increases market confidence, increases market profitability expectations, and reduces capital market uncertainty.

The number of announcements and advertisements issued as an ICT index has a negative and significant effect on the uncertainty of the return of the entire stock exchange index as an indicator of capital market uncertainty. Therefore, the hypothesis of the considerable impact of ICT on capital market uncertainty can not be rejected. With the increase of one unit in the number of announcements and advertisements published as an ICT indicator, on average, assuming that other conditions are constant, the uncertainty of the capital market has decreased. Whenever users in designated trading systems and platforms provide more accurate and timely information as a result of decisions made about the market as a whole (such as trading time, fluctuations, fluctuations, etc.) or specific stocks (reopen or stop Being a symbol, the decisions of the assembly regarding the increase of capital and distribution of profits, etc.) should be informed faster and more accurate and timely information should be provided in this regard, the decisions of the shareholders will be adjusted at a more appropriate speed. This will reduce the risk and consequently the uncertainty of the capital market (figures 7 and 8).

Then, to further ensure the accuracy of the estimation method and the estimation parameters in the main research model, the following tests (including normality test, heterogeneity test, model specification test, and autocorrelation test). It was done according to the classical assumptions, summarized in tables 5 and 6.

To investigate the existence of long-term relationships, the shore test method has been used in the combined study of the IPS method. Testing the shores can overcome the limitations of other methods used in previous studies (tables 7, 8 and 9).

Therefore, according to the test results and confirmation of the absence of problems such as structural failure, variance heterogeneity, and autocorrelation, the short-term model is approved in the same way as in the form of Schwartz and Ordinary. Also, the

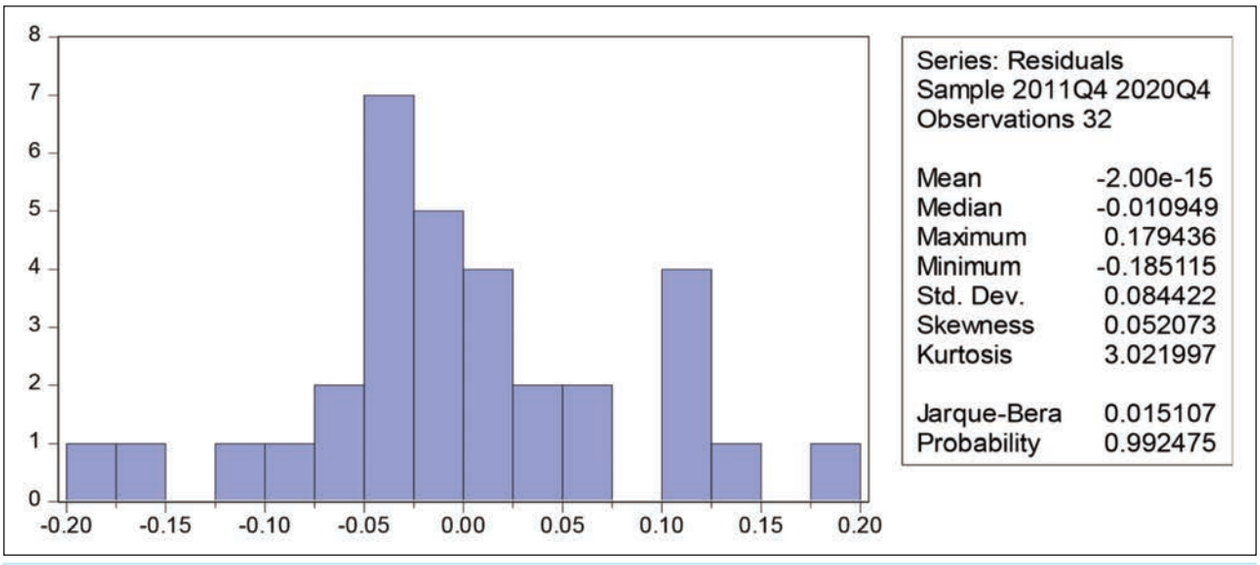

Fig. 7. Test for normality of estimation errors

Table 5

RESULTS OF THE BRUCH-GODFREY AUTOCORRELATION TEST				
F-statistic	1.680598	Prob. F(2,16)		0.2175
Obs*R-squared	5.555352	Prob. Chi-Square(2)		0.0622
Test Equation: Dependent Variable: RESID Method: ARDL Sample: 2011Q4 2020Q4 Presample and interior missing value lagged residuals set to zero.				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
FD(–1)	0.014052	0.131561	0.106807	0.9163*
FD(–2)	0.059459	0.169246	0.351317	0.7299*
FD(–3)	0.074335	0.197353	0.376659	0.7114*
INF	–0.00765	0.022622	–0.33794	0.7398*
INF(–1)	0.013833	0.040452	0.341959	0.7368*
INF(–2)	–0.0071	0.022386	–0.31726	0.7551*
LRGDP	0.056607	0.223598	0.253165	0.8034*
FREERATE	5.000007	4.760006	0.105045	0.9176*
FREERATE(–1)	–3.58001	5.300006	–0.06743	0.9471*
FREERATE(–2)	–1.53001	4.600006	–0.33215	0.7441*
FREERATE(–3)	7.050007	4.360006	0.161859	0.8734*
GOV	–0.11161	0.768837	–0.14516	0.8864*
FIN	5.030006	3.760005	0.133953	0.8951*
C	–0.43315	1.902482	–0.22768	0.8228*
RESID(–1)	–0.13708	0.27433	–0.49969	0.6241*
RESID(–2)	–0.45443	0.250878	–1.81134	0.0889*
R-squared	0.173605	Mean dependent var		–2.000015
Adjusted R-squared	–0.60114	S.D. dependent var		0.084422
S.E. of regression	0.106825	Akaike info criterion		–1.328399
Sum squared resid	0.182585	Schwarz criterion		–0.595531
Log-likelihood	37.25438	Hannan-Quinn criteria		–1.085474
F-statistic	0.22408	Durbin-Watson stat		2.305332
Prob(F-statistic)	0.997043			

Note: * 10% error level; ** 5% error level; *** 1% error level.

Table 6

RESULTS OF CONDITIONAL VARIANCE HETEROGENEITY TEST				
Heteroskedasticity Test: ARCH				
F-statistic	1.294481	Prob. F(1,28)		0.2649
Obs*R-squared	1.325657	Prob. Chi-Square(1)		0.2496
Test Equation: Dependent Variable: RESID^2 Method: Least Squares Sample (adjusted): 2012Q1 2020Q4 Included observations: 30 after adjustments				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	0.00883	0.00227	3.899015	0.0006***
RESID^2(–1)	–0.2088	0.18352	–1.137753	0.2649*
R-squared	0.044189	Mean dependent var		0.007337
Adjusted R-squared	0.010052	S.D. dependent var		0.010161
S.E. of regression	0.01011	Akaike info criterion		–6.28622
Sum squared resid	0.002862	Schwarz criterion		–6.19281
Log-likelihood	96.29332	Hannan-Quinn criteria		–6.25634
F-statistic	1.294481	Durbin-Watson stat		1.8841
Prob(F-statistic)	0.264866			

Note: * 10% error level; ** 5% error level; *** 1% error level.

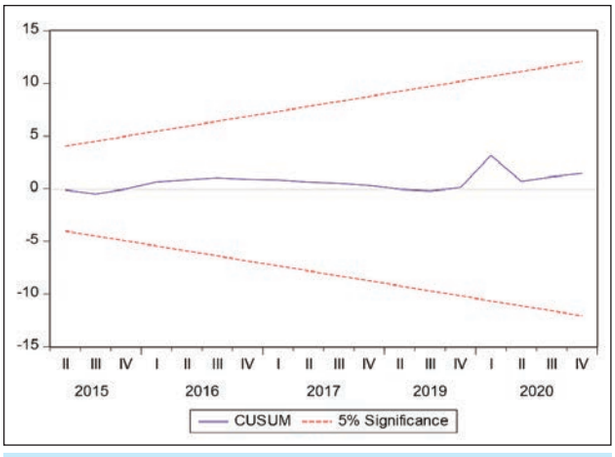

Fig. 8. Structural failure test by Qiosam method

Table 7

THE RESULTS OF THE CO-BAND BOUNDARY TEST TO EVALUATE THE EXISTENCE OF A LONG-RUN RELATIONSHIP		
ARDL Bounds Test Sample: 2011Q4 2020Q4 Null Hypothesis: No long-run relationships exist		
Test Statistic	**Value**	**K**
F-statistic	15.73506	5
Critical Value Bounds		
Significance	I0 Bound	I1 Bound
10%	2.26	3.35
5%	2.62	3.79
2.50%	2.96	4.18
1%	3.41	4.68

research model is estimated in the long run according to the confirmation of a long-term relationship. Table 10 shows the results of the long-term research model.

The results of long-term model estimation show that:

- The uncertainty of the return of the total stock market index as an index of capital market uncertainty in previous seasons has had a positive and significant effect on capital market uncertainty. This indicates a long-term transfer of uncertainty between seasons. Suppose there is an increase in tension in a particular season. In that case, the resulting excitement, in the long run, is not discharged in the same season. There is a possibility that the cycle of increasing uncertainty will continue into subsequent seasons in the long run.
- Inflation has a negative and significant effect on the yield uncertainty of the total stock index and securities as an indicator of capital market uncertainty. Therefore, the hypothesis about the considerable impact of inflation on capital market uncertainty cannot be rejected.
- Economic growth has a positive and significant effect on the uncertainty of the return of the entire stock exchange index as an indicator of capital market uncertainty. Therefore, the hypothesis about the considerable impact of economic growth on capital market uncertainty cannot be rejected. Considering that economic growth in Iran is strongly dependent on oil revenues and its derivatives; Also, the main volume of imports in the country is the import of intermediate goods for the production of final goods and, finally, their export; Sanctions and currency fluctuations have caused fluctuations in production and economic growth; Therefore, the

Table 8

THE RESULTS OF THE CO-BAND BOUNDARY TEST TO EVALUATE THE EXISTENCE OF A LONG-RUN RELATIONSHIP				
Dependent Variable: D(FD) Method: Least Squares Sample: 2011Q4 2020Q4				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
D(FD(–1))	3.594883	0.5299	6.784084	0.0000***
D(FD(–2))	1.470378	0.361897	4.06297	0.0007***
D(INF)	–0.059516	0.014563	–4.086663	0.0006***
D(FREERATE)	2.650005	6.640006	3.992681	0.0008***
D(FREERATE(–1))	4.950005	8.800006	5.626161	0.0000***
D(FREERATE(–2))	3.260005	7.440006	4.383904	0.0003***
C	–3.32778	3.008499	–1.106126	0.2825*
INF	0.025254	0.0087	2.902651	0.0091***
LRGDP(-1)	0.110826	0.350331	0.316348	0.7552*
FREERATE(–1)	–3.110006	5.120006	–0.607518	0.5507*
GOV(–1)	2.140962	1.397969	1.53148	0.1421*
FIN(–1)	2.630005	6.880005	0.381884	0.7068*
FD(–1)	–6.103416	0.673261	–9.065453	0.0000***
R-squared	0.92243	Mean dependent var		–0.00309
Adjusted R-squared	0.87343	S.D. dependent var		0.524517
S.E. of regression	0.1866	Akaike info criterion		–0.22845
Sum squared resid	0.6616	Schwarz criterion		0.367002
Log-likelihood	16.6553	Hannan-Quinn criteria		–0.03108
F-statistic	18.8273	Durbin-Watson stat		1.298827

Note: * 10% error level; ** 5% error level; *** 1% error level.

Table 9

SUMMARY OF THE RESULTS OF THE MODEL DIAGNOSTIC TESTS		
Summary of results	**Test statistics (probability level)**	**Title of exam**
The distribution of errors is very close to the normal pattern.	Jarque-Bera = 0.015107(0.992475)	Normality Test
There is no self-correlation based on the probability level of the F statistic greater than 0.05. If there is autocorrelation, it is necessary to estimate the pattern by the HAC (NEWEY WEST) method so as not to create the problem of autocorrelation in estimating the parameters of the bias pattern.	F(2,16) = 1.680598 (0.2175)	(LM Test)
Given that the probability level is higher than 0.05 based on the estimated statistics of Chi-square and F, there is no problem with variance inhomogeneity. Therefore, the model must be estimated as ORdinary. Suppose there is a conditional variance heterogeneity problem. In that case, it is necessary to estimate the model using the WHITE method so that the heterogeneity problem does not cause inefficiency and skew in the estimation parameters.	F(1,28) = 1.294481 (0.2649) Chi-Square(1) = 1.325657 (0.2496)	(ARCH)
There is no structural break. There is no structural break because it does not go beyond the boundary lines.	Graph	Structural Break
Compared with the one percent limit range (3.41–4.68) and the resulting F position above this set range, it can be concluded that the existence of a long-term relationship with 100% probability (100%) has been confirmed.	F(K=5) = 15.73506	(Bounds Test)

Table 10

RESULTS OF LONG-TERM MODEL ESTIMATION USING ARDL METHOD (3, 2, 0, 3, 0,0)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
D(FD(–1))	3.681091	0.312586	11.77625	0.0000***
D(FD(–2))	1.294925	0.191674	6.755881	0.0000***
D(INF)	–0.14069	0.021635	-6.50278	0.0000***
D(INF)	0.116693	0.021187	5.507841	0.0000***
D(LRGDP)	0.945229	0.226555	4.172179	0.0006***
D(FREERATE)	0.000044	0.000005	9.120681	0.0000***
D(FREERATE(–1))	0.000026	0.000005	5.658064	0.0000***
D(FREERATE(–2))	0.000034	0.000004	7.658965	0.0000***
D(GOV)	1.912389	0.791275	2.416845	0.0265**
D(FIN)	–8.9E-05	0.000038	–2.31342	0.0327**
CointEq(–1)	–6.30207	0.395435	–15.937	0.0000***
Cointeq = FD – (0.0011*INF + 0.1500*LRGDP – 0.0000*FREERATE + 0.3035*GOV – 0.0000*FIN – 1.6424)				

Note: * 10% error level; ** 5% error level; *** 1% error level.

stock returns of companies have been volatile, which has caused traders confusion and hesitation in decision-making, as well as increased uncertainty in the capital market.

- Exchange rate has a negative and significant effect on the performance uncertainty of the total stock market index as an indicator of capital market uncertainty. Therefore, the hypothesis about the considerable impact of economic growth on capital market uncertainty cannot be rejected. The direct impact includes those listed companies that are exported and priced at world rates, such as refining, petrochemical, metal, mining, and other industries. The exporters are more profitable and more profitable, so usually, after the exchange rate rises, the value of the shares of these companies will also increase. This is true today for half of all listed companies. Therefore, as the return on the overall index increases, the severity of uncertainty in the market decreases.
- The ratio of online transactions to the total volume of transactions as an ICT index has a negative and significant effect on the uncertainty of the return of the total index of the stock exchange as an indicator of capital market uncertainty. Therefore, the hypothesis on the significant effect of ICT on capital market uncertainty cannot be rejected.
- The number of announcements and advertisements issued as an ICT index has a negative and significant effect on the uncertainty of the return of the entire stock exchange index as an indicator of capital market uncertainty. Therefore, the hypothesis of the considerable impact of ICT on capital market uncertainty cannot be rejected.
- Good model fit tests (including autocorrelation, heterogeneity, normality, etc.) show no autocorrelation, variance heterogeneity, or structural failure that causes the model estimates to be biased.
- The results of long-term model calculations show that in addition to the significance of the estimated coefficients, according to the number of statistics <–1 CointEq (–1) = – 6.30, the errors are moderated sinusoidally and divergently. The adjustment rate is equal to 1 – CointEq (–1) = 1 – (–6.30) = 7.30. In other words, it takes about 7.5 seasons on average to completely neutralize the imbalance in capital market uncertainty.

CONCLUSION

This study investigates the impact of ICT on capital market uncertainty in Iran. For this purpose, the GARCH model has been used to estimate the yield uncertainty of the total stock exchange index as an index of capital market uncertainty. The vector autoregression model with distributed intervals (ARDL) has been used to estimate the model. The results of evaluating the model using quarterly data in the period 2011: 1 to 2020: 4 showed that in the short run, the return on the total index of the stock exchange as an indicator of capital market uncertainty has a negative and significant effect and in the long run a positive impact and has had a significant effect on capital market uncertainty. This indicates a lack of transfer of capital market uncertainty between the seasons in the short run. Suppose there is an increase in tension in one season. In that case, the resulting excitement is discharged in the same season. There is no reason for the cycle of increasing uncertainty to continue into subsequent seasons by changing the conditions. Market participants are smart and make the necessary adjustments to their investment portfolio in the same season under uncertain conditions. In the long run, the excitement resulting from the uncertainty of the return of the entire stock exchange index as an indicator of capital market uncertainty in the same season is not discharged, and there is a possibility of continuing the increasing cycle of uncertainty in subsequent seasons.

Also, the effect of the ratio of online or online transactions to the total volume of transactions on capital

market uncertainty in the long and short term is different. Since some capital market participants in Iran do not have stock exchange literacy, they are affected by the actions of other shareholders, especially significant shareholders, and imitate their behaviour. This factor has led to increased excitement and uncertainty in the capital market in the short term. While increasing trading volume, in the long run, has increased market confidence, increased market profitability, and reduced capital market uncertainty. This study's results align with the investigations of Sepehrdoost et al. [41]. In this regard, Cheng et al. [33] explained that ICT development has increased economic growth and financial development in high-income countries by increasing the number of people using the Internet and secure Internet platforms [33]. Brown et al. [34] found that the trading volume and frequency of capital market transactions decreased by about 5% on days when mobile Internet systems were slow.

Therefore, ICT has an influential role in online transactions [34]. Sepehrdoost et al. [103], in a study, showed that tools and equipment related to ICT have a positive and significant effect on the growth of the capital market of the Iranian Stock Exchange. In this regard, the number of announcements and advertisements published as another indicator of ICT also has a significant effect on the performance uncertainty of the total index of the stock exchange as an indicator of capital market uncertainty. Whenever users in designated trading systems and platforms provide more accurate and timely information as a result of decisions made about the market as a whole (such as trading time, fluctuations, fluctuations, etc.) or specific stocks (reopen or stop Being a symbol, the decisions of the assembly regarding the increase of capital and distribution of profits, etc.) should be informed faster and more accurate and timely information should be provided in this regard, the decisions of the shareholders will be adjusted at a more appropriate speed This will reduce the risk and consequently the uncertainty of the capital market. In this regard, Asongu and Moulin [104] stated that ICT is essential in information sharing and greater participation in exchanges and buying and selling investors' shares in financial markets. The use of ICT in financial markets will reduce marketing costs, increase the involvement of shareholders and investors, and reduce information asymmetry. This way, it can facilitate access to financial services among investors. Levine [105] also stated that ICT reduces information asymmetry and facilitates the investment process among investors.

Considering the impact of ICT on capital market uncertainty, it is suggested that efforts be made for transparency, ease of access, and updating and updating of information available to users in this area to prevent the severity of uncertainty and the degree of risk of transactions as much as possible. Preparation and development of codified programs in various fields such as communication, educational, cultural, and economic infrastructures to provide and use ICT infrastructure, optimal use of ICT human resources, increase productivity, and at the same time, support growth. The activity of small and medium companies in ICT is recommended. Also, developing countries should take appropriate policies to strengthen institutions active in ICT. Considering the significant effect of the exchange rate on capital market uncertainty, it is suggested to use more powerful tools such as call options and futures trading in the capital market of Iran's economy to prevent increased tension and money out of this area during severe market fluctuations. Currency is taken, and traders' portfolios are protected from damage.

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In-situ synthesis of magnetite nanoparticles on cotton fabrics – structural and magnetic properties

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ABSTRACT – REZUMAT

In-situ synthesis of magnetite nanoparticles on cotton fabrics – -structural and magnetic properties

In this research, the magnetic fabric was fabricated using in situ synthesizing of Iron oxide nanoparticles. To have cotton fabrics covered by magnetic nanoparticles, prepared Iron Oxide nanoparticles were deposited on it using an in situ method with 3 different concentrations of precursors while other factors such as pH, temperature, NaOH concentration, reaction container volume, and the chemical reaction time remained constant. $FeCl_3$ and $FeSO_4{\cdot}7H_2O$ were used as precursors. The results confirmed that magnetite nanoparticles with cubic structure, spherical shape and uniform distribution were deposited on the surface of cotton fabrics. The vibrating sample magnetometer (VSM) results revealed that the cotton fabric was covered by superparamagnetic magnetite nanoparticles.

Keywords: *magnetic fabrics, magnetic nanoparticles, cotton, textile, synthesise, metal nanoparticles*

Sinteza in situ a nanoparticulelor de magnetită pe țesături din bumbac – proprietăți structurale și magnetice

În acest studiu, țesătura magnetică a fost fabricată folosind sintetizarea in situ a nanoparticulelor de oxid de fier. Pentru a obține țesături din bumbac acoperite cu nanoparticule magnetice, nanoparticulele de oxid de fier au fost depuse folosind metoda in situ cu trei concentrații diferite de precursori, în timp ce alți factori cum ar fi pH-ul, temperatura, concentrația de NaOH, volumul recipientului de reacţie şi timpul de reacţie chimică au rămas constante. $FeCl_3$ și $FeSO_4{\cdot}7H_2O$ au fost utilizați ca precursori. Rezultatele obținute au confirmat că nanoparticulele de magnetită cu structură cubică, formă sferică și distribuție uniformă au fost depuse pe suprafața țesăturilor din bumbac. Rezultatele magnetometrului cu probă vibrantă (VSM) au arătat că țesătura din bumbac este acoperită de nanoparticule de magnetită superparamagnetică.

Cuvinte-cheie*: țesături magnetice, nanoparticule magnetice, bumbac, textile, sinteză, nanoparticule de metal*

INTRODUCTION

Unique properties such as large surface to volume ratio and quantum size effects of metal nanoparticles make them important materials in scientific research and industrial applications [1, 2]. High specific surface area, super-paramagnetism, low biotoxicity, and good modification ability [3] also make magnetic nanoparticles (MNPs) considerably crucial. In addition, they are potentially used in a wide range of fields including, nanomaterial-based catalysts [4] biomedicine [5] and tissue-specific targeting [6], magnetic resonance imaging [7] data storage [8] environmental remediation [9] and textile industry [10].

Iron (Fe), nickel (Ni), and cobalt (Co) are the most important metallic MNPs whose magnetic properties are high and their size, composition, and shape can be controlled and adjusted highly [11]. Iron oxide nanoparticles (ferrites) have two crystal structures of maghemite (Fe_2O_3, γ-Fe_2O_3) or magnetite (Fe_3O_4) and are the most explored magnetic nanoparticles. These nanoparticles are superparamagnetic, below 30nm in size, and they can show magnetic properties only if an external magnetic field is applied and once the external magnetic field is switched off, the remanence falls back to zero [12]. In general, Fe_3O_4 nanoparticles can be synthesized via both chemical and mechanical methods. The co-precipitation method is one of the chemical synthesis methods that are commonly used because the process is simple and inexpensive [13]. Iron oxide nanoparticles were also synthesized using a completely green biosynthetic method by reduction of ferric chloride solution using brown seaweed water extracts [14]. Other synthesis methods like hydrothermal method [15], microwave irradiation method [16], ultrasonic method [17] and sol-gel method [18] have been used to synthesize magnetite nanoparticles.

Metals are heavy, expensive and difficult to process, and in contrast, textiles are light, inexpensive and can be shaped to form three-dimensional structures and can be tailored with scissors or folded. Thus, the fabrication of metallized textiles is important nowadays. There are different methods to coat metal on textiles, such as electroless plating [19], airbrushing [20], vacuum depositing [21], sputter coating [22],

and in situ synthesis of nanoparticles on textiles [23]. Moreover, magnetic fibres are useful as elements of magnetic cores, parts of textile gauges, transmitters, and intelligent clothing products [10]. In addition, iron oxide [24] and Ag/Ni bi-metallic nanoparticles [25] are used as the remover of textile dye, which is a significant impurity, from water. As the magnetic properties of the Fe_3O_4 nanoparticles on the treated fabrics are more interesting than those of the Iron oxide nanoparticles powder, the physicochemical properties of cotton fabrics coated with iron oxide nanoparticles by the Pad-Dry Cure method were discussed [26]. In the other research work, magnetite and magnetic core-shell mesoporous silica nanoparticles were deposited onto cotton fibres by electrostatic Layer-by-layer assembly to form a promising material for many applications. [27]. Magnetic fabrics can be used in smart textiles, flexible sensors, flexible electromagnetic shielding materials, textile wastewater treatment, medical textiles, antibacterial materials, and catalysts. [10] It is possible to use magnetic textiles as a filter for reducing and removing colour in industrial wastewater. [30]

In this research work, Iron oxide nanoparticles were in situ synthesized on cotton fabric and the magnetization properties of prepared samples were investigated.

EXPERIMENTAL

Materials

In this research, Iron oxide nanoparticles were in situ synthesized on cotton fabrics using ferric chloride and ferrous sulfate. For this purpose, the molar ratio of two to one of $FeCl_3$ and $FeSO_4{\cdot}7H_2O$ was used.

In situ synthesis of nanoparticles on cotton fabric

To prepare sample 1, $FeCl_3$ and ferrous sulfate with concentrations of respectively 1 and 0.5 molar were added to the petri dish containing 500 ml distilled water. Being washed cotton fabric was put in the beaker containing $FeCl_3$ and $FeSO_4{\cdot}7H_2O$ solutions while the magnetic stirrer was stirring quickly and the temperature was fixed at 75 °C. The pH of the red solution was 1.5 which increased up to 11 by adding 200 ml of 1 molar NaOH dropwise and remained at this level during the chemical reaction until a black precipitation appeared. This process continued for 30 min. Then coated textile was washed with distilled water and its impurities were removed, then it dried at room temperature (figure 1).

The other samples were synthesized using half and one-third of the initial concentrations of $FeCl_3$ and $FeSO_4{\cdot}7H_2O$, named samples 2 and 3, respectively. For preparing these two samples, the conditions which were NaOH concentration, reaction container volume, temperature, pH and the time of chemical reaction were kept the same as the sample 1 condition.

Characterization method

To examine the crystallinity characteristics of samples, X-ray Diffraction analysis was utilized by the XRD instrument (STADI MP, made in STOE, Germany). The employed radiation was Cuk with a wavelength of 1.540598 Å, 2θ between the angles of 20 and 80 degrees and the voltage and current were 40 kV and 30 mA, respectively. Moreover, the step size and step time were set, in the order at 0.04° and 1 s. Conventional SEM studies were carried out using the EM3200 machine (KYKY Co., China) to investigate the morphology of the samples. Besides, for examining the formation of iron oxide nanoparticles, FESEM analysis was employed on a treated cotton sample utilizing the MIRA3 instrument (TESCAN Co., Czech Republic) in different magnifications at 5 and 15 kV. Afterwards, Energy Dispersive X-ray (EDX) analysis was employed to identify the presence of iron oxide on cotton fabrics. To examine the magnetic properties of the samples, VSM analysis was conducted through a vibrating specimen magnetometer, (VSM, Lake-shore model 7400 with a minimum of 0.0001 emu to a maximum of 50 emu and a maximum magnetic field up to 20 kOe).

Fig. 1. The photo of magnetized fabric (sample 1)

RESULTS AND DISCUSSION

To investigate the crystallinity and type of produced nanoparticles, XRD analysis was used and the results are shown in figure 2. The results show sharp peaks, which is evidence for the formation of Fe_3O_4 nanoparticles with a high degree of crystallinity and cubic structure. The production of magnetite nanoparticles was approved by a standard card (JCPDS No. 01-087-2334).

In figure 2, the X-ray diffraction pattern shows peaks at 2θ values of 18, 30, 35, 43.40, 57 and 63.5 representing the crystal structure of Fe_3O_4 nanoparticles. Moreover, the diffraction peaks are well-adjusted to the reference Fe_3O_4 card No01-087-2334.

According to data obtained from this diffraction pattern and using Debye-Scherrer equation 1 it can be possible to calculate the mean size of Magnetite crystalline domains (*D*):

$$D = K\lambda / \beta \cos\theta \qquad (1)$$

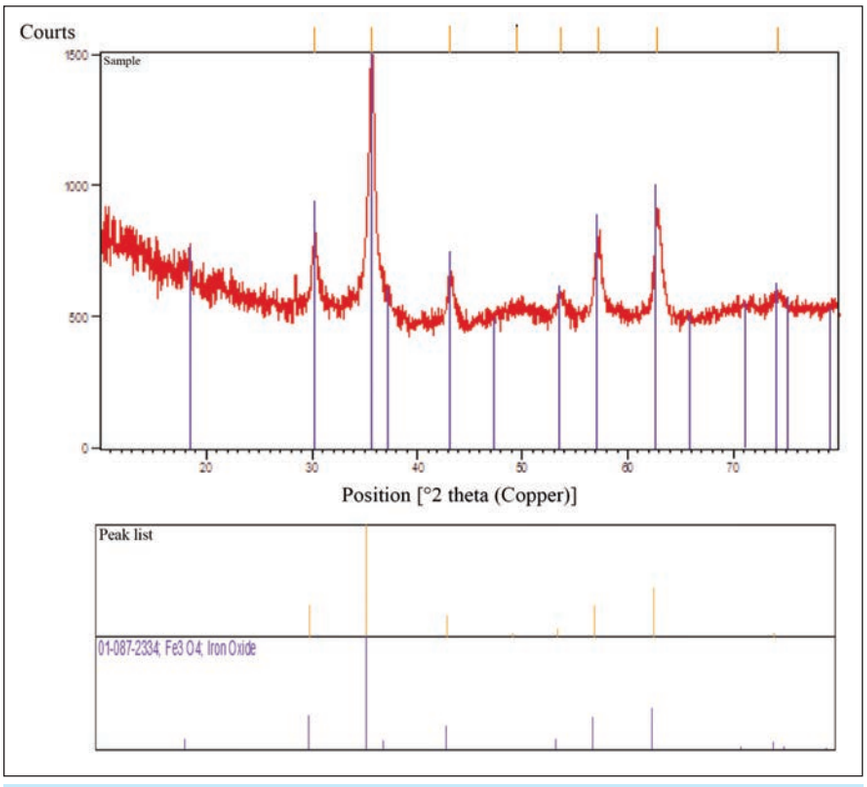


Fig. 2. X-ray pattern of nanoparticles

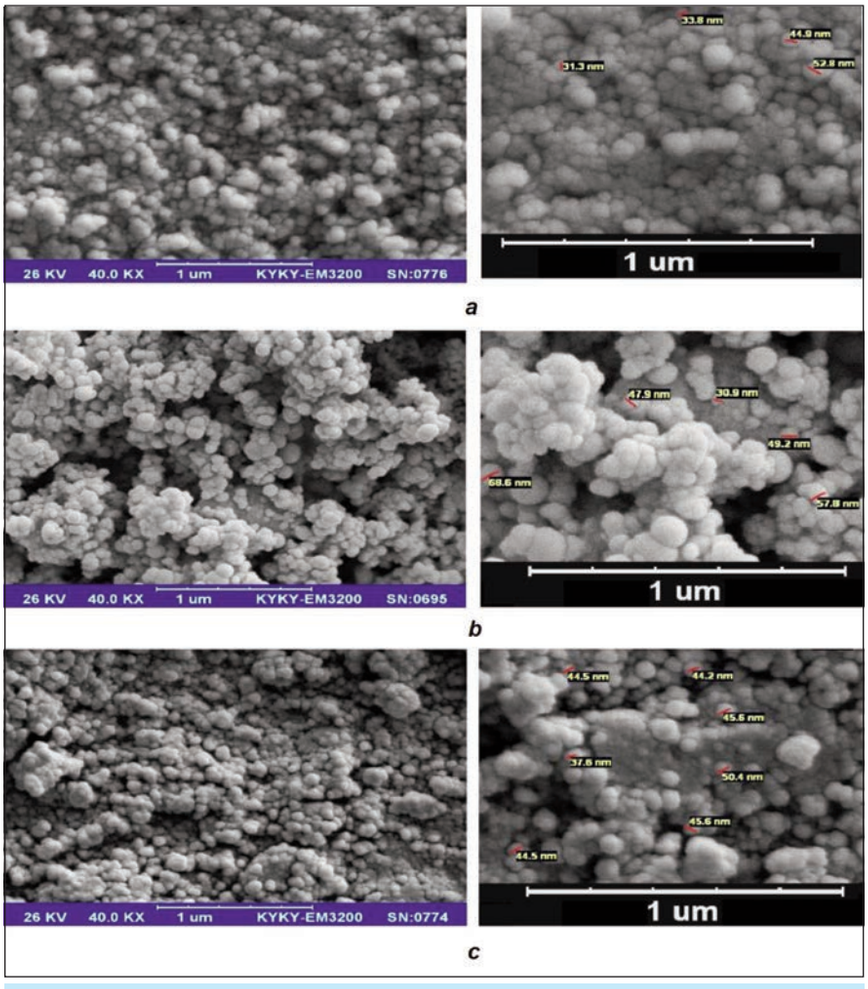


Fig. 3. SEM analyses of Magnetite nanoparticles in:
a – Sample 1; *b* – Sample 2; *c* – Sample 3

where D is the mean size of the crystalline domains, K is a dimensionless shape factor with a value close to unity, λ is the X-ray wavelength, β is the full width at half maximum (FWHM) and θ is the Bragg angle in radians. The crystallite size of the NPs was calculated to be 13–17 nm.

The advantage of this method for producing Iron oxide nanoparticles is its simplicity, low cost, and possibility to be done in every chemistry lab with simple chemical reagents. The chemical reaction goes on by the following equations:

$$FeSO_4 \cdot 7H_2O + 2FeCl_3 \cdot 6H_2O + 8NaOH \rightarrow Fe_3O_4 + 6NaCl + Na_2SO_4 + 17H_2O \quad (2)$$

$$4Fe_3O_4 + O_2 \rightarrow 6Fe_2O_3 \quad (3)$$

SEM analyses of three different samples depicted in figure 3 show that the magnetite nanoparticles are spherical in shape and their uniform size remained constant, ranging from 30 nm to 70 nm, by varying the concentration of precursors.

The morphology of the nanoparticles on cotton samples was investigated using FESEM analysis. FESEM analyses of the raw cotton without any deposited Magnetite nanoparticles have been shown in figure 4 with different magnifications. As it is seen, no nanoparticles, as it was expected, appear on the surface.

FESEM analyses of samples 1, 2 and 3 have been shown in figures 5, 6 and 7, respectively. It is seen that the surface of cotton fabrics has been covered by magnetite nanoparticles. The morphology of the nanoparticles on the surface of fabrics is spherical and it shows that the shape of in situ synthesized nanoparticles on cotton samples remains constant. According to these figures, as expected, the concentration of magnetite nanoparticles has

decreased with a decrease in concentration of the initial precursors, from sample 1 to sample 3.

The amount of Fe_3O_4 magnetite nanoparticles on the surface of cotton samples was compared via using EDS (Energy Dispersive X-ray) analysis as an elemental analysis. EDS analysis of a piece of raw cotton, used as a substrate, is shown in figure 8. As it was expected, there were not any Fe atoms on the textile before depositing.

Comparing the amount of Fe element in three samples (figures 9–11) the results show that its weight percent in sample three is minimum which is compatible with the concentration of the initial precursor of this sample that was the least and this result confirms the results of SEM analyses.

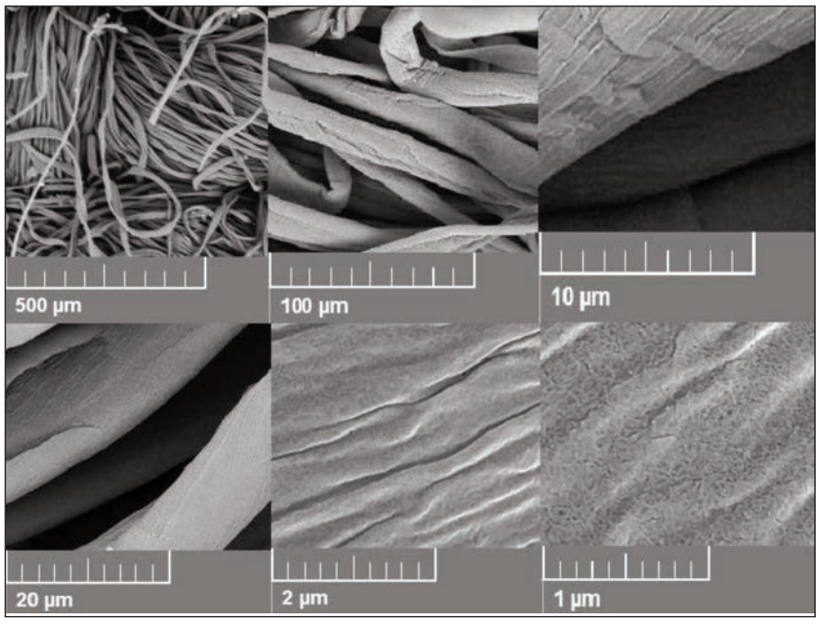


Fig. 4. FESEM analyses of raw cotton samples in different magnifications (in the absence of Magnetite nanoparticles)

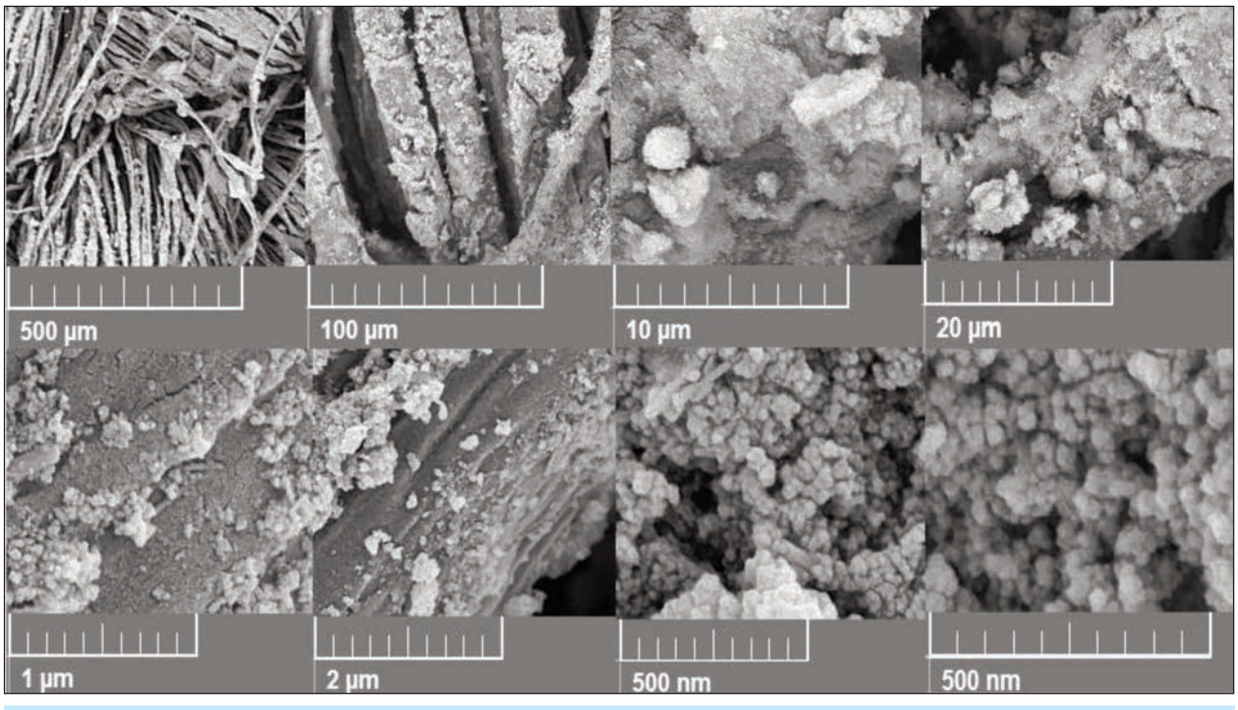


Fig. 5. FESEM analysis of Sample 1 (with magnetite nanoparticles)

As was mentioned in the experimental part, for measuring the magnetic properties of deposited samples, VSM analysis was used. Hysteresis loops of samples 1, 2 and 3 at room temperature with a maximum applied magnetic field of 10 kOe were measured and shown in figure 12. Magnetic analysis shows that magnetic hysteresis loops are not linear in average magnetic fields, which is evidence that the samples are not paramagnetic. Iron oxide displays superparamagnetic properties at room temperature when its size is below 30 nm [12]. As it is shown, all samples are superparamagnetic due to the presence of these nanoparticles. The reversibility of magnetic loops clarifies that the samples are isotropic without coercivity. According to what is seen, the magnetic saturation and the slope of the hysteresis loop showing magnetic susceptibility have decreased due to the presence of less Fe content, from sample 1 to sample 3. The magnetic properties of prepared samples are enough high to be adsorbed by a magnet (figure 1). Magnetic nanoparticles have many applications in the textile industry [24–28]. As such nanoparticles

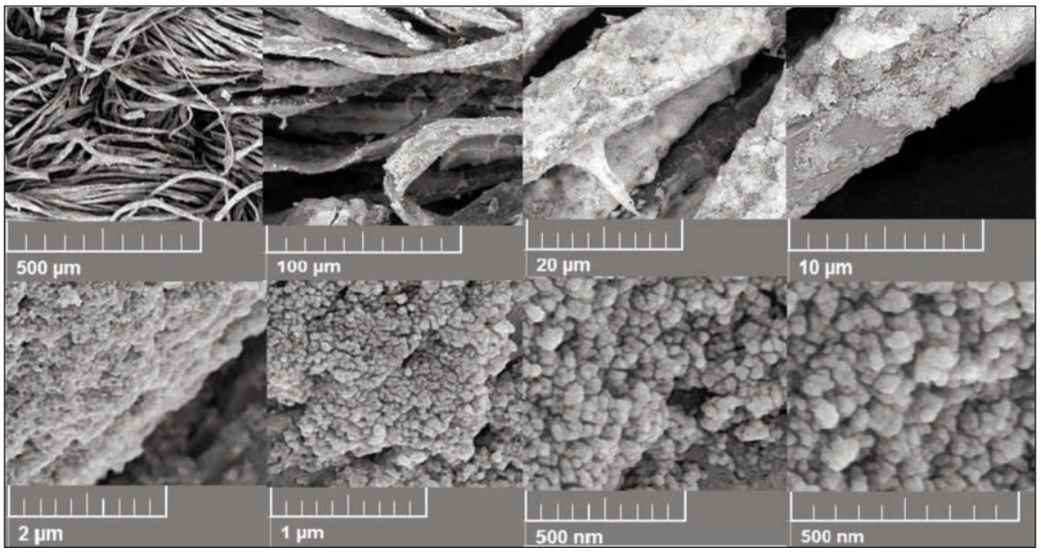


Fig. 6. FESEM analysis of Sample 2 (with magnetite nanoparticles)

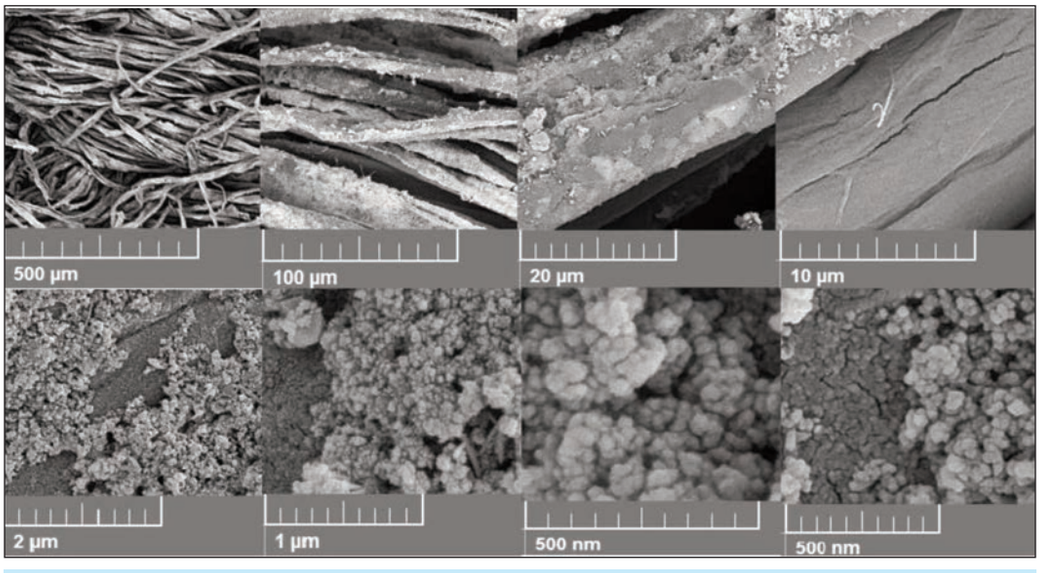
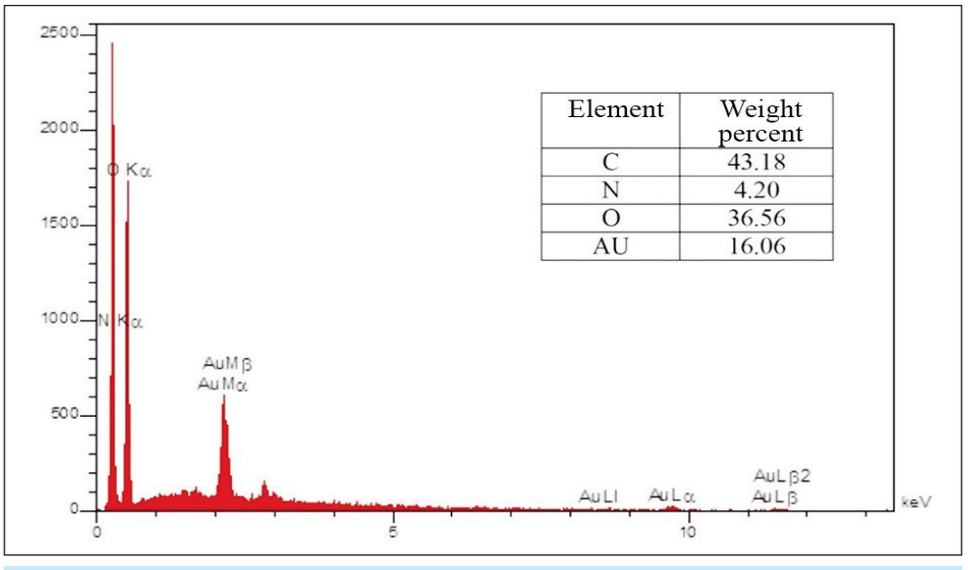
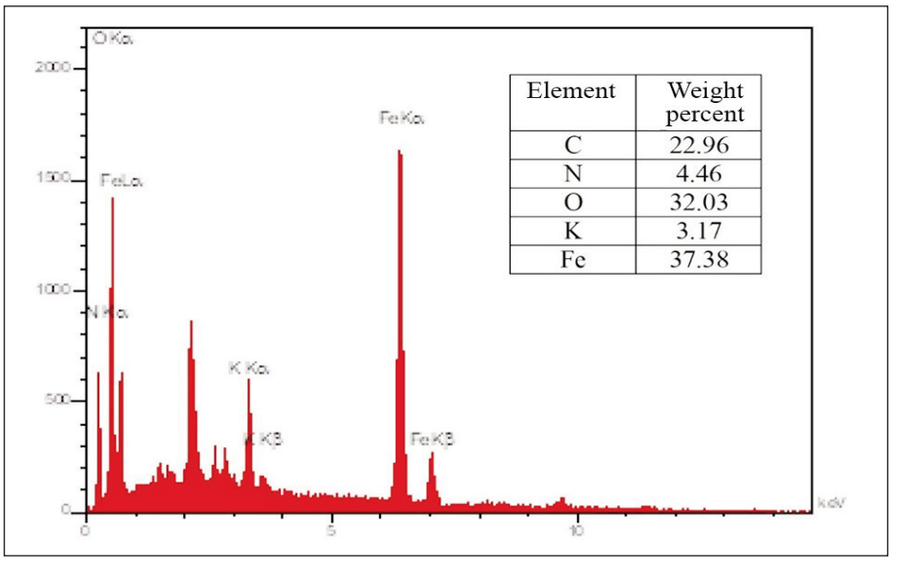


Fig. 7. FESEM analysis of Sample 3 (with magnetite nanoparticles)



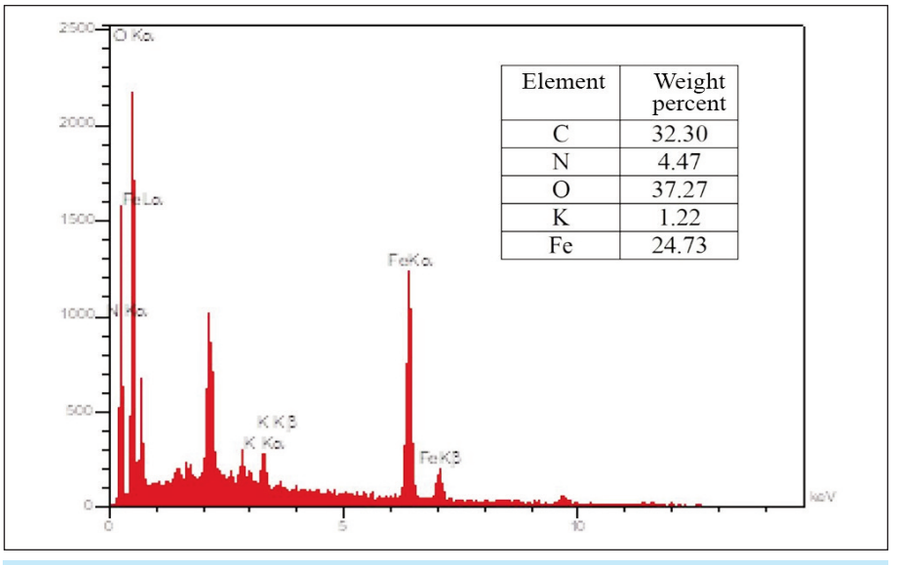
Element	Weight percent
C	43.18
N	4.20
O	36.56
AU	16.06

Fig. 8. EDS analysis of a raw cotton sample (in the absence of Magnetite nanoparticles)



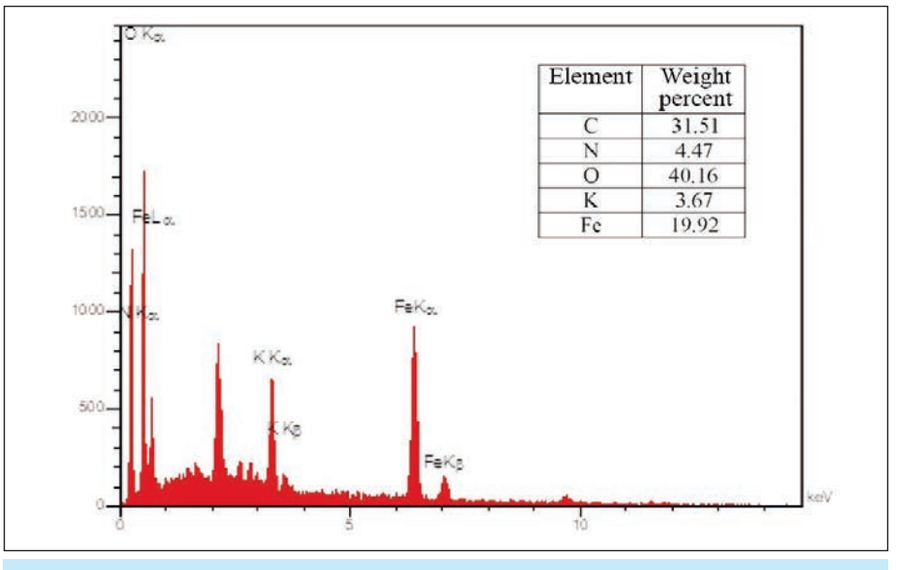
Element	Weight percent
C	22.96
N	4.46
O	32.03
K	3.17
Fe	37.38

Fig. 9. EDS analysis of sample 1



Element	Weight percent
C	32.30
N	4.47
O	37.27
K	1.22
Fe	24.73

Fig. 10. EDS analysis of sample 2



Element	Weight percent
C	31.51
N	4.47
O	40.16
K	3.67
Fe	19.92

Fig. 11. EDS analysis of sample 3

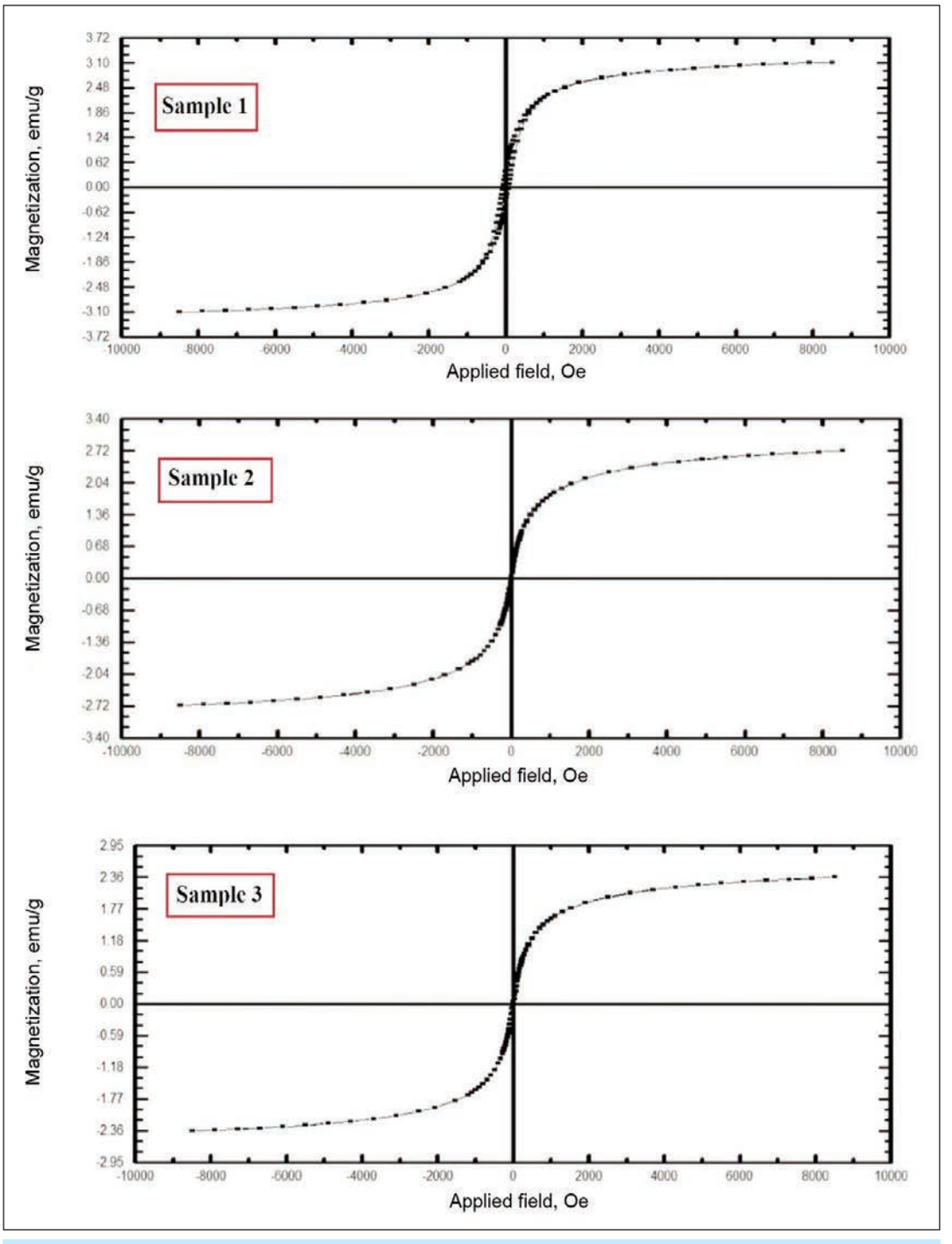


Fig. 12. Magnetic hysteresis loop for synthesized magnetic fabrics

can be simply dispersed in water, after dying the fabrics, wastewater was subjected to magnet, and unbounded magnetic dyes were collected, recycled, and saved for the next dyeing procedures, which is an environmentally friendly way for the wastewater treatment process [29]

CONCLUSIONS

XRD, SEM and FESEM analyses confirmed that magnetite nanoparticles with cubic structure, spherical shape and uniform distribution have been fabricated and in situ synthesized on cotton fabric. The precursors' concentration did not affect the size of nanoparticles and it just changed the concentration of nanoparticles. Based on the results of EDS, the amount of Fe deposited on the fabric sample is in direct proportion to the concentration of precursors. VSM analysis reveals that the in situ synthesized magnetite nanoparticles on cotton samples are superparamagnetic.

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Water sustainability of sub-Saharan African cotton industry: evidence from Mali

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DIADIE SACKO HUA CHENG

ABSTRACT – REZUMAT

Water sustainability of sub-Saharan African cotton industry: evidence from Mali

The world's cotton industry plays a significant role in the global economy, with cotton being used in around 50% of all clothing, household items, and other products. However, the production of cotton is also known to have a significant impact on the environment, particularly freshwater resources. Sub-Saharan Africa is particularly vulnerable, with 40% of the world's water-deprived people living in the region. Cotton is a vital cash crop in sub-Saharan Africa, serving as the main source of livelihood for over 2 million rural families, but its production is also water-intensive, requiring around 20,000 litters of water per kg of cotton yield. In addition, cotton farming in the region is largely dependent on rain, but countries are looking to expand their production and acreage through increased irrigation, putting further pressure on already stretched water resources. This essay investigates the sustainability of sub-Saharan Africa's cotton industry, using Mali as a case study. The region can increase its output significantly, but this must be done sustainably to avoid exacerbating the negative impact on freshwater resources. The study also discusses the water crisis in sub-Saharan Africa, cotton farming in Mali and the region, and the potential consequences of increased cotton production on families and the environment. Mali, currently the highest cotton producer on the continent is a convenient case study reflecting conditions in other sub-Saharan countries. By studying the scientific literature on the progression of cotton production and attendant problems in Mali and some other West African countries, I hope to inform policymakers in the region about some proven ways to improve cotton yield and processing while leaving water resources pristine. The plan centres on producing cotton in an eco-friendly manner through the adoption of organic cotton, and GM cotton and irrigation in suitable areas. At the same time, there is a need to reduce the grey water footprint by reducing chemical usage and treating effluents before discharge.

Keywords: *water footprint, sustainability, organic cotton, grey water, blue water, green water, millennium sustainable development goals*

Sustenabilitatea gestionării apei în industria bumbacului din Africa Subsahariană: dovezi din Mali

Industria mondială a bumbacului joacă un rol semnificativ în economia globală, bumbacul fiind folosit în aproximativ 50% din toate articolele de îmbrăcăminte, articole de uz casnic și alte produse. Cu toate acestea, se știe că producția de bumbac are un impact semnificativ asupra mediului, în special asupra resurselor de apă dulce. Africa Subsahariană este deosebit de vulnerabilă, 40% dintre persoanele lipsite de apă din lume trăiesc în această regiune. Bumbacul este o cultură comercială vitală în Africa Subsahariană, fiind principala sursă de trai pentru peste 2 milioane de familii rurale, dar producția sa este, de asemenea, consumatoare de apă, necesitând aproximativ 20.000 de litri de apă per kg de bumbac. În plus, agricultura de bumbac din regiune depinde în mare măsură de ploaie, dar țările caută să-și extindă producția și suprafața prin irigare sporită, punând și mai multă presiune pe resursele de apă deja reduse. Acest studiu investighează sustenabilitatea industriei bumbacului din Africa Subsahariană, folosind Republica Mali ca studiu de caz. Regiunea își poate crește producția în mod semnificativ, dar acest lucru trebuie făcut într-o manieră sustenabilă pentru a evita exacerbarea impactului negativ asupra resurselor de apă dulce. Studiul abordează, de asemenea, criza apei din Africa Subsahariană, agricultura de bumbac din Mali și din regiune și consecințele potențiale ale producției crescute de bumbac asupra familiilor și a mediului. Mali, în prezent cel mai mare producător de bumbac de pe continent, este un studiu de caz concludent care reflectă condițiile din alte țări subsahariane. Studiind literatura științifică despre progresia producției de bumbac și problemele aferente din Mali și din alte țări din Africa de Vest, este posibil ca factorii de decizie din regiune să fie înştiinţaţi cu privire la câteva modalități dovedite de a îmbunătăți randamentul și procesarea bumbacului, lăsând în același timp resursele de apă curate. Planul se concentrează pe producerea de bumbac într-o manieră mai ecologică prin adoptarea bumbacului organic și a bumbacului modificat genetic și irigarea în zone adecvate. În același timp, este necesar să se reducă amprenta de apă gri prin reducerea utilizării produselor chimice și tratarea efluenților înainte de evacuare.

Cuvinte-cheie*: amprenta de apă, sustenabilitate, bumbac organic, apă gri, apă albastră, apă verde, obiectivele de dezvoltare durabilă ale mileniului*

INTRODUCTION

Cotton is the most important textile crop in the world, being used in as much as 50% of all clothes, household items and other products [1]. At the same time, the growing and processing of cotton is considered to have one of the biggest negative footprints on the environment. This effect is particularly taxing on freshwater resources and sub-Saharan Africa as a region is among the most vulnerable. According to a

report by UNICEF, 40% of the world's water-deprived people live in sub-Saharan Africa, a proportion that amounts to 320 million people. Cotton is an important cash crop in sub-Saharan Africa, being the main source of livelihood for more than 2 million poor rural families [2]. At the same time, the crop and its products are water-intense, requiring around 20,000 litres for every kg of cotton yield [3]. As a result, about 73% of global cotton farming is dependent on irrigation, putting pressure on already overstretched water resources [4]. Producing a single jeans trouser can take up to 10,800 [3] during the processing phase, providing further context to the full extent of the effect of cotton on the water ecosystem.

The sub-Saharan African cotton farming industry is largely dependent on rain but most countries harbour ambitions to expand production and acreage and increased irrigation is one of the ways that they have earmarked to do this. Although the cotton industrial chain is one of the most important economic industries in the sub-Saharan region, the totality of its output is a small fraction of the $1.3 trillion global cotton industry [2]. As such, the region can increase its output immensely but it comes with dire implications on the environment, particularly water resources if it is done in an unsustainable manner. This essay investigates the continued viability of sub-Saharan Africa's way of growing cotton with Mali's cotton industry as the main example. The main challenge for the future is to increase Saharan Africa's cotton production without exacerbating the negative footprint that the industry already has on freshwater resources.

CONTEXTUALISING THE PROBLEM

Cotton farming in Mali and Sub-Saharan Africa

While there are reports of cotton being grown in southern Africa as early as the 16th century, commercial cotton was largely introduced to sub-Saharan Africa during the turn of the 20th century by colonial authorities looking to exploit large underutilized fertile farmland. Today, more than 20 countries in sub-Saharan Africa grow cotton for both domestic and international consumption. Cotton is an extremely important cash crop in sub-Saharan Africa, earning more than $15.5 billion in export revenue for farmers across the region [5]. The acreage under cotton cultivation increased steadily between the 1960s and the 1980s but has since stagnated and fluctuated periodically, with the early 2000s having seen a significant decline that has since rebounded in most countries [6]. Cotton in sub-Saharan Africa is mainly grown by smallholders on small farms together with other crops such as maize, potatoes and cassava. Currently, Africa only accounts for 4% of global cotton production [7], but most countries have been looking to up their production by many times their current levels. Many scholars agree that the current production levels are significantly below capacity owing to a combination of factors limiting optimal yield, especially at the cultivation stage.

Mali has been farming cotton since the 1950s and though production has fluctuated significantly, it has been on an upward trend in recent years. Figure 1 shows some of Africa's main cotton-farming countries, Mali is currently Africa's largest cotton producer, having produced about 760,000 tons in the 2021/2022 season. The crop is the second largest source of export revenue after gold, underlining the important economic value that it has on Malian households. The government has laid out ambitious plans to increase yield with a goal of at least 1.2 million tonnes by 2025. The country's cotton industry occupies a relatively precarious place, exacerbated by various local and international factors. This was demonstrated during the mid-2000s and early 2010s when a currency crisis coupled with low cotton prices saw a significant dip in cotton production in the country [8]. In a study conducted in the Sikasso region of Mali, a major cotton-producing area, Cooper and West [9] found a correlation between cotton cultivation and malnutrition and the destruction of natural capital. This suggests that despite cotton bringing in much-needed cash, could compete with food crops and create harsh conditions for families.

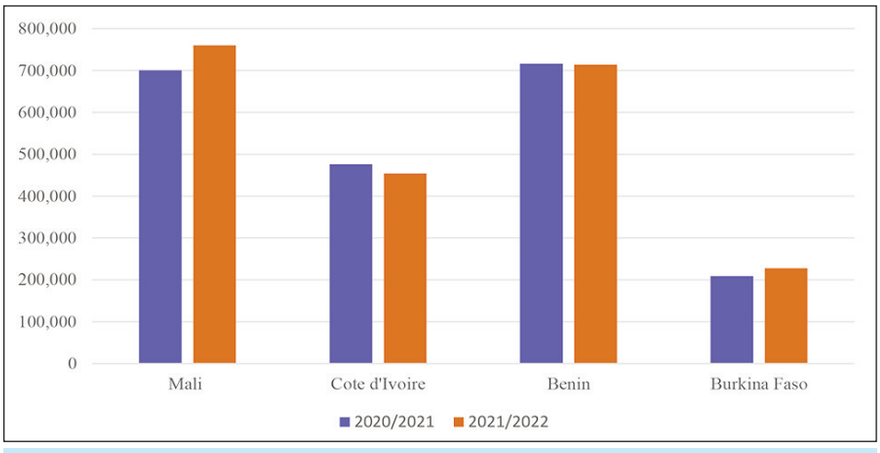

Fig. 1. Cotton production in selected West African countries (*Source: Adapted from https://ipad.fas.usda.gov/countrysummary/Default.aspx?id=DM&crop=Cotton*)

Sub-Saharan Africa's water crisis

Water availability is one of the most important elements under the Millennium Sustainable Development Goals. Africa faces the highest jeopardy of missing out on these goals and clean water shortage is one of the most important factors for this. Despite making up 22% of Earth's landmass, Africa has just 9% of the freshwater resources, making it the most water-scarce continent [10]. In addition, the resources are unevenly distributed, with 72% being concentrated in

central and western African regions where just 34% of the population of the continent lives [11]. Currently, Africa has the fastest-growing population of all the continents, with its population expected to double by 2050 [10]. As a result, the pressure on the continent's already threatened water resources will continue to pile up. According to McClain [11], sub-Saharan Africa must increase its crop production by 2% annually to meet the needs of the growing population. Considering that the region has also experienced the lowest rates of agricultural innovation, much of that increase will likely be met by increasing land under agricultural cultivation rather than increasing the productivity of existing farmland. Currently, only about 4% of sub-Saharan Africa's cultivated land is under irrigation and the region's leadership is hedging on increasing this figure to meet the agricultural and economic needs of the region's population [12]. In Burkina Faso for example, at least 3% of savannah is being converted to farmland every year, in line with the 3.3% population growth rate in the country [13]. The implication that this has is the further destruction of wetlands, forests and water bodies that the freshwater ecosystem depends on. As such, cotton cultivation and processing acts as a competing activity for precious resources and poses an existential threat to Earth's most vulnerable region.

With mixed arid and wet climactic conditions across the country, Mali mirrors the climactic conditions prevalent across sub-Saharan Africa and therefore is a fair representation for the rest of the region. While the north of the country is dominated by hot desert conditions, the south has a wet tropical climate. This contrast mirrors the uneven distribution of water resources that is also endemic in the rest of the region. According to UNICEF, over 20% of the country's population does not have access to safe drinking water and that proportion is expected to rise due to a rising population and the threat of political instability.

The water footprint of cotton

The water footprint of textiles has been a prominent topic of discussion in recent years and environmental sustainability has become an important consideration across various industries. When measuring the impact of the cotton production cycle, three types of water use are identified. Green water use refers to rainwater that helps sustain plants; blue water refers to irrigation water drawn from groundwater sources, and grey water refers to water that is used in the industrial stage to extract and condition fibre from the cotton fluff [14, 15].

Niinimäki et al. [1] estimate that in 2015, the textile industry used a total of 44 trillion litres of water, with cotton cultivation accounting for 95% of that figure. This figure represents 3.14% of global freshwater use [16] and the crop has a disproportionate effect in terms of negative outcomes. In fact, by some estimates, cotton cultivation and processing is responsible for 17% of global damage to freshwater resources [4, 16]. The most glaring example of the havoc that cotton cultivation can wreak on water ecosystems is the drying of the Aral Sea in central Asia which happened as a result of the diversion of major rivers feeding the lake to water large cotton farms located upstream. In central Africa, a similar effect has been observed, with Lake Chad reducing in size by 90% over the past 50 years. Among other factors, the United Nations attributes this effect to overuse of the lake water for irrigation [17]. The lake basin supports more than 30 million people and the continued devastation is a representation of the calamity that can be expected at an even larger scale in Africa without proper plans to mitigate irresponsible water use.

In a government-sponsored research effort on the impact of cotton farming on freshwater resources in Ethiopia, Zerihun et al. [18] found that there was a mismatch between water availability and water needs, with cotton largely being grown in areas where water scarcity is rampant. The government's sustainability plan sought to mitigate this scenario and boost cotton production in the country by increasing acreage in areas such as Omo, Abay and Mereb where water resources are more abundant [18]. This scenario replicates itself across the sub-Saharan Africa region. In West and Central Africa, a region that supplies 12–15% of the region's cotton fibre, the past decade has seen a sustained decline in yield, with diminishing water resources being one of the major culprits [19]. In South Africa, the availability and demand for water show an increasing mismatch. In the Limpopo basin for example, where a vast agricultural infrastructure exists, peak demand for cotton happens between July and November which is also the period when the basin is at its driest. As a result, over 52% of the Limpopo River's flow is abstracted to support the farming of cotton and other crops [14]. In Ghana, an environmental study found that the construction of dams for irrigation disrupted both upstream and downstream river ecosystems, leading to far-reaching negative implications on the water security of populations in those areas [20]. Equally, many irrigation-driven cotton projects in Africa are sustained by breaching environmental flow and are thus detrimental to the environment.

Aside from diverting water resources, the processing of cotton, as with other textiles introduces dangerous pollutants in freshwater bodies. The pollution of water resources by the cotton production chain starts during the cultivation stage. Herbicides and fertilizers used during the growing of cotton as well as chemicals used in processing eventually leach into waterways. This has the effect of further diminishing water resources because it makes available water unusable. Cotton is a pesticide-intensive crop. Cotton crop accounts for 6% of global pesticide use, and in sub-Saharan Africa, that figure rises to 50% [4]. A global study on the effects of fertilizer use in cotton farming on water quality found that Mali had some of the highest pollution rates. With the primary varieties being nitrogen-based fertilizer, the country's cotton

industry leached more than 1500 tons of contaminated water into the environment [15]. Nitrogen compounds contamination is associated with a wide variety of effects including bacteria balance and neurological diseases.

The curing of cotton fibre and dyeing of fabric requires the use of complex chemicals that are extremely harmful to human and animal life. These include chemicals like cyanide, sodium compounds, heavy metals and organic compounds. Sub-Saharan countries have lower approval and enforcement standards for effluent treatment which means that these chemical agents are highly likely to end up in waterways that are used for drinking water. In the Nigerian Lagos region, one of the most polluted zones in the world, textile manufacturing has been attributed as one of the most important contributors to the problem [21]. Similar effects have been observed in other regions. In Tanzania, the Msimbazi River was found to have a pH of up to 12, with the main culprit being jeans-making companies that release their effluents untreated into the river [22]. In Ethiopia, an ecological study sponsored by the government found that a thriving textile industry along the Borkena River was responsible for over 70% of metal effluents in the river despite coexisting along with a host of other industries such as steel mills, a brewery and meat processing plant that have more water usage in absolute terms [23]. These cases illustrate the harmful effects that the cotton fibre extraction process has on water resources, further compounding the hiving of water resources that the cultivation process creates.

SUSTAINABLE AND ALTERNATIVE METHODS

Whereas cotton production in other regions, primarily in developed countries, has largely moved towards sustainability by optimizing water use, sub-Saharan Africa has largely remained stagnated. For example, according to a report by the WWE, irrigation-dependent cotton farming in the United States has improved water efficiency by 75% in the last two decades [24]. This has been enabled by a combination of developments including the use of drip irrigation, seed improvement technology, and changing to more productive strains. Aside from a slow start in adopting technology, sub-Saharan Africa has also been hesitant to start growing improved cotton varieties because of the belief that they are harmful. According to Marquardt et al. [7], only eight sub-Saharan countries had adopted genetically modified cotton by 2018, accounting for just 9% of their joint production. Meanwhile, countries outside sub-Saharan Africa had a 90% adoption rate of GM cotton in 2020. There must be interventions at all levels of the cotton supply chain, which is illustrated in figure 3.

Genetically modified cotton

GM cotton has been in use around the world for many decades. The concept of genetic modification allows for the production of varieties that are more resistant to several hostile conditions such as water scarcity, pests and temperature variations. In sub-Saharan Africa, there has been a lag in the adoption of GM cotton, with the few countries that have done so leaning towards pest-resistant varieties. Most of the top producers in the region including Mali, Cameroon, Burkina Faso and the Ivory Coast have banned genetically modified cotton. Those that permit GM cotton such as Kenya, South Africa, Malawi and Eswatini grow cotton at a lower production rate. Currently, there are three types of GM cotton that are available commercially. The first type, insect-resistant (IR), is genetically coded to handle toxins from Bacillus thuringiensis. The second type is herbicide tolerant (HT), which tolerates compounds such as glufosinate, glyphosate, and dicamba at a much higher concentration rate. The third type is a combination of these two attributes [7].

Organic cotton

The growth of organic cotton has been a highly advocated step that is now proliferating across sub-Saharan Africa. Initiatives such as Cotton Made in Africa (CmiA), Better Cotton Initiative and Organic Cotton Accelerator have been active in many countries setting standards and activating preference among farmers towards organic cotton. These initiatives are aimed at encouraging the growth of organic cotton by providing incentives to farmers. They largely discourage farmers from using genetically modified cotton and irrigation as well as a host of synthetic pesticides. Among the incentives that farmers receive include improved seeds, higher prices and exclusive access to select markets worldwide. Organic cotton is beneficial to the water ecosystem because it limits the use of pesticides and fertilizers, thereby limiting the pollution of waterways. The variety has shown promise when executed according to stringent standards that ensure every input is provided accurately. In Benin, farmers who converted to organic farming experienced a 50 percent leap in yield per hectare with costs dropping by up to 30 percent between 2017 and 2019 [7]. While this initiative was done in a highly controlled case study, organic cotton generally yields lower output than conventional cotton. In Zimbabwe and Senegal for example, the yield was observed in another study to reduce by 10 to 20% when farmers switched to organic cotton. However organic cotton fetches consistently higher prices and this more than offsets the yield gaps. Globally, the demand for cotton is increasing by 20% annually as multinational brands seek to position themselves as embracing environmental sustainability [24]. As such, organic cotton is one of the solutions that poor farmers in sub-Saharan Africa should be looking towards in protecting their local water resources. Aside from the cultivation stage, various organic cotton strains have benefits that cleanse the processing and fabric production stages. For example, naturally coloured cotton strains such as Tanguis and Peruvian Pima reduce the need for dye application. According to Radhakrishnan [3], naturally coloured cotton does

better under organic growing conditions, thereby making it advantageous throughout the cycle. It also requires less water and other inputs.

LOOKING TO THE FUTURE

How the issue will evolve

It appears that different profiles of farmers will benefit from unique cotton-growing approaches. For the longest time, Sub-Saharan Africa has been held back by lower technological prowess exacerbated by a lack of economic resources. In its clamour to improve its cotton production, solutions that have worked in other regions are ill-suited to the region. Irrigation becomes a poor fit because of the water-scarce nature of the sub-Saharan region. The solution for intensification of cotton yield for Sub-Saharan Africa has to be different from what other regions have actuated. In areas where rain-fed cotton farming is applied, organic farming seems to be the most viable alternative since the price differential for organic cotton compensates farmers for potentially lower yield over conventional cotton.

As shown in figure 2, the cotton exports for West Africa's major cotton-growing countries have been on the rise for the past five decades. However, as a percentage of total global water consumption for cotton processing, Sub-Saharan Africa's impact is negligible. 90% of the cotton produced in sub-Saharan Africa is destined for export [24]. This means that currently, the processing happens elsewhere and thus it helps to spare the region of most of the pollution that is associated with the processing of cotton fibre and fabric. In future, as the region develops its industrial capability and local demand for high-quality textiles increases, countries within the region will look to retain much of the cotton processing within the region. As such the water footprint associated with cotton processing will rise alongside that of cultivation. This reality further contextualizes the problems that the cotton industry will continue to pose to Africa's freshwater resources. The entire sustainability push for the cotton industry will require a multi-pronged approach that arrests the effect at different stages of the cotton production chain. Such an approach should be cognizant of the varied scenarios that farmers across the region and within individual countries face and seek to optimize their yield according to their unique challenges.

Optimising the cultivation stage

Because sub-Saharan Africa's cotton crop is mostly rain-fed and hand-cultivated, there has generally been a lower effect on the environment as compared to other regions that do more intensive farming reliant on irrigation. Many governments have been looking to move towards large-scale irrigation as a way to increase their countries' cotton yield but this poses the threat of competition for already limited water resources. Rain-fed cotton cultivation generally has a lower impact on water resources but has a much lower yield than irrigated cotton. The biggest obstacle to intensification remains the fact that most farmers in sub-Saharan Africa are resource-poor, thereby denying them the ability to fund improvements and endure disruptive effects that new technologies and farming techniques may temporarily bring about [25]. Further, low-tech interventions such as mulching which helps to increase water retention and percolation to plant roots have largely been underutilized [11]. The blueprint for sustainable water use in arid Africa has largely been anchored on increasing water retention while reducing evaporation to make the best of erratic rains.

Water harvesting has been advanced as a potential solution to water shortages in areas where rainfall is limited and highly seasonal without increasing the

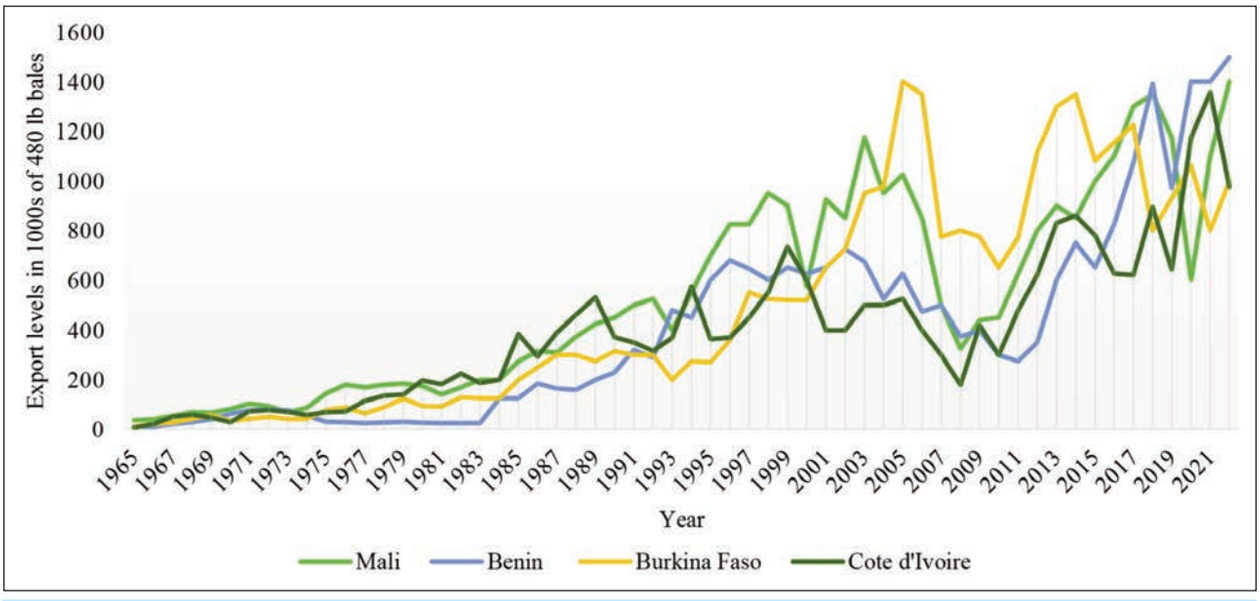

Fig. 2. Cotton exports of selected West African countries
(*Source: https://www.indexmundi.com/agriculture/?country=ci&commodity=cotton&graph=exports*)

negative footprint on water resources. Cotton is a crop that can benefit greatly from this approach. In one study conducted in rural Tanzania, water was harvested and stored in underground pits and water pans and then redirected to farms during the dry season. The result was a much higher maize yield, reaching up to 400% of normally cultivated farms [11]. Similar results can be expected by smallholder cotton farmers who are dependent on highly erratic rainfall to water their cotton crops.

These low-tech methods are highly suited to organic cotton growth but their implementation is reliant on the presence of bodies that provide incentives, without which farmers would have to take on great losses in revenue. GM cotton on the other hand is resource-intensive and is best suited to farmers who have access to funds and sophisticated equipment. While it is highly effective in increasing yield in North America and parts of Asia, genetically modified cotton has been implemented through high rates of mechanization, automation and complex monitoring tools. GM cotton is designed to optimize the uptake of resources such as fertilizer, therefore improvement in yield is contingent on the maximum provision of these resources. In India for example, there has been a very high cost associated with switching to GM cotton. The costs rose by 78%, 245%, and 158% for seeds, fertilizer and insecticide respectively. Overall, the production cost of Bt cotton rose by 143% [7]. A similar survey conducted in Mexico showed comparable increases in the cost of inputs with a concurrent 80% increase in cotton production since GM cotton was introduced in the country in 1996 [26]. At the same time, 40% of farmers who were surveyed indicated that they would be willing to return to conventional cotton if the option was available to them. This method is therefore not suitable for smallholder farmers in sub-Saharan Africa.

Ultimately, the solution for sub-Saharan Africa's cotton farming intensification efforts will require that government and private stakeholders invest in the more technological aspects of the crop while smallholders gravitate towards organic crops. Even then, large-scale cultivation projects will be operating in a highly constrained environment because of the scarcity of water resources. As such, any increases in irrigated land for cotton will have to operate within these constraints through several methods such as locating irrigation projects in areas with underutilized water resources. The Zambezi Basin in Southern Africa, the Congo Basin in the DRC and the Tana and Athi Basins in Kenya are some of the areas that have underutilized water resources that can support the expansion of high-tech and irrigation-dependent cotton growth without putting excessive pressure on water resources.

Mali has been one of the adopters of organic cotton in Sub-Saharan Africa. However, adoption has been negligible, accounting for only 200 tons out of the country's total annual yield. According to Westerberg et al. [27] some of the additional low-tech solutions that farmers in Mali have adopted include agroforestry practices, rotation with legumes and grazing of cotton residues to livestock. Mali exports more than 95% of its cotton, with China, India and Bangladesh being the main destinations. The country currently aims to increase the local consumption of cotton, with the government looking to process 10 to 25% of locally-grown cotton. What this indicates is that more of the crop's water footprint will be felt within the country, a problem that many of the other countries in sub-Saharan Africa will also face (figure 3).

Dealing with wastewater

In the processing phase, one of the most harmful effects is the release of effluents from dyeing and other cotton fibre treatment processes. Samsami et al. [28] explore several viable processes for treating wastewater from dyeing. These include membrane technology, nano-filtration, adsorption and biological methods. A variety of these methods are used in different regions outside Africa but none of them are

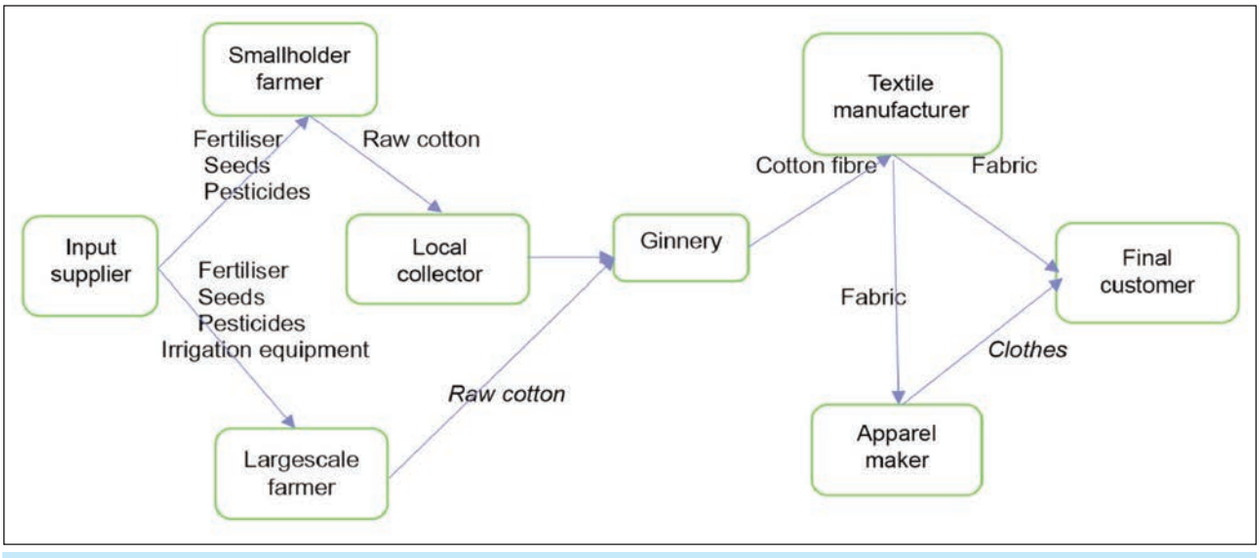

Fig. 3. Cotton industry value chain in West Africa

wholly effective in eliminating chemicals, particulate matter and biological agents. Instead, a hybrid method combining two or more methods has been shown to create be much more effective at decontamination. Therefore, such methods should be explored by sub-Saharan African countries more intently to provide sustainable solutions to the inevitably rising industrial activity surrounding cotton. A similar review conducted by Georgiou and Aivasidis [29] found cost-effectiveness to be a major obstacle to implementing many of these processes. On their own, each of these methods was not able to completely decontaminate water or remove discolouration, therefore there is a need to combine different methods as well as for further research and innovation surrounding the problem of water contamination by the cotton industry.

In a comparative study, Babu et al. [30] found a combination that started with electrochemical oxidation before performing biological treatment was effective at removing dyes and organic compounds. In addition, the process could also incorporate a photochemical treatment at the end to remove microbial life, though, with cotton processing, this is not a big priority. Babu et al. [30] also found that this chain presented the most cost-effective method since it does not involve a lot of complicated technology. As Awomeso et al. [31] assert, the government has a role in closing the loopholes that exist through the lax application of environmental laws that allow companies to pollute at will. This is an area of the cotton sustainability effort in that the government has a power monopoly and farmers have very little sway. At the same time, water recycling can help reduce water use by minimising the amount of water that is directed from rivers and other freshwater bodies. Overall, there is a need for sub-Saharan cotton projects, both small-scale and large scale to close loopholes that lead to inefficient water use. This effort encompasses solutions ranging from efficient irrigation methods to water recycling.

CONCLUSION AND RECOMMENDATIONS

As a region that is hungry for economic development, sub-Saharan Africa's priorities require a tough balancing act between increased resource exploitation and environmental sustainability. This reality faces the cotton industry. Increased cotton production is a vehicle for lifting people out of poverty but at the same time jeopardizes clean water resources that are already ravaged by unsustainable exploitation and the growing threat of climate change. Pegging economic development to activities that further the depletion of important basic resources poses a paradoxical scenario for countries in the region. Essentially, the dual challenge of climate change and rising water demand raises a dire challenge for sub-Saharan Africa's sustainable future. Cotton cultivation and processing as a pillar of economic empowerment for rural economic sustenance and transformation cannot be disputed. Therefore, upending the crop from existing farms is not a prudent direction to take. Instead, there is a need for greater adoption of technology including mechanized farming methods, and improved seeds that increase yield without necessarily increasing pressure on the water resources that are already used today.

This essay recommends a multipronged approach to preempting the damage that cotton could precipitate in future for sub-Saharan Africa. In summary, the solutions include:

- Encouraging organic cotton among smallholders: organic cotton is cheaper to grow and is less impactful on water resources. While producing a lower yield, it fetches higher prices in some markets and the net result is higher income for farmers. The key to the successful implementation of organic cotton farming lies in the utilization of sustainable raw materials in the entire production lifecycle. Continuing projects in various countries have shown positive impacts in both environmental aspects as well as improving quality of life. In Turkey, some researchers showed that organic cotton reduced the leaching of fertilizer residue into freshwater resources. Equally, a pilot study in Meatu, Tanzania found great improvement in cotton yields, while also facilitating extensive positive socioeconomic reforms.
- Strategically placed irrigation projects: because modernization of cotton farming is still highly relevant, government and large private entities need to invest in irrigation but in a sustainable way that only utilizes water resources in areas where they are not at immediate risk of depletion. Currently, many cotton irrigation projects are placed in suboptimal locations where their activities are highly disruptive of local livelihoods through their impacts on water resources.
- GM Cotton: the use of GM cotton can help increase yield without the need for increased acreage that would threaten wetlands. The use of GM cotton has consistently shown neutral to strongly positive increases in yield in areas where it has been implemented. In Mexico for example, Rocha-Munive et al. [26] switching to Bt cotton yielded up to 80% increases in yield per hectare without any additional strain on water resources.
- Waste water management: ending the practice of water contamination by cotton factories releasing effluents into rivers could ease the destruction of water resources. Developed countries like the USA have put into place stringent water use laws that have significantly arrested pollution and water wastage from cotton cultivation and processing.

Currently, sub-Saharan Africa's contribution to greenhouse gas emissions through the region's cotton-related activities including cultivation, transportation and processing is negligible and this will remain the case at least for the foreseeable future. However, governments need to start looking at possible models of minimising that tenet of environmental impact because it also has a bearing on the availability of water resources.

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The effect of dyeing tubes' structure on the colour difference of yarns

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ŞİMŞEK GÜNDÜZ GONCA

ABSTRACT – REZUMAT

The effect of dyeing tubes' structure on the colour difference of yarns

In the study, the effect of the structure of the dyeing tubes used in bobbin dyeing on the colour difference of the yarns was investigated. For this purpose, dyeing was done using 5 dyeing tubes with different dye permeability. Yarn samples were taken from the inner, middle and outer winding layers of the dyed bobbins. The colour difference of the yarns was measured with a spectrophotometer. It was observed that as the dye permeability of the dyeing tubes increased, the colour difference decreased and a more homogeneous dyeing was obtained. When the bobbins were evaluated in terms of diameter, it was seen that the colour difference was at least in the middle diameter. As the dye permeability increased, the colour distribution along the bobbin diameter became more homogeneous. In addition, it was determined that the colour difference decreased in fine yarn and high winding density.

Keywords: *bobbin dyeing, dyeing tubes, useful surface coefficient, winding density, colour difference value (ΔE)*

Influența structurii tuburilor de vopsire asupra diferenței de culoare a firelor

În studiu, a fost investigată influența structurii tuburilor de vopsire utilizate în vopsirea bobinelor asupra diferenței de culoare a firelor. În acest scop, vopsirea s-a realizat folosind 5 tuburi de vopsire cu permeabilitate diferită a coloranților. Au fost prelevate mostre de fire din straturile de înfășurare interioare, mijlocii și exterioare ale bobinelor vopsite. Diferența de culoare a firelor a fost măsurată cu un spectrofotometru. S-a observat că pe măsură ce permeabilitatea la colorant a tuburilor de vopsire a crescut, diferența de culoare a scăzut și s-a obținut o vopsire mai omogenă. Când bobinele au fost evaluate din punct de vedere al diametrului, s-a evidenţiat că diferența de culoare s-a observat cel mai puțin în diametrul mijlociu. Pe măsură ce permeabilitatea coloranților a crescut, distribuția culorii de-a lungul diametrului bobinei a devenit mai omogenă. În plus, s-a evidenţiat că diferența de culoare a scăzut în cazul firelor fine și cu o densitate mare de înfășurare.

Cuvinte-cheie*: vopsirea bobinelor, tuburi de vopsire, coeficient de suprafață util, densitate de înfășurare, valoarea diferenței de culoare (ΔE)*

INTRODUCTION

Dying the yarns in bobbins is a more suitable method in terms of technical and economic compared to other dyeing methods. The positive aspects of this method are that the yarns can be sent to the weaving without any additional processing after dyeing, that large lots can be dyed at once, that it can work at low chemical substance ratios, and that all kinds of fibres can be dyed with all kinds of dyestuffs in HT type boilers. Various parameters affect the dyeing of yarns in bobbin form. These parameters are related to dyeing (type and quality of dyestuff used, temperature of dyeing solution, circulation rate and method of dyeing solution, pumping pressure, technical parameters of dyeing device), those related to the quality of the winding structure of the bobbins (density, unevenness), structure of the tubes are grouped as (the shape of the tubes face, the shape and number of the holes in its face, and the size of the area of the holes) [1].

In a study examining some dyeing parameters affecting the dyeing process of yarns, it is said that unidirectional dye solution flow causes uneven dyeing. For smooth and optimum dyeing results, inside-out and outside-in circulation of the dyeing solution should be provided [2]. Pump speed affects the painting's unevenness. In bobbin dyeing, pump speed and circulation time should be adjusted according to yarn count and bobbin density [3, 4]. In the mathematical model developed by Guelli Ulson de Souza et al., the dye concentration in the dyeing bath liquid outside the bobbin, the dye concentration in the bath liquid surrounding the yarn but inside the bobbin and the dye concentration in the yarn were defined. The mathematical model has been shown to have good accuracy when compared with the experimental results. Thus, the consumption of dyes and other auxiliary materials required for the dyeing process will be minimized [5]. Mancusi et al. described the bobbin dyeing process with a set of time-dependent partial differential equations that govern the convection, distribution and adsorption of dye in the dyebath and along the bobbin threads. The flow direction inside the bobbins was periodically reversed and investigated by applying periodic forcing. It has been stated that the periodic change in the flow direction does not affect the regime profile. Still, the reverse process plays an important role in the dye distribution

at the beginning and provides a better dye distribution [6].

In a study examining the winding structure in the dyeing of yarns in bobbins, the rise angle of the yarn during winding, the winding cross angle, the winding density, the type and count of the wound yarn, the winding type, the shape and dimensions of the winding structure were determined as the important parameters that determine the winding structure. It is shown that when the yarn tension increases during winding, the bobbin density increases, the variation of the winding stiffness along the diameter of the bobbin decreases linearly, and the winding stiffness is higher at the edges of the bobbin compared to the middle [7]. Belforte et al. determined the winding angle and yarn tension as basic parameters during the winding process. Higher winding angle values help maintain the bobbin shape. Higher yarn tension values ensure that the package shape is maintained after the dyeing cycle. It has also been shown that applying a variable tension during the winding process is not beneficial [8]. Colour values were measured by dyeing the bobbins wound at a certain winding density, winding pressure, winding speed and winding angle values. It has been determined that the degree of colour uptake in these regions is different by winding the yarns at different tensions in the inner-middle and outer regions of the bobbin [9]. Soft hardness values of dyeing bobbins are important in terms of dyeing efficiency and errors in bobbin dyeing based on inside-out and outside-in solution circulation. The winding density varies along the length and diameter of the bobbin. Density increases along its length at the edges of the bobbin relative to its middle part, and along its diameter, with the inner diameter of the bobbin relative to its outer diameter. Abdelkader studied the variation of density along the length of the bobbin. He made recommendations for reducing the density variation [10]. The quality of the winding process is an important factor affecting the yarn dyeing quality and efficiency. Çalhan et al. designed a system to provide high-quality and reproducible staining. For this, they used 3D printing and image processing techniques. With the designed system, the bobbin winding densities were calculated, the difference between the windings was determined and production was started [11]. The structure and properties of the yarns produced with different spinning systems affect the colour efficiency in bobbin dyeing. Özdemir and Oğulata produced ring compact, open-end rotor and vortex (MVS) yarns in different yarn counts by using 100% cotton from the same blend. They measured the hardness values by obtaining dyeing bobbins with a constant density (370 g/dm^3) from the yarns. They stated that the stiffness of dyeing bobbins formed with vortex yarns is lower than ring, compact and rotor bobbins. It has also been shown that the effect of the spinning system on the package stiffness is statistically highly effective. In other words, the bobbin stiffness values of the yarns produced according to different spinning systems, which are wound at the same density value, are different. For this reason, it has been concluded that, in addition to the bobbin density, the bobbin hardness value is an important parameter for smooth and easier circulation of the solution, reaching the desired colour values, and preventing dyeing errors such as inner-middle-outside colour difference [12, 13]. Özdemir and Oğulata investigated the effects of different structures and properties of yarns produced by ring, compact, rotor and air-jet (vortex) spinning systems on the bobbin dyeing colour efficiency. For this, bobbins formed by winding on perforated plastic dyeing tubes according to the soft winding principle with a density of 370 g/dm^3 were dyed. It has been shown that under the same conditions, vortex and rotor yarns can be dyed darker than ring and compact yarns [14]. Özdemir and Oğulata tried to determine the relationship between dyeing differences and parameters affecting dyeing unevenness. The parameters affecting the colour difference values in bobbin dyeing were considered as material parameters (yarn count, bobbin density) and machine parameters (pump rotation, circulation time and temperature gradient). The colour difference values of the bobbin were estimated by performing linear multiple regression analysis with these parameters. In the dyeing and analysis results, it was observed that the colour difference values of the bobbins wound with thin threads were lower than those of thick threads. In addition, it was determined that the colour difference values increased as the bobbin density increased [15].

In a study in which the structure of the tubes in the dyeing of the yarns in bobbins was examined, the amount of energy consumed by dyeing at different pressures was examined. When the pump pressure is increased, more energy is consumed. Considering the colour values, it has been shown that dyeing with tubes with high paint permeability will reduce the pump pressure and save energy [16]. Fettahov et al. reported that the amount of dyestuff can be reduced by 10–15 % by using tubes with a high dye permeable area [17]. In addition, it has been shown that the colour difference along the winding diameter is lower in tubes with high dye permeability [18, 19]. Mahmudova states that the amount of yarn waste also decreases in dyeing made with tubes with a high dye permeable area [19].

Dyeing tubes differ according to the material they are produced, their shapes, sizes, the structure of the face, as well as the shapes, sizes and placement of the holes on the face. Plastic and steel tubes according to the material they are produced, conical and cylindrical tubes according to their shapes, rectangular, square, triangle, circle, ellipse and other geometric shaped perforated tubes according to the shapes of the holes on the face, tubes with equal and uneven distribution according to the placement of the holes on the face, can be classified as smooth and ribbed tubes according to their form [1, 20]. When the litera-

ture is examined, it has been seen that there are few studies investigating the structure of dyeing tubes. Unlike other studies, for the first time, experiments were carried out using 5 dyeing tubes with different dye permeability. Thus, the effect of the structure of the dyeing tubes on the dyeing of the yarns in bobbin form was examined in a systematic and detailed way, contributing to the literature.

MATERIAL AND METHOD

Material

The bobbins made of 100% cotton yarns of Ne 30 and Ne 50 from the same blend were dyed with reactive dyestuff. Bobbins were formed by winding on 5 dyeing tubes with different dye permeable areas. The dyeing tubes used in the study are shown in figure 1.

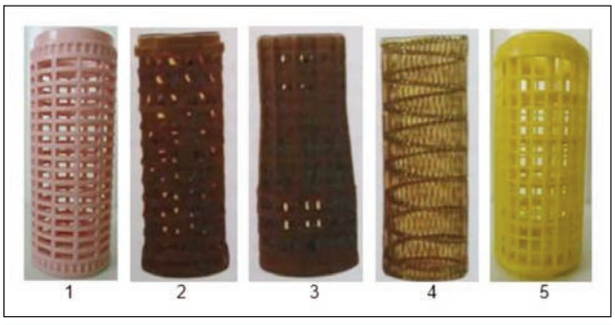


Fig. 1. The dyeing tubes used in the study

The useful surface coefficient (USC), which expresses the paint permeability of the tubes, was calculated with the help of equations 1 and 2 given in the study of Fettahov et al. [1]:

$$USC = \frac{SD}{SG} \quad (1)$$

$$USC\% = 100 \cdot \frac{SD}{SG} \quad (2)$$

where *SD* is the sum of the hole areas on the tube's face and *SG* is the general area where the tube's face is covered with wrap.

Again, considering the dyeing tubes classification made in the same study, the dyeing tubes used were classified (table 1).

In bobbin dyeing, cylindrical tubes with smooth surfaces and uniformly hole-distributed plastic material, indicated by number 1, are mostly used. In rib tubes indicated with numbers 2 and 3, the wound yarn does not sit directly on the holes. A certain gap remains between the tubes and the lower surface of the winding and the contact area of the dyeing with the winding face increases. The flex tube shown with the number 4 consists of two layers of surfaces, and therefore, the dye solution passing through the first layer with a large gap can easily pass to the yarn wound on the second layer. The high-performance plastic dyeing tube, numbered 5, is the dyeing tube with patent number EP 2083106 A1, produced by increasing the surface transfer area [21].

Table 1

CLASSIFICATION OF DYEING TUBES

Number	Dyeing tubes type	Useful surface coefficient	
		Ratio	Percentage
1	Smooth plastic cylindrical tube	0.44	44
2	Circular rib plastic cylindrical tube	0.34	34
3	Plastic conical tube with ribs along its length	0.30	30
4	Flex tube	0.68	68
5	High-performance plastic dyeing tube	0.82	82

Method

Before the dyeing process, dyeing bobbins were created by soft winding at a fixed bobbin density (0.36 g/cm^3 and 0.40 g/cm^3) using two different counted yarns. At this stage, the SSM TW2-W Digicone cross-winding machine was used. All of the test bobbins have the same diameter and were prepared as 15 cm. The yarn count parameter can affect colour difference values. For this reason, the averages of the number values of the yarns wound on the tubes were compared and it was tested whether the difference between the averages was significant at a certain confidence level. For this purpose, one-way analysis of variance was performed. The results of the analysis are given in table 2. As can be seen from the table, the differences between the levels of the yarn count factor are not statistically significant (P>0.05).

Table 2

RESULTS OF ANALYSIS OF VARIANCE

Factor	Dependent variable	Mean	P
Bobbin (Ne 30)	Count	29.50	0.537
Bobbin (Ne 50)	Count	50.35	0.461

The dyeing of the bobbins was carried out in the Thies brand HT bobbin dyeing machine with a machine capacity of five bobbins. By keeping the dyeing parameters constant, the dyeing process was repeated 3 times for each group and a total of 60 bobbins were dyed. The dyeing prescription is given in table 3 and the dyeing graph is given in figure 2.

After drying, all samples were conditioned under standard atmospheric conditions (20±2 °C and 65±2% humidity) so that moisture differences do not cause incorrect evaluations in the colour value. In bobbin dyeing, dyeing evenness is evaluated by measuring the colours of the yarns taken from different diameters of the bobbin. For this reason, the colour difference value was measured along the diameter of the

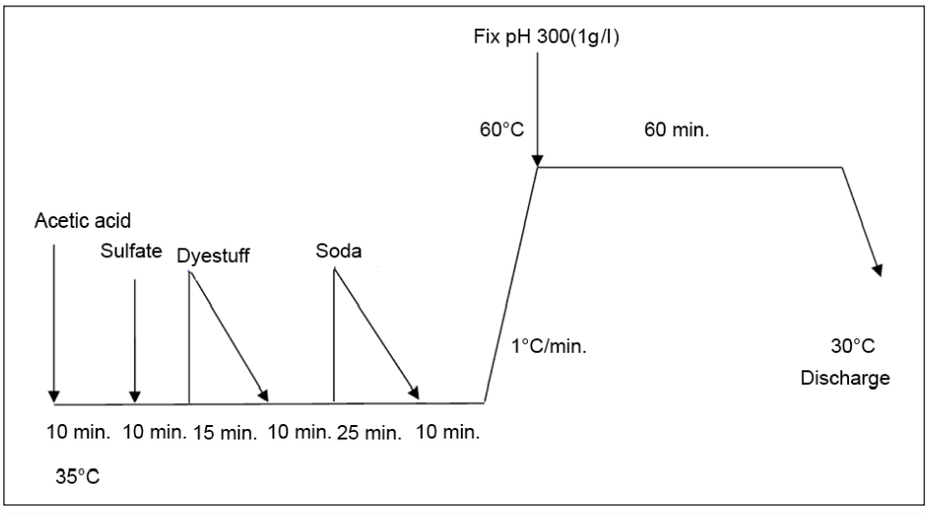


Fig. 2. Green colour dyeing graph

Table 3

REACTIVE DYESTUFF DYEING PRESCRIPTION

Colour	Dyestuff	Dyestuff (%)	Salt (g/l)	Soda (g/l)
Green	Levafix yellow CA Levafix red CA Levafix blue CA	0.66 0.025 0.78	40	12

bobbin in the study. To be able to measure the colour, first of all, the yarns were wound on cardboards at constant tension, in equal amounts, in a parallel and homogeneous manner. For this, two samples were taken on cardboard papers from the inner, middle and outer winding layers of the middle part of the dyed bobbins according to their length. In the colour difference measurement, the colour value in the outer diameter of the bobbin was accepted as a reference for all bobbins and colour difference values were determined accordingly. Colour measurements were calculated under D65 daylight according to the CIELab formula [22]. Datacolor brand spectrophotometer was used in the study. Microsoft Excel program was used to evaluate the obtained colour differences.

RESULTS AND DISCUSSION

Bobbins formed by wrapping the useful surface coefficient on different tubes were dyed and the colour difference values were measured. Table 4 shows the colour difference values of the bobbins wrapped with Ne 30 yarns in two different densities and the colour difference values of the bobbins wrapped with Ne 50 yarns in two different densities. The colour difference value was measured at different diameters of the bobbins, the inner (7 cm), middle (9.5 cm) and outer (12 cm) diameters. It was observed that the highest average colour difference value in Ne 30 and Ne 50 yarns was obtained with the dyeing tube with a useful surface coefficient of 0.30 in both winding densities, and the lowest average colour difference value with 0.82. At a winding density of 0.36 g/cm^3, the average colour difference value of the 3rd tube is 1.49 times the average of the 5th tube. At a winding density of 0.4 g/cm^3, the average colour difference value of the 3rd tube is 1.87 times higher than the average colour difference value of the 5th tube. In addition, the average colour difference value of the bobbins formed with Ne 50 thread is lower than the bobbins formed with Ne 30 thread. When the colour difference values of the yarns wrapped on all tubes with different dye permeability were compared, it was seen that fine yarns were dyed more homogeneously.

The change graph of the average colour difference depending on the useful surface coefficient of the tubes was obtained with the Microsoft Excel program (figure 3 and 4). As can be seen, the average colour difference decreases as the useful surface coefficient increases. It is seen that the average colour difference values of the bobbins at 0.40 g/cm^3 winding density obtained with Ne 30 yarn are lower than the colour difference values of the bobbins at 0.36 g/cm^3 winding density (figure 3). It is seen that the average colour difference values of the bobbins at 0.40 g/cm^3 winding density obtained with Ne 50 yarn are lower than the colour difference values of the bobbins at 0.36 g/cm^3 winding density (figure 4). When the bobbin winding density increases, the unevenness of the

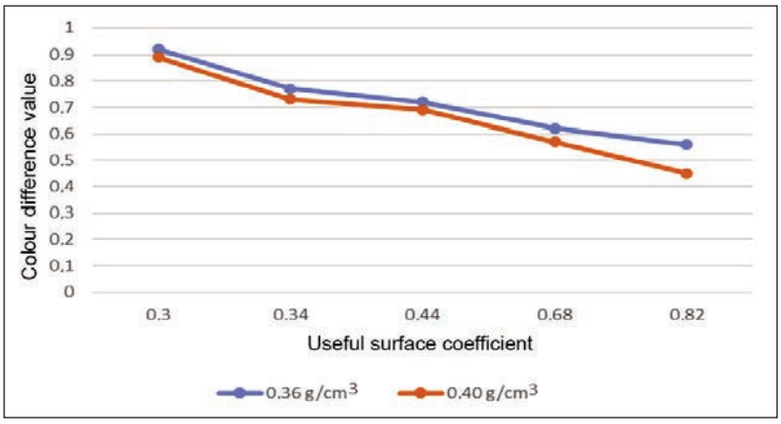


Fig. 3. Change of average colour difference value depending on useful surface coefficient at different winding densities with Ne 30 yarn

Table 4

COLOUR DIFFERENCE VALUES OF DYEING WITH DIFFERENT DYEING TUBES				
Useful surface ratio	**Winding density (g/cm^3)**	**Bobbin diameter (cm)**	**Colour difference ΔE** (Ne 30 yarn count)	**Colour difference ΔE** (Ne 50 yarn count)
0.44	0.36	7	0.73	0.68
		9.5	0.65	0.55
		12	0.80	0.61
0.34	0.36	7	1.03	0.72
		9.5	0.53	0.54
		12	0.75	0.70
0.30	0.36	7	0.86	0.96
		9.5	0.76	0.50
		12	1.14	0.70
0.68	0.36	7	0.68	0.68
		9.5	0.59	0.40
		12	0.61	0.48
0.82	0.36	7	0.57	0.43
		9.5	0.52	0.36
		12	0.60	0.46
0.44	0.40	7	0.69	0.59
		9.5	0.60	0.49
		12	0.76	0.62
0.34	0.40	7	0.98	0.61
		9.5	0.49	0.53
		12	0.70	0.67
0.30	0.40	7	0.82	0.66
		9.5	0.73	0.59
		12	1.11	0.81
0.68	0.40	7	0.56	0.51
		9.5	0.53	0.42
		12	0.63	0.56
0.82	0.40	7	0.46	0.38
		9.5	0.40	0.33
		12	0.49	0.44

winding can be reduced. It is thought that this situation leads to more homogeneous dyeing at a winding density of 0.40 g/cm^3.

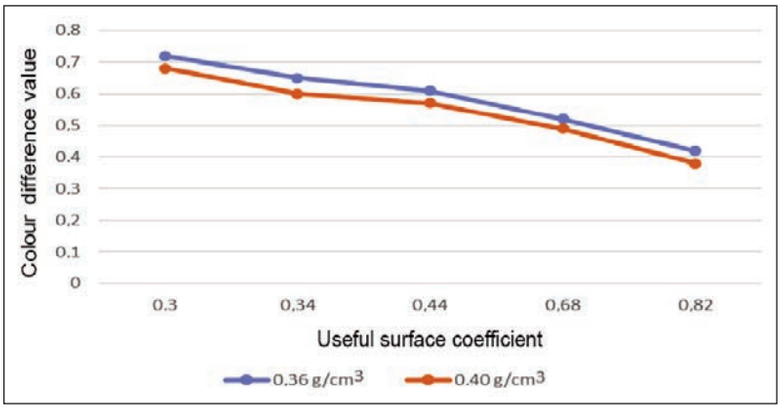
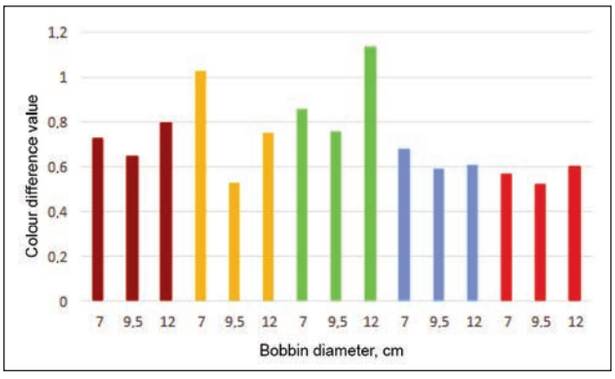


Fig. 4. Change of average colour difference value depending on useful surface coefficient at different winding densities with Ne 50 yarn

In figure 5, colour difference changes are seen along the diameters of Ne 30 yarn bobbins, which are wound on each tube in two different densities. In figure 6, colour difference changes are seen along the diameters of Ne 50 yarn bobbins, which are wound in two different densities on each tube. In the figures, bobbins formed with the number 1 tube are shown in claret red. the bobbins formed with the number 2 tube in yellow. the bobbins formed with the number 3 tube in green, the bobbins formed with the number 4 tube in blue, and the bobbins formed with the number 5 tube in red. When all the bobbins are evaluated, it can be said that the colour difference seen in the outer diameter is higher than the inner



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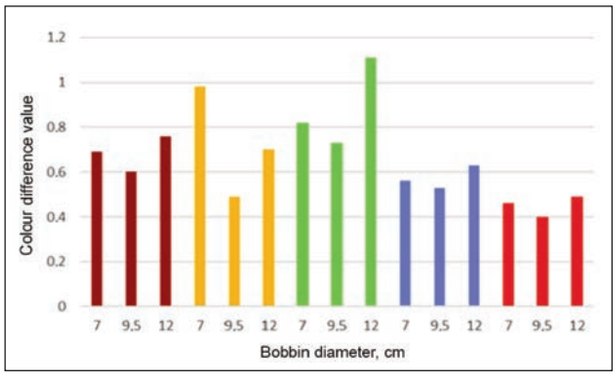
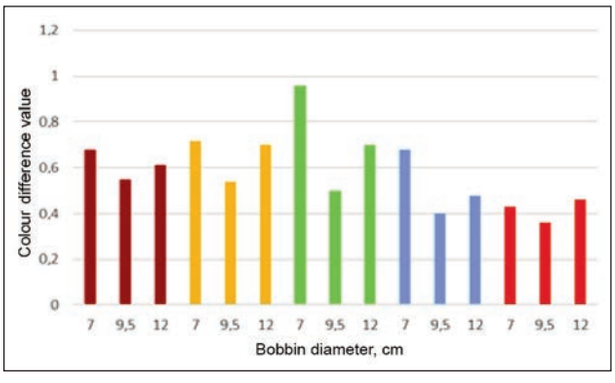


b

Fig. 5. Colour difference change according to the diameter of the bobbins on different tubes: *a* – Yarn count: Ne 30, density: 0.36 g/cm^3; *b* – Yarn count: Ne 30, density: 0.40 g/cm^3



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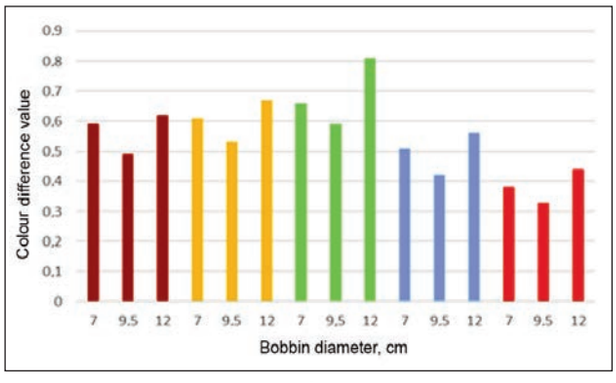

b

Fig. 6. Colour difference change according to the diameter of the bobbins on different tubes: *a* – Yarn count: Ne 50, density: 0.36 g/cm^3; *b* – Yarn count: Ne 50, density: 0.40 g/cm^3

diameter. It was also observed that the colour difference was at least 9.5 cm in diameter.

CONCLUSIONS

The quality of the bobbin winding structure (density. evenness) and the structure of the dyeing tube (the shape of the tube's face, the shape and number of the holes on the face, and the size of the hole area) are important in terms of ensuring that the dye solution is evenly distributed throughout the winding. In the study, bobbin dyeing was carried out by wrapping yarns with different numbers, 0.36 g/cm^3 and 0.40 g/cm^3 winding density, on different dye permeability tubes. The dye permeability of the dyeing tubes used was determined by the useful surface coefficients. The lowest useful surface coefficient was found to be 0.30, and the highest coefficient was 0.82.

The 2.7-fold difference in dye permeability affected the colour distribution. It was observed that as the dye permeability increased, the colour difference decreased and a more homogeneous dyeing was obtained. It is thought that the dyeing efficiency can be increased and the use of dyestuffs can be reduced when the yarns are dyed with dyeing tubes, which have a higher ability to pass the dye solution. Thus, production costs will also be reduced.

It was observed that the colour difference values of the bobbins obtained with Ne 50 yarns were lower than those obtained with Ne 30 yarns. The colour difference decreased when the yarn was thinner. As the yarn gets thinner, the cotton of the same weight is spread over a larger area. Thus, since there will be fewer fibres per unit area, the dye solution will penetrate the yarn more easily. This provides a more homogeneous dyeing. The colour difference values of the dyeing made with a winding density of 0.40 g/cm^3 obtained with Ne 30 and Ne 50 yarns are lower than the dyeing made with a winding density of 0.36 g/cm^3. The bobbins were dyed more homogeneously in the dyeing parameters studied, with a winding density of 0.40 g/cm^3. It is thought that this is because the increase in density may reduce the unevenness of the winding. As a result of the evaluation of the samples taken from the inner, middle and outer diameters of the bobbins, it was seen that the average colour difference values were different from each other. When the colour difference between the inner, middle and outer diameters of all bobbins wound with Ne 30 and Ne 50 yarns in two different winding densities is evaluated, it was observed that the colour difference in the middle diameter was the lowest. In addition, it was determined that the colour difference seen in the outer diameter was higher than the inner diameter. The density of the winding layers

of the bobbin varies depending on the pressure of layers of yarn. Depending on this situation, while there is a more balanced density change in the middle diameter, the density tends to decrease in the outer diameter. The obtained colour difference value results were related to the density variation between the winding layers. By dyeing with tubes with different dye permeability, the amount of dyestuff usage can be compared in later studies and the effect on the cost can be calculated.

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Examining the dependence of textile company performance on macroeconomic variables

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ABSTRACT – REZUMAT

Examining the dependence of textile company performance on macroeconomic variables

The textile sector in India has good fundamentals and has become an interesting sector for equity investors. The performance of textile companies in India is volatile in the market for various reasons. This study aims to examine the dependence of Indian textile company performance on macroeconomic variables. Based on the market capitalisation, the top 10 textile companies were selected as samples for the study, the annual net profit ratio, return on asset ratio, operating ratio and the earning per share data of selected companies were collected from 31st March 2004 to 31st March 2021. For the same period, the Inflation, Crude oil price, GDP of the service sector, GDP of the manufacturing sector and the GDP of the agricultural sector in India were gathered. The results of multivariate regression analysis revealed that the changes in Inflation, GDP from agriculture and GDP from the service sector are affecting the performance of textile companies in India.

Keywords: *textile companies, performance, economic indicators, multiple regression model, EPS, operating profit, return on asset, net profit*

Analiza dependenței performanței companiei textile de variabilele macroeconomice

Sectorul textil din India are baze solide și a devenit un sector interesant pentru investitorii de capital. Performanța companiilor textile din India este volatilă pe piață din diverse motive. Acest studiu își propune să analizeze dependența performanței companiilor textile din India de variabilele macroeconomice. Pe baza capitalizării pieței, primele 10 companii textile au fost selectate ca eșantioane pentru studiu, rata profitului net anual, rata rentabilității activelor, raportul de exploatare și datele privind profitul pe acțiune ale companiilor selectate au fost colectate în perioada 31 martie 2004 până în 31 martie 2021. Pentru aceeași perioadă, au fost colectate inflația, prețul țițeiului, PIB-ul sectorului de servicii, PIB-ul sectorului de producție și PIB-ul sectorului agricol din India. Rezultatele analizei de regresie multivariată au arătat că schimbările din inflație, PIB-ul din agricultură și PIB-ul din sectorul serviciilor, afectează performanța companiilor textile din India.

Cuvinte-cheie: *companii textile, performanță, indicatori economici, model de regresie multiplă, EPS, profit din exploatare, rentabilitatea activului, profit net*

INTRODUCTION

The Indian textile industry is one of the oldest industries. It generates over 33.17 million jobs directly and 54.85 million jobs indirectly. It also has many competitive advantages due to its quota regime [1]. The textile industry has been one of the major contributors to the Indian economy as the second-largest employer after agriculture [2]. It contributes 2% of GDP, 7% of industry output in value [3], 27% to foreign exchange and 5% to the global trade in the textiles and apparel industry [3]. India is the second-largest producer of textiles, with a 6.5% share, after China, with 52.2% [2]. The history of the Indian textile industry goes back to ancient times. Indian industry has grown from a cottage industry to a well-organised, technologically advanced one. India produced the finest cotton, silk, and muslins with the help of abundant raw materials and skilled workers, which were then exported to Europe, creating a huge market and market segmentation [4]. These strong fundamentals of the Indian textile sector have attracted many investors to this sector [5, 6].

However, few studies have stated that the Indian textile industry has a complex structure due to many players independently operating in the industry, like spinning, weaving and knitting. Indian textile companies could not dominate in the global market due to many firms not having enough capacity to meet the demand [3]. The COVID-19 pandemic has worsened the situation [7]. Moreover, many macroeconomic variables influence the performance of equities, commodities and companies. Studies by Kumar et al. [6, 8] stated that the price of crude and other economic variables influence the price of tyre manufacturing companies and rubber-based industries.

A study by Egbunike and Okerekeoti [9] revealed that the GDP and inflation rate have influenced the financial performance of manufacturing companies in Nigeria. The exchange rate, inflation and economic growth have influenced the stock prices of companies in India [10, 11]. The socio-political factors and macroeconomic variables are properly aligned to progress in the economic growth of the country [12]. The GDP and inflation rate influence the exchange rates in developing and developed countries [13]. As crude products are largely used in the textile manufacturing process, the price of crude futures will influence the price of textile equities in India[6]. Above stated literature has revealed that the financial performance of manufacturing companies in Nigeria, the stock prices of companies in India and the exchange rates of several countries are responding to changes in the macroeconomic variables of those countries. However, the study concerning the influence of macroeconomic variables on the Indian textile industry is not covered in detail in the existing academic literature. Hence, it is important to carry out a specific study concerning the influence of macroeconomic variables on the performance of Indian textile companies. With this background, this study aims to examine the dependence of Indian textile company performance on different macroeconomic variables.

LITERATURE REVIEW

The 2008 financial crisis had a significant impact on the Indian textile industry. The financial crisis's immediate impact was on the United States textile industry. This caused the textile industry to diminish consumer spending. The retailers experienced decreased sales, and Apparel imports too declined. As retailers experienced negative sales, global suppliers were also negatively affected [14].

Recently, the Indian textile industry has suffered due to the COVID-19 pandemic. An industry that offers millions of jobs is in trouble due to low sales volumes, economic slowdown, and a lockdown. The apparel sales dropped to a whopping 84%, which is the lowest in recent industry trends. Indian domestic apparel industry was estimated to be US $75 billion in 2020–21, down from US $106 billion [15]. The industry has seen a whopping 30% drop in sales. The above points confirm that any economy's textile business depends on the prevailing economic conditions. The world has suffered severely due to one virus. It had an impact on industry, lifestyle as well as economy. The textile industry is the second largest employer after agriculture, which is severely affected in India [16]. The Indian economy and its growth rate depend on the performances of three different sectors. Agriculture is the primary, manufacturing is the secondary and the service sector is the third. This study aims to examine the dependency of the Indian textile sector on primary, secondary and tertiary sector GDP, domestic inflation and international crude oil prices.

Several studies from the international markets have stated that the performance of manufacturing companies will be affected by various economic indicators. For example, the financial performance of textile companies shows a negative correlation between inflation and the unemployment rate [17]. Structural analysis of company expenses and a comparative analysis of costs proved that financial evaluation is necessary for textile companies [18].

The bivariate or multivariate regressions examine the linkages between financial performance and economic indicators [19, 20]. The study revealed that the financial structure has a significant and negative impact on profitability in terms of ROA and shows a positive and significant impact on the profitability on ROE. Unanticipated crises like a market downturn, radical uncertainties and the global pandemic have put business societies in the competitive stage of sustainability. Technological upgradation helps in innovation and sustenance [21]. Hence in this study, we have used multiple regression models to examine the relationship between the selected macroeconomic variables and the performance of selected Indian textile companies.

DATA & METHODOLOGY

Based on the market capitalisation, the top 5 Indian textile companies have been selected as samples for the study (table 1).

Table 1

MARKET CAPITALISATION OF THE SELECTED TEXTILE COMPANIES IN INDIA

Sl. No	Name of the company	Market capitalisation
1	Page	46,467.54
2	Trident	24,537.03
3	KPR Mill	19,999.54
4	Alok industries	11,295.92
5	Welspun	6,303.81

(*Source: official website of Money control*)

For the selected companies, the annual net profit ratio, return on asset ratio, operating ratio and the earning per share data from 31st March 2004 to 31st March 2021 have been collected from the official website of moneycontrol.com. For the same period, the Inflation, Crude oil price, GDP of the service sector, GDP of the manufacturing sector and the GDP of the agricultural sector in India are gathered from the official website of the Reserve Bank of India (RBI).

Further, this study has used multiple regression analysis methods to examine the connections between the above-stated ratios and selected economic indicators. Multiple regression analysis studies the relationship between the dependent and independent variables. The general presentation of the multiple regression model is shown in equation 1:

$$PT = \beta_0 + \beta_1 GDPA_{1n} + \beta_2 GDPM_{2n} + \cdots + \beta_3 GDPS_{3n} + \beta_4 CP_{4n} + \varepsilon_e \quad (1)$$

where *PT* is the measure of the performance of the textile company, *GDPA* – the GDP from the agricultural sector, *GDPS* – the GDP from the service sector, *GDPM* – the GDP from the manufacturing sector, *CP* – the crude oil price, β_0 – the intercept and the β_1, β_2, β_3, β_4 – the relationship coefficients of textile company performance with agricultural GDP, manufacturing GDP, Service sector GDP and crude oil price, respectively.

ANALYSIS AND DISCUSSIONS

The results of the multiple regression models are presented in table 2. In the developed multivariate regression model, the GDPs of agriculture, manufacturing, service, crude oil price, and inflation are independent variables and the net profit margin, return on asset, Earnings per share and operations profit as dependent variables. The coefficient of 0.07 for the Net profit margin of Page industries with inflation is positively significant at a 95% confidence level. This implies that the net profit margin of the company responds positively to the inflation of the economy. The coefficients of inflation and service GDP for the KPR mill are negatively significant at a 90% level; which indicates that the net profit margin of the KPR mill is negatively correlated with inflation and GDP from the service sector. The GDP_SERVICE coefficient for Trident is also negative at –0.44, which is significant at the 90% level. The goodness of fit of the estimated model can be measured by the statistical values of R-squared and adjusted R-squared, these

Table 1

RESULTS OF MULTIPLE REGRESSION MODEL

Economic Indicator	Alok	KPR Mill	Page	Trident	Welspun
Net Profit Margin					
CRUDE	0.55	–0.02	0.01	–0.06	–0.09
GDP_AGRI	–1.54	–0.36	0.13	0.07	–0.17
GDP_MANUFACTURINGG	1.85	–0.14	0.13	0.15	–0.17
GDP_SERVICE	–2.50	**–0.59***	0.07	**–0.44***	0.30
INFLATION	–0.84	**–0.09***	**0.07****	0.01	0.03
R-squared	0.13	0.60	0.63	0.48	0.41
Adjusted R-squared	–0.23	0.44	0.48	0.24	0.16
Return on Assets ratio					
CRUDE	0.04	0.00	0.05	0.04	0.04
GDP_AGRI	–1.83	**–0.32****	0.14	0.04	–0.31
GDP_MANUFACTURINGG	–2.29	–0.07	0.12	0.00	0.07
GDP_SERVICE	**5.21****	**–0.40***	0.28	–0.23	–0.14
INFLATION	–0.38	**0.07****	**0.14****	0.01	0.04
R-squared	0.54	0.92	0.51	0.47	0.54
Adjusted R-squared	0.35	0.89	0.31	0.23	0.34
Operation Profit					
CRUDE	0.71	0.05	0.01	–0.05	**–0.108***
GDP_AGRI	–0.77	**–0.578****	0.16	0.03	–0.01
GDP_MANUFACTURINGG	–3.53	–0.07	0.23	0.14	–0.09
GDP_SERVICE	0.20	–0.35	0.17	–0.28	0.22
INFLATION	–1.32	–0.01	**0.108****	0.01	0.00
R-squared	0.24	0.57	0.56	0.23	0.28
Adjusted R-squared	–0.07	0.44	0.38	–0.12	–0.02
Earnings per share					
CRUDE	0.31	–0.46	–2.40	–0.03	0.28
GDP_AGRI	–0.36	–1.42	–5.05	0.16	–0.14
GDP_MANUFACTURINGG	–1.46	–2.67	–0.26	0.39	**–2.63***
GDP_SERVICE	0.33	2.29	–8.91	0.28	2.43
INFLATION	–0.59	–0.42	0.61	**0.13***	–0.21
R-squared	0.18	0.25	0.49	0.36	0.38
Adjusted R-squared	–0.16	–0.06	0.27	0.06	0.13

Note: ** indicates significant at 95% confidence level; * indicates significant at 90% confidence level.

values greater than or close to 0.5; this implies that the estimated models for KPR Mill, Page Industries and Trident are a good fit.

The return on asset ratio measures the performance of assets of an organisation. The coefficient of –0.32 for KPR mill with GDP from agriculture in India is negatively significant at a 95% confidence level. This implies that, as the agricultural GDP increases, the return on assets of the KPR mill decreases. The same relationship is evident from the negative coefficient of –0.40 with GDP from the service sector. However, the coefficient of Inflation for the KPR mill is positive and significant at a 95% level. The coefficient of GDP from the service sector to Alok industries is positive and significant at a 95% level. This implies that the performance of Alok industries will increase with the increased GDP from the service sector. The coefficient of Inflation for Page Industries' return on asset ratio is positive and significant at a 95% level. The coefficient of 0.14 implies that the return on asset ratio of the company will increase with the inflation in the economy. The R-squared and adjusted R-squared values for these significant estimates are close to or greater than 0.05, this indicates that the model is a good fit.

Operating profit shows income from the core operations of the business. The coefficient of –0.578 for KPR Mills with GDP Agriculture in India is negatively significant at 95% level. This indicates a negative growth with KPR Mills' operating profit as the GDP of agriculture increases. The coefficient of 0.108 is significant; this shows a positive correlation for Page Industries with Inflation in India. The R-squared and adjusted R-squared values for these estimates are greater than or close to 0.5; this implies that the estimated models for KPR Mill and Page Industries are a good fit.

Earnings per share are calculated by dividing the company's profit by the total number of shares. The coefficient 0.13 is positively correlated for Trident with inflation in India at 90% level, which means growth in inflation will lead to growth for Trident. The coefficient –2.63 for Welspun with GDP Manufacturing in India is negatively significant at the 90% level. This indicates a negative growth with Welspun when the GDP of Manufacturing increases. The R-squared and adjusted R-squared values for these estimates show greater than or close to 0.5; this implies that the estimated models for Welspun are a good fit.

CONCLUSION

Indian textile industry is one of the biggest contributors to employment, GDP and export business of the country. Even though clothing is one of the basic requirements of mankind, the demand, supply and operation performances of textile companies in India are not stable. Because of this, the price and return on textile equities in India are not stable. This study has examined the linkages between the macroeconomic variables and the performance of Indian textile manufacturing companies. Study results indicate that the Inflation in the economy will affect the profitability of the textile companies in India. Particularly, KPR mills, Page Industries and Trident Company's profitability are affected by Inflation. The significant coefficients for GDP from the Agricultural sector proved that the return on assets ratio and operating profit ratio of KPR mill have a negative impact. The significant coefficients for the operating profit ratio and EPS also proved that inflation in the economy does impact the performance of Page and Trident companies' performance. Hence, this study concludes that the performance of Textile Company in India may vary with changes in economic variables like Inflation and GDP of the country. This study may help the textile sector equity investors for their buy and sell decisions in the market. This study contributes to the segment of literature in the field of the textile industry, precisely in India. It is important to understand the dependency of any business on the external variable. Such understanding may help the industry stakeholders in their managerial and investment-related decisions.

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Designers' potential in sustainable fashion: a systematic literature review

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ABSTRACT – REZUMAT

Designers' potential in sustainable fashion: a systematic literature review

Given the unsustainable issues of environmental pollution, resource waste, and industrial cycle blockage, the garment industry, has sought an innovation for sustainable development led by the linear economy. The circular economy (CE) advocates closing and correcting material and energy circuits, minimising resource entry and waste, and improving emissions and energy consumption. Most practices under the existing CE model address the outcome rather than comprehending the source. As one of the most critical players in the apparel industry, designers understand the source of product development. In this paper, existing sustainable design practices (SDPs) in the transition of the apparel industry to CE were summarised through a systematic literature review. The extent of designers' involvement in CE was explored through a correlation study and data analysis between SDPs and the processes of product development (PDP) and production process (PP). Furthermore, the designers' potential to contribute sustainably to the CE transformation within the apparel industry was discussed via qualitative analysis. The findings demonstrated infrequent involvement in PP by designers, whose voices were limited in the apparel industry, and that the possibility of more designer involvement in SDP. Therefore, this research only focused on the sustainability potential of designer-led PDPs. Lastly, the potential and limitations of applying PDP three-dimensional visualisation as a designer-led SDP were presented.

Keywords: *designer, circular economy, sustainability, sustainable design practice, product development process*

Potențialul designerilor în moda sustenabilă: un studiu sistematic al literaturii

Având în vedere problemele nesustenabile ale poluării mediului, ale deșeurilor de resurse și ale blocajului ciclului industrial, industria de îmbrăcăminte a căutat o inovație pentru dezvoltarea sustenabilă condusă de economia liniară. Economia circulară (CE) pledează pentru închiderea și corectarea circuitelor de materiale și energie, minimizarea intrării de resurse și a deșeurilor și îmbunătățirea emisiilor și a consumului de energie. Majoritatea practicilor din cadrul modelului CE existent abordează rezultatul, mai degrabă decât să înțeleagă sursa. Fiind unul dintre cei mai importanţi jucători din industria de îmbrăcăminte, designerii înțeleg sursa dezvoltării produsului. În această lucrare, practicile de design sustenabil (SDP) existente în tranziția industriei de îmbrăcăminte la CE au fost rezumate printr-un studiu sistematic al literaturii. Amploarea implicării designerilor în CE a fost explorată printr-un studiu de corelare și analiză a datelor între SDP-uri și procesele de dezvoltare a produsului (PDP) și procesul de producție (PP). În plus, potențialul designerilor de a contribui în mod sustenabil la transformarea CE în cadrul industriei de îmbrăcăminte a fost discutat prin analiză calitativă. Studiile au demonstrat implicarea rară în PP a designerilor, ale căror voci erau limitate în industria de îmbrăcăminte și posibilitatea unei mai mari implicări a designerilor în SDP. Prin urmare, acest studiu s-a concentrat doar pe potențialul de sustenabilitate al PDP-urilor conduse de designeri. În cele din urmă, au fost prezentate potențialul și limitările aplicării vizualizării tridimensionale PDP, ca SDP-uri conduse de designeri.

Cuvinte-cheie*: designer, economie circulară, sustenabilitate, practică de design sustenabil, proces de dezvoltare a produsului*

INTRODUCTION

The fashion industry is one of the leading international economy sectors, where global transactions amounted to $45 billion in 2016 [1]. As the fashion industry employs more than 300 million people worldwide, it is a significant economic force and a critical driver of global gross domestic product (GDP) [2]. Nevertheless, the fashion industry is the second largest polluter globally with a carbon footprint that exceeds that of all maritime transport and international flights combined [3]. Worldwide, the fashion industry generates approximately 40 million tons of textile waste annually most is sent to landfills or incinerated [4]. Dozens of trends that change products between seasons yearly drive the fashion industry [5], specifically fast fashion. With economic globalisation, the textile and apparel industry can compare the value of raw materials and labour globally and identify the most convenient and profitable channel to grow [6]. Naturally, there are hidden costs behind the high turnover and profitability, such as the unsatisfactory quality of low-priced products. Additionally, the fast-changing fashion styles conceal thousands of overstocked products. Fast fashion popularity also leads to unhealthy use habits [7] and short product lifespan [8].

The World Commission on Environment and Development (WCED) introduced the sustainable development concept in 1987. Sustainable development refers to "the ability to meet the needs of the

present without compromising the needs of future generations" [9]. The goal of sustainability is open, unrestricted, and acting on the environment, economy, and society as a whole [10]. 'Closed-loop recycling' refers to an early sustainability initiative to recycle resources and avoid waste and pollution. Closed-loop recycling is positive but its environmental benefits cannot offset the ecological damage caused by the fashion industry. In an ideal recycling system, recycled textile materials should generate added value rather than increase the energy burden and create secondary waste.

Sustainability has become a critical driver of the future of the fashion industry [2]. In the sustainable fashion brand Stella McCartney, every brand department and aspect is required to focus on sustainability thinking. Sustainability thinking enables brands to achieve the environmental milestones of 2030 (halving carbon emissions) and 2050 (zero emissions) [4]. Thus, sustainability is no longer an option but a path that must be developed, leading fashion brands to consider ethical and social responsibility in their value systems.

The apparel industry has been dominated by the linear economy where linear resources and products flow in one direction to waste [11]. Contrastingly, a circular economy (CE) is a closed material flow loop in a financial system [12] that aims to dissociate economic growth from resource consumption while maintaining the highest value for product components and resource use [13, 14]. The CE seeks to reduce waste generation while increasing resource utilisation, which indicates it is a sustainable development model [15]. The shift in the apparel industry's economic model towards a CE is not a trend but a requirement of market, economic, social, and ecological factors. The CE model prioritises sustainability [16] and advocates maximising the product cycle as a key strategy to extend product sustainability [17]. In the ideal CE, production and energy resources form a closed loop, which enables "using waste as production" [18]. The involvement of all stakeholders in sustainable innovation can lead to a valid CE.

The CE reverses waste use as an essential and sustainable resource [19] where waste generated at various production stages is technologically redistributed and reused [20]. Examples of waste redistribution and reuse include zero-waste practices, second-hand shops, upcycling, chemical recycling [3], collaborative fashion, slow fashion [21], trash fashion [22], and open-resource fashion [23]. For example, zero waste aims to reduce fashion industry resource waste, where raw material waste and pollution are reduced by developing and experimenting with more efficient production processes [14]. Slow fashion refers to slowing product development and production and engaging in small-volume, slow clothing production using local infrastructure, resources, and traditional craftsmanship [24]. Supply chain streamlining is predominantly established locally [18], which encourages local businesses to commit to sustainability through a collaborative sharing approach and collaborating to build local CE models that support green ecology, drive resource- and knowledge-sharing, and promote sustainable diffusion [14]. Reuse (recycling) re-energises production waste, excess products, and waste of various origins (production process residues and technical residues from physical and chemical recycling) through chemical and physical recycling. Long-life design [25] and second-hand fashion both aim to extend product life and increase durability [26]. As an open and shared design philosophy, the open-source design emphasises knowledge-, skill-, and resource-sharing, which renders the industry chain transparent [21] and encourages consumer participation and self-design. Subsequently, the open-source design creates an emotional bond between the product and the consumer and introduces emotional value to the product, thus extending its lifespan.

The CE pioneers developed many sustainable design practices (SDPs), most of which were strategically proposed from the top down by business owners or companies. Eco-entrepreneurs who advocate sustainability from a designer's perspective proposed some practices [27]. Each aforementioned SDP exhibits distinctive characteristics that reflect sustainable approaches to transform the CE from different perspectives. These SDPs consider CE and sustainability based on material use, refined production, post-consumer recycling, and the emotional value of the product.

The study has two recursively related objectives: to (i) study designers' involvement in existing SDPs during the apparel industry transition to a CE and (ii) explore specific directions for designers to create sustainable contributions between the product development process (PDP) and production process (PP). Sustainable garment industry development cannot achieve a valid CE by relying solely on a material revolution and addressing waste. Previous scholars have demonstrated the theoretical possibility of a single-perspective SDP. Nonetheless, some SDPs involve many additional resources and energy exchange in practical application. Designers have little influence on aspects beyond the PDP and PP, such as supply chain and marketing activities [28]. Furthermore, PDP and PP sustainability in the fashion industry should be considered; therefore, deconstructing them from a designer's perspective is vital.

The CE transformation and sustainable development of the fashion industry is a wide-ranging circular system that requires the participation of the whole chain, mutual assistance and collaboration, and completion. The linear development mindset should be abolished to challenge the traditional industrial structure. The traditional linear PDPs and PPs should be separated and the innovation of each link should be discussed individually. In this research, designers' organisational functions and obligations were thoroughly examined. The dissection of various PDP and PP segments aided the examination of traditional industrial process limitations and the discovery of designers' sustainability potential and each link.

RESEARCH DESIGN

The first research layer involved a systematic literature review (SLR). The SLR aids in the identification of the academic literature appropriate to a particular research area and the critical evaluation of the topic. The SLR was used to summarise the SDPs that have emerged in the CE-led apparel industry, deconstruct PDPs and PPs, and discuss the relationship between designers and the PDP and PP aspects. In the first layer, the phenomena presented by the data were discussed using qualitative analysis; subsequently, the second layer was built on the findings. Designers' potential to contribute sustainably to SDPs from the PDP and PP perspectives and specific strategies for designers to engage with SDPs were explored.

Before the articles were read and filtered out, research questions were established for the two research directions (SDP and PDP plus PP). The questions were based on the research objectives to aid the discovery of the objectives in a logical and targeted manner and to improve the literature reading efficiency. The SDP questions are as follows:

1. Who are the proposers of the existing SDPs?
2. What are the specific forms and limitations of these SDPs?
3. Can these SDPs be categorised among themselves at a strategic level?

The PDP and PP questions are as follows:

1. How many processes are included in traditional PDP and PP?
2. Does the PDP in the industry differ based on the business direction?

1. Which individual steps in the PDP and PP are relevant to designers?

Figure 1 depicts the flow chart of the SLR. The first layer targeted three critical areas: SDP, PDP, and PP. An initial literature search was conducted using the keywords (figure 1), which retrieved 91 SDP-related articles and 329 articles related to PDP and PP. Inclusion and exclusion criteria were established to limit the study scope and increase precision and efficiency, which included the aspects of language, publication year, article type, and the relevance of the article level, title, and abstract. The study focused only on English-language literature with the publication date limited to within the last 10 years. The article type mainly entailed review papers while journals and article level were limited to Science Citation Index (SCI) journals and PhD theses, respectively. The articles that were weakly relevant to the study were screened out based on the titles and abstract contents. Finally, 32 SDP articles and 26 PDP and PP articles were included in the analysis.

Snowball research was conducted during the literature reading by expanding the references of articles with greater relevance. Eleven articles in addition to the initial 32 were selected in the SDP direction and six articles in addition to the initial 26 were selected in the PDP and PP direction. The final part of the SLR involved analysing and filtering helpful information from the 75 publications screened. Subsequently, the articles were thoroughly read and analysed to address the research questions. The typical SDP forms were summarised, the essential PDP and PP components were listed, and the results were analysed.

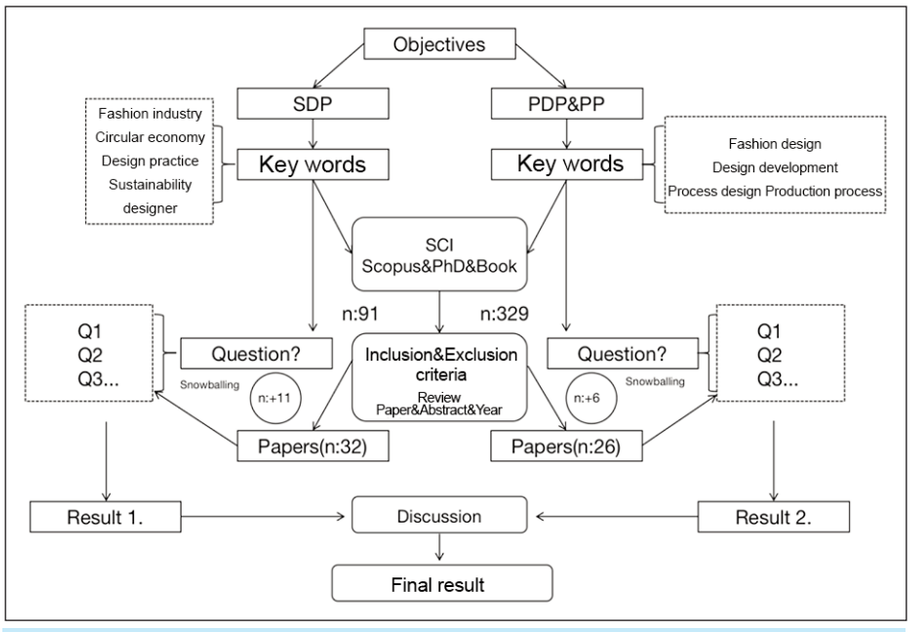

Fig. 1. The SLR flow chart

RESULTS AND DISCUSSION

Elaboration and discussion of SLR results

In this section, the SLR findings are presented, the specific SDP types are summarised, and the strategies and limitations of the proposed SDPs are discussed. The PDP and PP are listed in this section and designers' relevance at each step is discussed. The 17 types of SDPs currently applied in the fashion industry under the CE were summarised based on the literature research (see figure 2). The 17 SDPs are related to four fashion industry segments: product development, production, supply chain, and marketing services (figure 2).

Longevity design [25] and open-source design are ostensibly product development initiatives by a company or business owner and not designers, who are only one of the necessary participants in both initiatives. 'Longevity design' is an overarching term for other sustainable practices [29], which include high-quality design, design for permanence, functional design [18], and modular design [30]. The SDPs in

Serial Number	Sustainable Design Practices
SDP1	Zero Waste
SDP2	Slow Fashion
SDP3	Sustainable Materials
SDP4	Recycle
SDP5	Streamlining Supply Chains
SDP6	Second-hand Fashion
SDP7	Trade-in
SDP8	Rental Services
SDP9	Restoration
SDP10	Longevity Design
SDP11	Quality Design
SDP12	Timeless Design
SDP13	Functional Design
SDP14	Modular Design
SDP15	Open Source Design
SDP16	Collaborative Design
SDP17	Halfway Product Design

Fig. 2. List of typical SDPs in recent years

longevity design aim to extend product life and increase emotional permanence between the product and the consumer [26]. Traditional design concepts that challenge changing fashion aesthetics influence longevity strategies [31]. High-quality design is a designer-proposed sustainable design tool based on garment durability and aesthetic longevity [25]. Designers believe that high-quality design products could lead to consumers viewing their purchase as an investment and even result in a legacy for the product [18]. The difference between timeless and high-quality design is that timeless-design products should be free of season and trend constraints [25]. Therefore, instead of following seasons and trends, the PDP develops a timeless series contemporaneously and places more initiative into supply chain and production optimisation. Nevertheless, timeless design ignores an apparel product function: bringing emotional value to the consumer. Designs that eschew trends and seasons are limited and fail to meet consumers' fashion expectations and demands [32]. Functional design refers to products designed with more inclusive construction. For example, sizes can be added, removed, or adapted to a broader range of seasons. Modular design is a means of extending product life via disassembly into individual groups that can be freely combined to render the product more pleasing to use. While modular design may be feasible for accessories, such as shoes, bags, and jewellery, modular clothing structure is complex.

Open-source design encourages consumer participation in design. For example, Threadless, an online artist community and e-commerce site based in Chicago, USA, is sustainable by providing a supply chain for artists and consumers. The practice encourages each artist to build their community on the platform, publish their work, and facilitate sales. The emphasis of open-source design on participation is aligned with bespoke businesses as it does not apply to traditional industrial product development structures. Collaborative design and halfway product design attempt to create an emotional bond between the product and consumer via consumer involvement, which introduces emotional value to the product and thus extends its lifespan. While consumers can create an emotional bond by engaging with the design, the longevity of this emotional bond and whether it is only a short-term passion challenges the applicability of this SDP.

Zero waste and slow fashion are two SDPs that focus on production processes. Bruna [14] suggested that "zero waste involves innovation in key resources, key activities, and cost structures". Zero waste attempts to maximise the use of every inch of fabric in fashion production via efficient layout and cutting techniques, which leads to near-zero production waste [17] but inevitably extends the cutting bed process and consequently risks reducing productivity. The concrete forms of zero practices are to reduce and improve packaging materials [33] and recycle textile waste. Slow fashion initiatives advocate slowing product development and production to focus on local supply chains and production. The limitation of slow fashion is that companies and brands cannot economically compete with economies of scale where their sales and profits decline with slowing turnover rates [34]. Furthermore, the traditional processes and small production runs for slow fashion products may lead to higher production costs [35]. Despite being cognizant of the importance of sustainability, consumers also expect more economical, fashionable, and high-quality products. Therefore, the slow fashion initiative requires more incentives.

Sustainable materials, reuse, and supply chain streamlining are SDPs that are relevant to the supply chain. In the aforementioned SDPs, the use of biodegradable fabrics, accessories, and packaging use was identified as a promising practice to effectively reduce the apparel carbon footprint. For example, vegan initiatives eliminate animal-based raw materials, furs, and leather given that processing and finishing animal-based raw materials use much energy and generate much pollution [14]. Regardless, even the production and consumption processes for 100% biodegradable materials do not necessarily produce fewer carbon emissions than non-environmentally friendly materials [18].

'Reuse' encompasses recycling and reuse. Recycling strategies include energy recovery and resource recovery and the forms of recycling include mechanical and chemical recycling [3]. For example, textile waste can substitute fossil fuels as a heat and electricity source [26]. Recycled textile waste is shredded to form cloth strips for carpet production. Synthetic materials are chemically treated to refine fibres again [36] and textile finishing waste water is recycled and

purified for other uses. Although emerging technologies can sort recycled fibres by type [37] and reprocess them into fibres [38], blended textiles are difficult to refine in practice due to a lack of technology and only natural fibres (cotton, linen, silk, and wool) are relatively easy to refine [18]. Reprocessing and refining also involve using chemical additives, water, and energy [37]. Furthermore, the consideration of economic factors should examine whether the technical and economic costs required for textile separation and recycling follow a CE and are not additional waste. The motivation and incentive of supply chain companies to recycle and reuse also affect the applicability of the practice. Streamlining supply chains can reduce some unsustainable impacts of off-site supply chains. For example, transport and logistics pollute the environment and waste resources. Collaborative supply chains require a common economic philosophy and values among partners and satisfy the profit motive. Therefore, identifying compatible partners is a potential challenge.

Recycling and restoration are SDPs applied to market services. Second-hand, replacement, and rental services are all part of product recycling. Effective selection and sales through second-hand shops and online platforms aim to achieve sustainability by extending product life [39]. For example, consumers have the opportunity to trade used products through a consumer-to-consumer (C2C) model on platforms, such as Xianyu in China and Vinted in Lithuania. Rental services are designed to extend product life, which provides customers with short-term access to products. These aforementioned SDPs are also subject to limitations, such as water- and labour-intensive screening, cleaning, and sorting during recycling. Furthermore, what is the fate of rejected products that are screened out? Whether they remain in landfills or are incinerated is also unknown. Moreover, consumers consider the hygiene of second-hand products a significant obstacle. Restoration extends the life of a garment through preservation and repair. Regular maintenance and restoration ensure that the product quality and appearance remain satisfactory. Additionally, highly skilled repair craft and techniques can fully restore the beauty of a product. Repair is more complicated than maintenance, and standard refinishing techniques cannot satisfy consumers' fixation on aesthetics.

Elaboration and discussion of PDP and PP results

Apparel company PDPs can vary significantly based on the business type and are mainly divided into branded and bespoke PDP (PDPb and PDPc, respectively). Figure 4 depicts the specific PDPb and PDPc processes. Traditionally, seasons and trends guide the apparel industry to enhance product line development [5], which begins with collecting trends and summarising previous season market feedback. Product development begins only after design planning and designing have been completed. The subsequent steps involve fabric selection for collection, item, and pattern design, pattern presentation, and iterative pattern adjustment until the final pre-production pattern is finalised [40]. The PDP for customised products begins with customer communication where the product is designed by combining the client's intentions with the designer's professional knowledge. The design, paper pattern, and process are finalised via communication and adjustment with the client and repeated fittings until the custom-made product is completed [41].

Figure 3 lists all the steps in branded and bespoke product development separately. In this figure, the designer-related aspects of PDPb and PDPc are marked in blue. In PDPb, the designer leads the design concept, fabric selection, and style design and is involved in the subsequent patterning, process design, style and construction examination, and idea exchange. In PDPc, the designer is mainly responsible for communicating with the client, supporting the client professionally, collaborating on the product design, and participating in the subsequent stages of patterning, craftsmanship, fitting, and idea exchange. Figure 4 demonstrates that the designer can lead 38% and 33% of the sessions in PDPb and PDPc, respectively. The PDP does not involve a set number of sample adjustments but typically includes two reviews: the first for the style and pattern and the second for the overall effect of the sample in the correct fabric. If the style, structure, and process details require modification during the second review, a third sample will be made and reviewed until the desired

Serial Number	Product Development Process (Brand)	Serial Number	Product Development Process (Customization)
PDPb1	*Collecting Fashion Trend and Market Feedback*	*PDPc1*	*Communication of customer needs*
PDPb2	*Fashion Trend analysis*	*PDPc2*	*Information gathering*
PDPb3	*Planning Design*	*PDPc3*	*First draft design*
PDPb4	*Fabric Selection*	*PDPc4*	*Selection of fabrics and accessories*
PDPb5	*Collection Design*	*PDPc5*	*First proposal discussion (without physical objects)*
PDPb6	*Item design*	PDPc6	body measurements
PDPb7	Pattern Design	PDPc7	paper pattern design
PDPb8	Sewing Technology Design	PDPc8	sewing process design
PDPb9	Preliminary sample production	PDPc9	first prototype production
PDPb10	Examination of style and construction	*PDPc10*	*Second design discussion (physical fitting)*
PDPb11	pattern modification	PDPc11	Revision of the design
PDPb12	Reproduction	PDPc12	Paper pattern revision and craftsmanship
PDPb13	Examination of pattern, construction, fabrics and sewing techniques	PDPc13	Reproduction
PDPb14	Modification of 2nd samples	PDPc14	Review of pattern, construction, fabrics and workmanship
PDPb15	2nd sample production	PDPc15	Modification of the second sample
PDPb16	Confirmation of pre-production samples	PDPc16	Production of 2nd samples
		PDPc17	Modification of 2nd samples
		PDPc18	Production of final samples

Fig. 3. The PDPb and PDPc processes

Serial Number	Production Process
PP1	Pre-production Sample Confirmation
PP2	Determining Production Quantities
PP3	Purchase of Fabrics and Fccessories
PP4	Pattern Grading
PP5	Cutting Process
PP6	Sewing
PP7	Finishing Process
PP8	Quality Control
PP9	Packaging
PP10	Stocking

Fig. 4. List of all the steps of the product process

effect is achieved. During bespoke product development, the number of prototype adjustments may increase due to changes in customer opinions.

Figure 4 depicts the PP flow. Following confirmation of the pre-production sample, the production department determines the production quantity with the merchandising department and senior management. The purchasing department purchases the fabric and accessories according to the production quantity and transports them to the factory. Simultaneously, the pattern maker performs bulk goods production, followed by cutting, sewing, finishing, quality control, and packaging. Thus, the entire PP process requires minimal designer involvement.

Designer involvement in the CE

Each PDP and PP session is matched to the SDP. To measure the designer's involvement in the current SDP, indirect measurements were made via the PDP and PP to enumerate the involvement of the PDP links associated with the designer in the SDP. The designer's involvement was calculated using the following formula:

$$Designer\ involvement = X/(X + Y + Z) \times 100\% \quad (1)$$

where X, Y, and Z refer to the number of green, blue, and white markers.

Figure 5 shows the link between the SDPs and the two types of PDP and PP, with different coloured markings showing the relevance of the fashion designer to the SDPs. In Figure 5, the green markers indicate the PDP and PP steps that could theoretically be matched to the SDP. Blue markers indicate the designer-related steps in the PDP that could match the SDP. White markers indicate that the SDP is irrelevant to any PDP and PP step.

Based on the formula, the designer's involvement in the SDP was ideally 41% in both PDPb and PDPc (figure 6). Ideally, a proportional representation of the fashion designer's participation in the presentation of the SDPs is expected. Theoretically, the involvement level was approximately 50% but differed from the actual situation as PDPs and SDPs were matched using the ideal state (all possible aspects of a designer's involvement in a PDP were counted as valid data). The SLR revealed that designers' sole involvement in the fashion industry was in selecting biodegradable and environmentally friendly fabrics, high-quality designs, and bespoke collaborative designs. In practice, designers' involvement with SDPs in PDPb and PDPc was only 11.76%. Figure 7 shows the actual level of involvement of fashion designers in SDPs after the survey.

Figures 6 and 7 depict the ideal and actual designers' involvement in the SDP, respectively. The comparison between Figures 6 and 7 demonstrates that designers' actual participation in SDP is shallow

Serial Number	Sustainable Design Practices	Steps associated with SDP in PDPb	Sign	Steps associated with SDP in PDPc	PDPcn.	PSteps associated with SDP in PP	Sign
SDP1	Zero Waste	PDPb9、PDPb12、PDPb15	●	PDPc9、PDPc13、PDPc16	●	PP5	●
SDP2	Slow Fashion	PDPb8	●		○		○
SDP3	Sustainable Materials	PDPb4	●	PDPc4	●	PP3、PP9	●
SDP4	Recycle	PDPb12、PDPb15	●	PDPc13、PDPc16	●		○
SDP5	Streamlining Supply Chains		○		○		○
SDP6	Second-hand Fashion		○		○		○
SDP7	Trade-in		○		○		○
SDP8	Rental Services		○		○		○
SDP9	Restoration	PDPb12、PDPb15	●	PDPc13、PDPc16	●		○
SDP10	Longevity Design	PDPb3	●	PDPc3、PDPc10	●		○
SDP11	Quality Design	PDPb6、PDPb8	●	PDPc3、PDPc10	●		○
SDP12	Timeless Design		○	PDPc3、PDPc10	●		○
SDP13	Functional Design	PDPb6、PDPb7	●	PDPc3、PDPc7、PDPc10	●		○
SDP14	Modular Design	PDPb6、PDPb8	●		○		○
SDP15	Open Source Design	PDPb3	●	PDPc1	●		○
SDP16	Collaborative Design	PDPb3	●	PDPc1	●		○
SDP17	Halfway Product Design		○		○		○

● the steps of the PDP and PP that could theoretically be matched to the SDP.
● the steps related to the designer in the PDP that could match the SDP.
○ the SDP is irrelevant to any of the steps in the PDP and PP.

Fig. 5. The designer's involvement in the PP and PDP

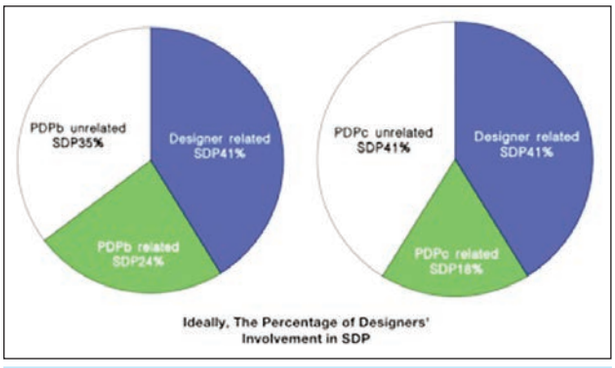

Fig. 6. Ideal designers' involvement in SDP

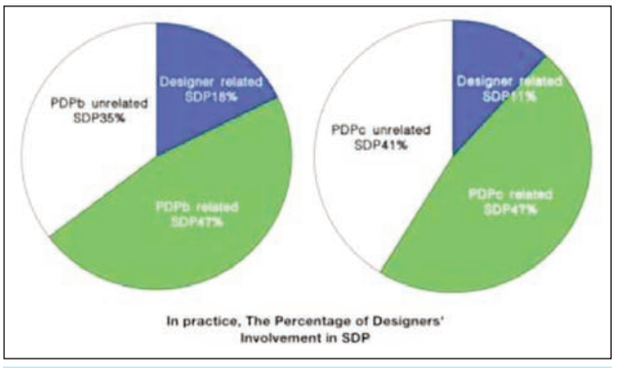

Fig. 7. Actual designers' involvement in SDP

when analysed at both internal and external levels. The internal factor is that designers have a limited voice in the traditional apparel industry. Designers only work based on the set direction issued by top management and are typically only responsible for the tasks within their responsibilities. Designers are rarely involved in strategy-level company or brand work. Thus, designers lack sufficient motivation to engage in subjective CE.

The external factor refers to the organisational and entrepreneurial neglect of the role of designers and traditional PDP and PP. Entrepreneurs typically deem the transformation of the CE and sustainable growth as strategic company deployment and should evaluate their systems regarding CE transformation in more detail. Furthermore, the lack of knowledge on sustainability leads to strategic transformation initiatives being limited to obsessive recycling actions and addressing the wasteful results. The SLR revealed that strategy proponents believe that the apparel industry's sustainable development breakthroughs are limited to addressing pollution, recycling waste, enhancing product durability, increasing the added value of products, and fostering emotional customer value. The limitations of the aspects above were discussed in the previous section.

PDP three-dimensional (3D) visualisation

Resolving local pain points cannot improve the fashion company's transition to a CE and involvement in sustainable development. Companies should make both internal and external changes. Internal reform refers to the achievement of sustainability in all business aspects while external reform requires building an externally sustainable industrial ecology by linking with partners, such as supply chains, manufacturers, and customer service providers. As an internal key to the apparel business, PDP is inherently unsustainable. As illustrated in figure 3, the repeated prototype adjustment link in both PDPb and PDPc is an unsustainability pain point and a sustainability breakthrough point. Eliminating prototype conditioning in PDP is an advantageous approach to transition to sustainability in PDP where product iteration efficiency is improved and resource waste associated with repeated prototype production is resolved. Thus, sustainable design is not an afterthought but focuses on the entire design process.

Designers can upgrade their PDPs with technology by using computerised 3D virtual technology to replace the sample commissioning aspect of traditional PDPs to render the PDP a 3D visual, which digitally produces the design presentation. Ideally, computers perform style design, pattern-making, sample-making, and structural commissioning. The PDP 3D visualisation enables rapid iteration of the design solution, reducing the lead time to obtain the desired design and swiftly identifying the design early in the process. More importantly, 3D visualisation replaces traditional proofing and addresses the unsustainable issues caused by repeated prototyping. Therefore, the PDP 3D visualisation initiative is an effective means for designers to contribute to sustainable development. The PDP 3D visualisation challenges the traditional PDP process by combining a workflow that would otherwise require several departments to collaborate in one session.

Appropriate 3D rendering software, such as Clo3D, Gerber Technology, and Human Solutions [40], requires the software user to possess a comprehensive range of skills. Using 3D software requires knowledge and skills in design, construction, technology, and software operation, which challenges designers and other PDP participants. Furthermore, PDP 3D visualisation presents the following organisational challenges: how the key players (experienced paper pattern-makers and skilled craftspeople) in traditional PDP should be involved in PDP 3D visualisation when the PDP structure requires major reorganisation. The perceptions and imagining of 3D virtual products differ from physical reality. Therefore, the extent to which the visualised product would fulfil organisational and consumer expectations is subject to unknown challenges.

CONCLUSION

The apparel company's transition to the CE requires a concerted effort from internal and external business cycles. In this study, 75 articles on SDPs, PDPs, and PPs in the apparel industry were analysed. First, existing SDPs in the apparel industry were identified

and the motivations of existing sustainable initiatives at the strategic level were analysed. Second, the internal links between the current PDP and PP in the apparel industry were deconstructed. Mapping the internal links to existing SDPs enabled the indirect measurement of designers' involvement in the CE. Third, a sustainability breakthrough in designer-led PDP was proposed by replacing physical garment sample production with PDP 3D visualisation, eliminating the waste associated with repeated sample commissioning. Finally, the barriers and limitations of PDP 3D visualisation were presented. Sustainable reform of the PDP segment challenges traditional processes, where it presents challenges to the direct collaborative approach of segment participants. This suggests that the designer-led application of PDP sustainability faces many obstacles.

The limitations of this research were as follows: apparel industry PDPs were not limited to PDPb and PDPc due to the different audiences and markets served by the companies, such as original equipment manufacturer (OEM) business PDPs and webcast product PDPs. Thus, it is possible to expand research on apparel industry PDPs. Furthermore, the main research aim is to focus on designers' sustainable potential, as the PP and designers were weakly correlated. Therefore, studying SDPs in PPs requires further development. As the PDP 3D visualisation application faces several barriers, more in-depth research on how it can be integrated into practical organisational applications is needed, such as how designers can be trained with comprehensive skills and how the aesthetic differences between 3D renderings and natural objects can be reduced.

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Inclusion complexes of β-cyclodextrıne with Fe_3O_4@HA@Ag Part II: Their use in the production of PVP nanowebs

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ABSTRACT – REZUMAT

Inclusion complexes of β-cyclodextrıne with Fe_3O_4@HA@Ag Part II: Their use in the production of PVP nanowebs

Humic acid is a material formed as a result of the degradation of animal and plant wastes, it cleans heavy metals which are industrial wastes that threaten both the environment and human health. In part I of this study, the Fe_3O_4@HA@Ag compound was synthesized, its inclusion complex with β-cyclodextrin was prepared by using the kneading technique and obtained inclusion complexes were characterized. In this study, part II, nanowebs were formed from the inclusion of complex-containing polymer solution via the electrospinning method. The electrospinning solution consisted of β-CD:Fe_3O_4@HA@Ag inclusion complexes at the rate of 5%, 7.5% and 10% by weight and the polyvinylpyrrolidone (PVP) polymer as the carrier. The obtained nanoweb material was characterized by instrumental methods such as SEM, FTIR, XRD, and TGA. The results obtained from FTIR, XRD and TGA revealed that β-CD:Fe_3O_4@HA@Ag inclusion complexes containing nanowebs were successfully produced. The uniform fibre formation was detected from SEM images. The average fibre diameter of 5%, 7.5% and 10% β-CD:Fe_3O_4@HA@Ag inclusion complex containing nanowebs were measured to be 612.5 nm, 610.8 nm and 431.2 nm, respectively.

Keywords: *β-cyclodextrin, Fe_3O_4@HA@Ag, inclusion complex, electrospinning, nanoweb*

Complecși de incluziune ai β-ciclodextrinei cu Fe_3O_4@HA@Ag Partea a II-a: Utilizarea acestora în producția de nanovăluri PVP

Acidul humic este un material format ca urmare a degradării deșeurilor animale și vegetale și curăță metalele grele care sunt deșeuri industriale ce amenință atât mediul, cât și sănătatea umană. În partea I a acestui studiu, compusul Fe_3O_4@HA@Ag a fost sintetizat, complexul său de incluziune cu β-ciclodextrină a fost preparat prin utilizarea tehnicii de malaxare, iar complecșii de incluziune obținuți au fost caracterizați. În partea a II-a a acestui studiu, nanovălurile au fost obținute din soluția de polimer care conține complex de incluziune, prin metoda de electrofilare. Soluția de electrofilare a constat din complecși de incluziune β-CD:Fe_3O_4@HA@ la o rată de 5%, 7,5% și 10% în greutate și polimerul polivinilpirolidona (PVP) ca purtător. Materialul de nanoväl obținut a fost caracterizat prin metode instrumentale precum SEM, FTIR, XRD, TGA. Rezultatele obținute din FTIR, XRD și TGA au evidenţiat că au fost produși cu succes complecși de incluziune β-CD:Fe_3O_4@HA@Ag, care conțin nanovăluri. Formarea uniformă a fibrelor a fost detectată din imaginile SEM. Diametrul mediu al fibrei de 5%, 7,5% și 10% pentru complexul de incluziune β-CD:Fe_3O_4@HA@Ag, care conține nanovăluri a fost măsurat la 612,5 nm, 610,8 nm și, respectiv, 431,2 nm.

Cuvinte-cheie*: β-ciclodextrină, Fe_3O_4@HA@Ag, complex de incluziune, electrofilare, nanoväl*

INTRODUCTION

This article is the second part of the study, on the production and characterization of the β-CD:Fe_3O_4 @HA@Ag inclusion complex and this part includes electrospinning of nanowebs of β-CD:Fe_3O_4@HA@Ag inclusion complex with polyvinylpyrrolidone (PVP), as the carrier polymer [1]. Magnetic nano-materials such as Ferrite (Fe_3O_4) have attracted the attention of researchers in recent years due to their electrical, magnetic and optical properties, and these materials have found use in many different fields [2].

Humic acid (HA) is an organic macromolecule substance that emerges as a result of the degradation of animal and plant wastes in nature. It is among the materials that have the capacity to clean heavy metals, as a result of forming a complex with heavy metals, which occur as industrial waste and threaten both the environment and human health by passing into the soil [3]. HA has strong complexing ability with metal ions because it consists of large amounts of carboxyl, phenolic hydroxyl and carbonyl groups [4–7]. Today, active groups and other compounds in HA are used to prepare polymer composite materials that are insoluble in water and have good adsorption properties. In recent years, the materials used for the modification of HA are mostly carbon-based materials, metal oxides and synthetic polymer materials [8–11]. Compared with other materials, natural polymer

materials have a wide variety, diversity of resources, and low cost. Natural polymer materials can reduce the solubility of HA and increase the adsorption capacity of HA when they react through cross-linking. Therefore, natural polymer-modified HA materials as metal ions adsorbents have greater potential than other materials [4, 12–13].

Silver has been used safely in many areas for centuries as a broad-spectrum antimicrobial agent with antibacterial, antifungal and antiviral properties. Silver has been used for many years in the forms of metallic silver, silver nitrate and silver sulfadiazine for the treatment of burns, wounds and numerous bacterial infections. This is because silver is a very broad-spectrum antibiotic, there is virtually no bacterial resistance to silver, and it is non-toxic at low concentrations [14].

PVP was synthesized by Reppe in 1938 as a result of the polymerization reaction of N-vinylpyrrolidone monomer produced by acetylene chemistry. In the literature, hydrogels have found wide use in wound dressings, and scaffolds, in the development of drug and gene delivery systems, and in biomedical treatments [15]. The importance of PVP has been demonstrated by the commercialization of homopolymers, copolymers and crosslinked structures. Its amphilicity is due to the polar lactam group in the hydrophilic pyrrolidone and the non-polar methylene part, which offers lipophilicity [16]. It has found wide use in biomedical applications due to its chemical stability, non-toxicity and biocompatibility. PVP is widely used in the development of nanofibers, scaffolds, drug and gene delivery systems [17, 18]. The main working principle of the electrospinning technique is the application of electrostatic forces on a polymer liquid mixture to produce nanofibers or nano scaffolds. It is a simple conventional method for the production of different biodegradable materials and composites [19]. Electrospinning involves the injection of a charged polymer solution through a metallic needle (spinneret) by forming a Taylor cone at the needle tip and a jet of polymer solution, into a counter-charged collector [20, 21].

Magnetic nanocomposites containing Fe_3O_4, HA and silver (Ag) were synthesized by Amir et al. [2]. In another study, the Fe_3O_4@HA@Ag complex was directly doped into PVP, but it was stated that homogeneous distribution could not be achieved in the carrier polymer due to solubility problems [22].

Furthermore, Yildiz et al. produced Fe_3O_4@Cs@Ag in their previous study [23]. However, since this nanocomposite contains chitosan in its structure and its cost is high, HA recovered from waste was used instead of chitosan in this study, and thus a more environmentally friendly and inexpensive complex nanocomposite was obtained. In the first part of this article, which was previously published, the Fe_3O_4@HA@Ag compound was synthesized, the inclusion complex of Fe_3O_4@HA@Ag with β-cyclodextrin prepared by mass kneading technique, and characterized by performing various instrumental analyzes [1]. In this study, nanoweb containing β-CD:Fe_3O_4@HA@Ag inclusion complex was obtained by electrospinning method from solution by using PVP as the carrier polymer. The prepared nanoweb was characterized by SEM, FTIR, XRD and TGA.

MATERIAL AND METHOD

The substances used in the β-CD:Fe_3O_4@HA@Ag inclusion complex were $FeCl_3.6H_2O$, $FeCl_2.4H_2O$, $C_{187}H_{186}O_{89}N_9S_1$ (HA), $AgNO_3$, $NaBH_4$, NH_3 and they were obtained from Merck, while polyvinylpyrrolidone ((C_6H_9NO) X, MW = 1.300.000), N, N-dimethylformamide (DMF), ethanol (solvent) were obtained from Sigma ALDRICH companies.

PVP (10% w/v) solution was prepared using pure ethanol. Since it was concluded in our previous work that the 1:2 inclusion complex of β-CD with Fe3O4@HA@Ag prepared by kneading technique was found to have better results [1], in this nanoweb production part of the work, 1:2 β-CD:Fe_3O_4@HA @Ag was used in different weight ratios (5%, 7.5% and 10% by weight). Inclusion complexes were dissolved in DMF (10 ml), by vigorously stirring at 50°C for 6 hours. Then, the PVP solution and the solution containing β-CD:Fe_3O_4@HA@Ag were mixed to prepare the electrospinning solution. The prepared electrospinning solution was placed in a 10 mL syringe and placed in a single-needle electrospinning device with an inner needle diameter of 0.7 mm for nanoweb production. The nanoweb material was obtained by setting the device parameters at a 0.5 mL/h feed rate, 17 kV voltage and a 15 cm collection distance. Fourier transform infrared (FTIR) spectra of the nanoweb material were recorded in transmission mode with the BRUKER, VERTEX 70 ATR spectrometer. The FTIR spectrums of the samples were taken in the wavenumber range of 4000–400 cm^{-1}. X-ray diffraction measurements (XRD) of the crystal structure of the samples were analysed with a Bruker AXS diffractometer and the surface morphology was analysed with a Quanta FEG 250 scanning electron microscope (SEM) (FEI, Netherlands).

Thermogravimetric analysis (TGA) of the samples was characterized by a Perkin Elmer Instruments brand TGA device. 6 mg of sample in powder form was inserted into the equipment. The analysis was carried out under a nitrogen atmosphere with a heating rate of 10°C/min. The temperature ranged from room temperature to 900°C.

RESULTS AND DISCUSSION

FTIR results

The surface chemistry of the nanoweb containing different amounts of β-CD:Fe_3O_4@HA@Ag inclusion complex (5%, 7.5% and 10%) was investigated using the FTIR spectrum (figure 2). In the spectrum of β-CD:Fe_3O_4@HA@Ag/PVP nanowebs, peaks at ~1650 cm^{-1} and ~1415 cm^{-1} correspond to -COO

groups, while peaks at 2980 cm^{-1} and 2870 cm^{-1} correspond to -CH_2, -CH_3. The PVP polymer has a peak at 3420 cm^{-1} showing the O-H stretch band. The peaks at 2953 cm^{-1} and 1656 cm^{-1} indicate asymmetric stretching of CH_2 and C-O stretching, respectively [24]. Therefore, FTIR results confirmed that the obtained nanowebs contain β-CD:Fe_3O_4 @HAAg in the structure (figure 1).

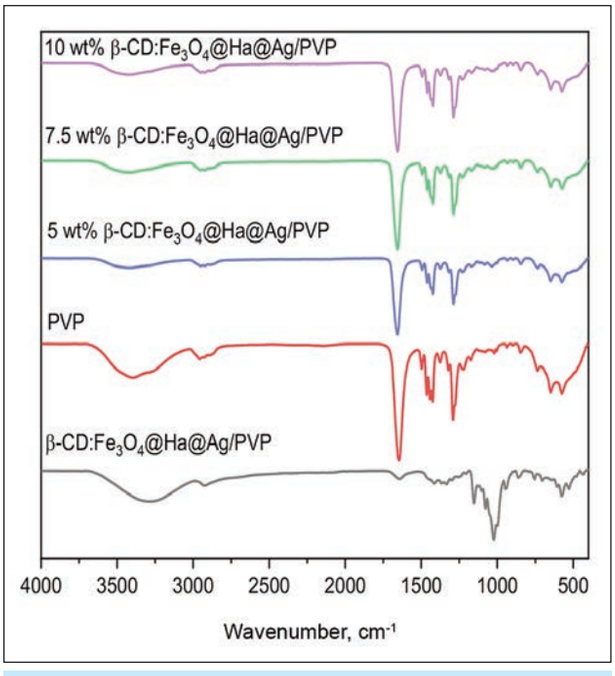

Fig. 1. FTIR spectra of produced nanowebs

SEM results

SEM images of produced nanowebs containing 5%, 7.5% and 10% by weight inclusion complex are presented in figure 2. In the SEM images, it was seen that no beads were formed and composite nanowebs were produced successfully. The uniform fibre formation was detected from SEM images. The fibre diameter distribution and mean fibre diameter of 5%, 7.5% and 10% β-CD:Fe_3O_4@HA@Ag inclusion complex containing nanowebs were measured. The data was plotted in histograms and given in figure 2. The mean fibre diameter was found to be 612.5 nm, 610.8 nm and 431.2 nm for 5%, 7.5% and 10% β-CD:Fe_3O_4 @HA@Ag inclusion complex-containing nanowebs, respectively.

XRD results

Produced nanowebs were analyzed by XRD for the determination of their crystal structures. The XRD patterns of nanowebs with three different ratios (5%, 7.5% and 10% by weight) of β-CD:Fe_3O_4@HA @Ag/PVP inclusion complex are shown in figure 3. The presence of both Fe_3O_4 ((220), (311)) (JCPDS No.75-0033)) and Ag (111) (JCPDS No.87-0720) was observed in samples which contained 7.5wt% and 10wt% Fe_3O_4@HA@Ag [2,25]. In the 5wt% β-CD:Fe_3O_4@HA@Ag/PVP nanoweb sample, a peak of Fe_3O_4 was observed, but the Ag peak was weak since the amount of Ag was relatively low as compared to others.

TGA results

Thermograms of TG analysis of β-CD:Fe_3O_4@HA @Ag magnetic nanowebs are shown in figure 4. The 10% weight loss observed in the range of 25–200 °C was associated with the removal of water vapour and volatiles of the H_2O absorbed by the starting materials and solvents used in solution preparation, such as DMF, and ethanol. Weight losses between 200 and 400°C refer to the decomposition of metallic precursors and degradation of beta-cyclodextrin. It was seen that the degradation of PVP started at an onset temperature of 400°C and ended at an offset temperature of ~500°C. When the TGA thermograms of β-CD:Fe_3O_4@HA@Ag/PVP nanowebs are examined, it is seen that there is a weight loss compatible with the amount of β-CD:Fe_3O_4@HA@Ag.
Examining the total weight losses at 600°C, it was seen that the amount of β-CD:Fe_3O_4@HA@Ag in the structure and the weight loss exhibited an inversely proportional attitude as expected.

CONCLUSION

In this study, humic acid recovered from the waste was used instead of the chitosan used in the previous study, and a homogeneous distribution in the PVP matrix was achieved by preparing an inclusion complex with β-CD. Nanowebs, containing 5%, 7.5% and 10% by weight β-CD: Fe_3O_4@HA@Ag inclusion complex into 10% PVP polymer solution, was produced by using the electrospinning method. Considering the SEM images and the fibre diameter measurements, the average fibre diameter of 5%, 7.5% and 10% β-CD:Fe_3O_4@HA@Ag inclusion complex containing nanowebs were found to be 612.5 nm, 610.8 nm and 431.2 nm, respectively, which revealed successful production of nanowebs. Fe-O bonds were visible in the FTIR results of nanowebs containing the inclusion complex at different weight ratios, and the peaks displayed in the XRD patterns supported the FTIR results. In all three samples, both Fe_3O_4 and Ag were seen according to the XRD result, and the intensity of the respective peaks differed only by the amount of β-CD:Fe_3O_4@HA@Ag (5%, 7.5% and 10%). Therefore, in nanowebs containing 5% β-CD:Fe_3O_4@HA@Ag, the peak associated with Ag, belonging to the (111) crystal plane, was found to be quite weak. In TGA thermograms, it was seen that the use of inclusion complex in the β-CD structure increased the degradation temperature and revealed a stable structure.
In the study, the inclusion of the structure in the form of an inclusion complex, which was added to the Fe_3O_4@HA@Ag structure and prepared with HA and β-CD obtained from the waste, increased the homogeneity and formed a stable structure. Although the antibacterial properties of the active substance

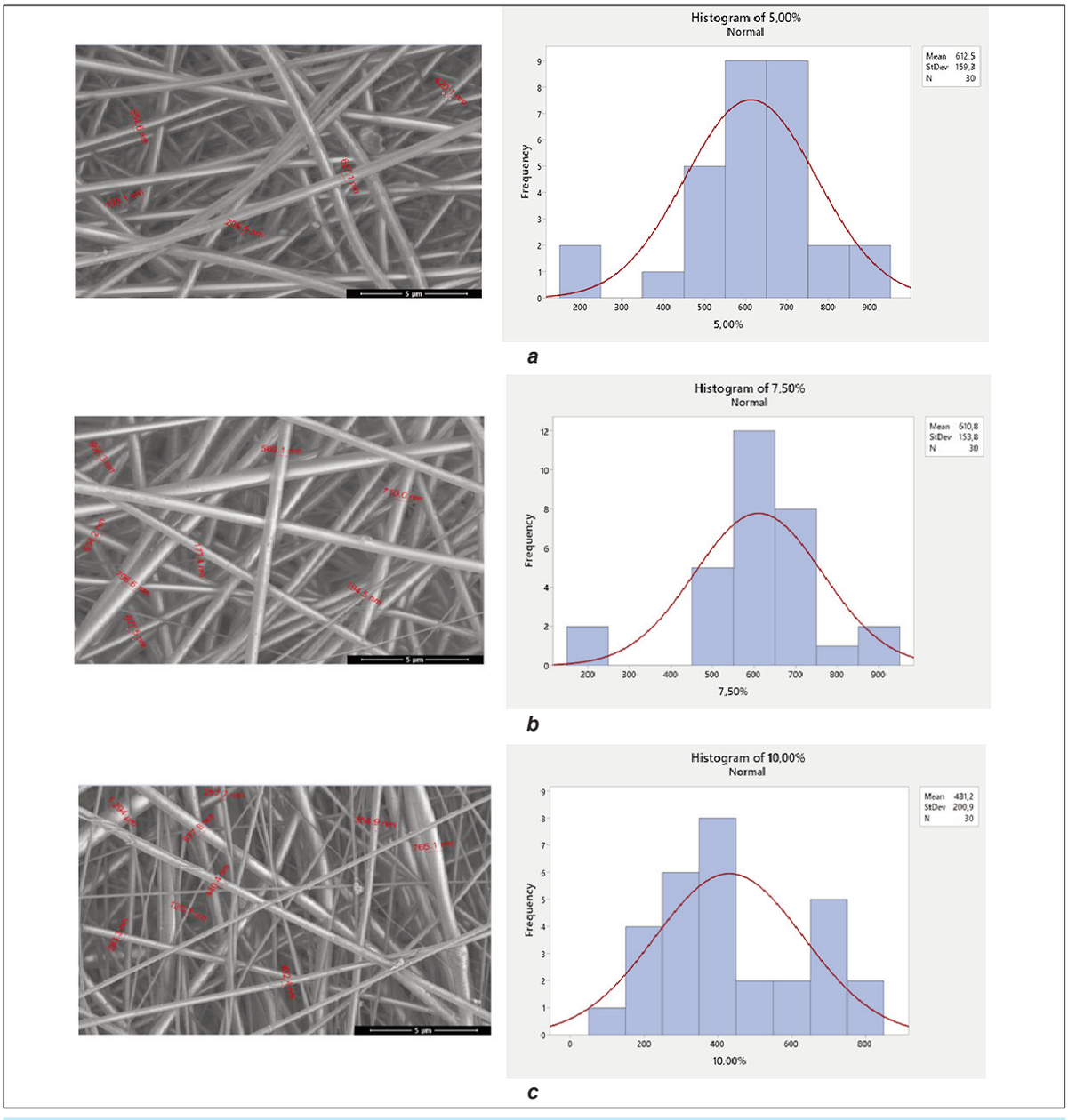

Fig. 2. SEM images and fibre diameter distribution of produced nanowebs: *a* – 5wt% β-CD:Fe_3O_4@HA@Ag/PVP; *b* – 7.5wt% β-CD:Fe_3O_4@HA@Ag/PVP nanoweb; *c* – 10wt% β-CD:Fe_3O_4@HA@Ag/PVP)

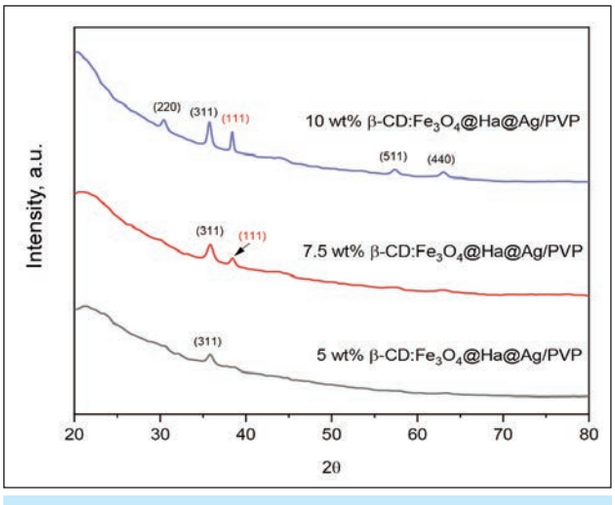

Fig. 3. X-Ray powder diffraction pattern of produced nanowebs

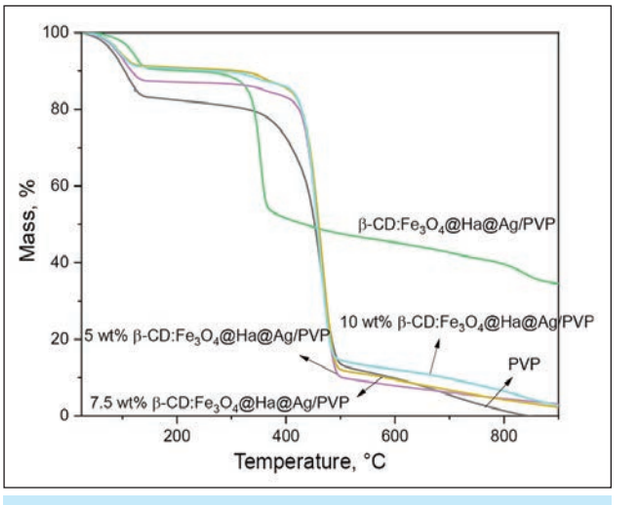

Fig. 4. TGA thermograms of produced nanowebs

Fe_3O_4@Ag were examined and positive results were obtained in previous studies [22, 23], to clarify the usability of the nano-surfaces produced in this study in the medical field, it was considered to perform antibacterial, cytotoxicity and histological tests in the future studies.

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An investigation of firm performance via electronic ability-motivation-opportunity enhancing practices towards Saudi Arabian garment sector employees

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ABSTRACT – REZUMAT

An investigation of firm performance via electronic ability-motivation-opportunity enhancing practices towards Saudi Arabian garment sector employees

This study aims to explore ability-motivation-opportunity (AMO) practices to enhance sustainable HRM in the electronic environment. The authors further investigated whether sustainable e-HRM (SEHRM) may improve firm performance. Data was collected from the employees of the Saudi Arabian garment sector. Collected data was analyzed by applying structure equation modelling (SEM) by using smart-PLS. Results indicate that three dimensions of e-HRM positively and significantly impact firm performance. Results further suggest that SEHRM substantially mediates the relationship between e-HRM practices and firm performance. To establish SEHRM systems, an emphasis must be placed on e-HRM practices that improve employees' abilities and motivation. Once employees comprehend the importance of EHRM, they will be attracted towards this system routinely for activities such as goal planning and performance evaluation. Creating SEHRM helps improve the functions of the business. This study will help business professionals to adapt EHRM to improve the firm performance.

Keywords: *electronic HRM, ability enhancing, opportunity enhancing, motivation enhancing, firm performance, garments sector*

Studiu asupra performanței firmei prin practici electronice de îmbunătățire a abilităților, motivaţiei şi oportunităților față de angajații din sectorul de îmbrăcăminte din Arabia Saudită

Acest studiu își propune să exploreze practicile de îmbunătățire a abilităților, motivaţiei şi oportunităților (AMO) în managementul resurselor umane (HRM) durabil în mediul electronic. Autorii au investigat în continuare dacă e-HRM durabil (SEHRM) poate îmbunătăți performanța firmei. Datele au fost colectate de la angajații din sectorul de îmbrăcăminte din Arabia Saudită. Datele colectate au fost analizate prin aplicarea modelării ecuațiilor structurale (SEM), prin utilizarea smart-PLS. Rezultatele au indicat faptul că trei dimensiuni ale e-HRM au un impact pozitiv și semnificativ asupra performanței firmei. Rezultatele au mai evidenţiat că SEHRM mediază în mod substanțial relația dintre practicile e-HRM și performanța firmei. Pentru a stabili sisteme SEHRM, trebuie să se pună accent pe practicile e-HRM care îmbunătățesc abilitățile și motivația angajaților. Odată ce angajații înțeleg importanța EHRM, ei vor adopta cu siguranță acest sistem în mod uzual pentru activități precum planificarea obiectivelor şi evaluarea performanței. Crearea SEHRM este utilă pentru a îmbunătăți funcțiile afacerii. Acest studiu va ajuta profesioniștii din afaceri să adapteze EHRM pentru a îmbunătăți performanța firmei.

Cuvinte-cheie*: HRM electronic, îmbunătățirea abilităților, îmbunătățirea oportunităților, îmbunătățirea motivației, performanța firmei, sectorul de îmbrăcăminte*

INTRODUCTION

The implementation of e-HRM, also known as EHRM, resulted in profound changes to every facet of human resource management. Due to the all-pervasive nature of information technology, the management of human resources has taken on a greater level of significance [1]. When it comes down to it, electronic, human resource management (e-HRM) is just a phrase that refers to the utilisation of technology to carry out a wide variety of human resource management tasks (such as recruiting, selection, training, performance evaluation, and career advancement and development of employees in every company) [2]. It is essential to distinguish between traditional HR information systems and electronic human resource management [3]. The former is responsible for managing the human resources departments of organizations, while the latter is more concerned with the actions of employees and other stakeholders [4]. Another concern over the ability to maintain operations over the long run has surfaced as a direct result of the expanding usage of technology and the subsequent depletion of available resources. Sustainable development can be implemented concerning material and immaterial resources (intellectual, capital, and infrastructure) [5].

Although e-HRM practices and SEHRM systems have become more prevalent in the last decade, e-HRM was first discussed by some researchers [6,

7], when they categorised e-HRM into three significant categories: operational e-HRM, relational e-HRM, and strategic e-HRM (the latter of which deals with more core activities such as training, performance evaluation, and strategic e-HRM) [8]. An organization's operational activities are transformed when it implements a long-term sustainable electronic human resource management system (e-HRM) [9]. Three different e-HRM positions were defined in some studies [10, 11], which are referred to as transactional, classic, and transformative e-HRM roles. HRM's benefits to organizations can no longer be understated, especially in light of the wealth of information currently at our fingertips [12]. With the help of e-HRM, manual or analogue organizational records and data can be converted to digital form for use in the future [13]. Therefore, businesses might investigate the potential of electronic information transformation to achieve strategic goals, such as developing long-term e-HRM systems through electronic human resource management [14, 15].

In recent years, managing e-HRM practices and SEHRM systems in a dynamic capacity has become increasingly important. In this day and age, characterized by the economy of knowledge and the technical exchange of information among various organizations, successful results can be produced; recently, the global environment has grown more dynamic than ever before, which has altered the landscape for different human resource processes and emotional capacities [16, 17]. When companies and organizations use the most practical combination of available intellectual capital and technological resources, they can analyse and improve upon what has been produced in the past, allowing sustainable electronic and human resource practices and systems. However, according to the available research, EHRM's drawbacks have prevented many businesses from utilizing it [18]. Nevertheless, this technology is vital for long-term human resources management and business performance promotion because of the current epidemic and the fragile economic climate [19].

The outcomes of this study positively impact the management of information systems and human resources. The results of our research also revealed significant effects in the real business world. We found a beneficial impact on business outcomes brought about by e-HRM.

Section 2 presents the theoretical foundation, followed by the creation of hypotheses; Section 4 explains the research strategy; Section 5 focuses on Saudi Arabia and PLS-SEM-based analysis, and Section 6 concludes with theoretical and practical implications.

LITERATURE REVIEW

Theoretical background

Organizational theories and dynamic capabilities enable businesses to adjust their resource base actively. A business's capacity to strategically use its resources and expertise is a primary factor in determining whether it will succeed in the long run [20]. It is possible to generate, reproduce, and reconfigure dynamic capabilities in various settings. These operations may be carried out in a variety of different environments. To direct the growth and development of organizations, dynamic talents, particularly those that pertain to human resources, need to be uncovered [21]. Because of the emotional skills and organizational behaviour of today's employees and staff, the dynamic capability view, also known as the DCV, is an excellent fit for today's modern organizations. A wide range of internal and external organizational elements affect dynamic capacity [22].

Hypotheses development

Even in the most recent decade, there has been a significant increase in the adoption of e-HRM practices and SEHRM. Integrating time-honoured HR practices with cutting-edge information and communication technology is the driving force behind EHRM, often known as e-HRM. The end goal of e-HRM is to deliver automated human resources services [23]. Only if it provides a SEHRM, which in turn offers unique strategic initiatives to adapt to the demands of organizations in terms of social, financial, economic, technological, and ecological elements, can the use of e-HRM be effective [1].

Companies must work together to put e-HRM practices into effect and keep them going if they want to achieve their strategic goals [24]. By utilizing Internet channels such as e-brochures or online marketing, companies' human resources departments play a critical part in recruiting potential applicants for open positions [25, 26]. E-HRM allows for incorporating training and development activities to cultivate organizational values. If an organization is focused on achieving its long-term strategic goals, it can have SEHRM. Thus, we hypothesise.

H1a: AEHRM practices significantly affect SEHRM systems.

H1b: AEHRM practices positively relate to firm performance.

In conjunction with EHRM practices, work in organizations is undergoing significant transformation [23]. E-HRM practices are at the forefront of the movement toward acknowledging e-sustainability HRMs in this age of continuously developing technology. Without a doubt, it is essential to recognize that businesses that can use digital technology are modifying their perspectives on the best e-HRM practices and the most SEHRM [24]. Opportunities such as the establishment of electronic job designs can aid companies in encouraging employees to make ethical decisions, even though these employees may have different work profiles (administration, sales and marketing, finance, etc.) [27, 28]. In the current atmosphere of ruthless competition, developing sustainable paradigms for e-human resource management is an urgent necessity [29]. It is employee programs, which might take the shape of employee representatives and unions, that will play a significant role in this

respect [30, 31]. By conducting employee surveys on topics related to digital organizational culture, businesses can better predict whether or not e-HRM best practices will be adopted inside their organizations [32]. It is equally as important to be aware of the astoundingly excellent goods made possible by technological breakthroughs, which are helping in the global expansion of businesses, as it is to be mindful of the ethical difficulties linked to a SEHRM.

H2a. OEHRM practices significantly relate to SEHRM systems.

H2b. OEHRM practices positively influence firm performance.

When HRM systems and practices provide sufficient opportunities for employee growth and development, it becomes possible for organizations to have good work teams [33]. The relevance of such career-oriented initiatives has increased as a direct result of the application of contemporary technology to the procedures involved in human resource management [34, 35]. Regardless of employment status (part-time vs. full-time) and job description, companies will face various challenges associated with implementing electronic human resource management (e-HRM) and SEHRM. Workers' need to understand e-HRM practices and how they are connected to ethical behaviour has significantly increased in recent years [36]. Now more than ever, businesses must combine digital performance indicators and objectives with incentive and variable compensation programs [37, 38]. Despite the undeniable reality that digital platforms allow more freedom, companies must include corrective methods if ethical standards are violated. Therefore, we hypothesise:

H3a. MEHRM practices significantly affect SEHRM systems.

H3b. MEHRM practices positively relate to firm performance.

"SEHRM systems" are described as preserving the environment and all of its components for continued usage. In response to this need, business organizations have refocused their efforts on developing e-HRM systems that are more environmentally friendly [39, 40]. How an organization approaches problems relating to the environment is one of the most critical factors determining the effectiveness of such programs. Procedures for ethical e-HRM are required to have a long-term e-HRM system [41]. Additionally, actions must be continuously monitored. The company provides its staff members with the appropriate training assignments, allowing them to acquire the knowledge and comprehension necessary to use the available e-HRM resources effectively [42]. It is anticipated that businesses that embrace environmentally friendly practices will see improvements in the performance of their employees [43]. In this context, a good return on investment may be obtained by a company if the company is successful in retaining workers through improved talent management achieved through the use of e-HRM practices [11]. Utilizing technologically advanced e-HRM solutions can further bolster the firm's reputation and goodwill in the market [44]. Because of this, businesses will be able to exercise more excellent cost management over the long term, ultimately improving their net productivity.

H4: SEHRM systems significantly affect firm performance.

H5a: AEHRM and FP is mediated by SEHRM

H5b: OEHRM and FP is mediated by SEHRM

H5c: MEHRM and FP is mediated by SEHRM

CONCEPTUAL FRAMEWORK

Figure 1 shows the direct and indirect relationships.

RESEARCH METHODOLOGY

The researchers behind this study developed a questionnaire based on previous theories. Participants in this study were the employees of the garments sector of Saudi Arabia. Participants filled out a questionnaire to give their responses. The reason behind selecting these five cities in Saudi Arabia is that this country is the most vibrant of human resources in business activities. Respondents were contacted through emails. It was decided to conduct pilot research with 40 participants. Revisions to the final questionnaire have been made to better suit the needs of research participants as a result of the input of academic experts and corporate sector specialists. In addition to checking for typos and grammatical issues, the team also double-checked the information

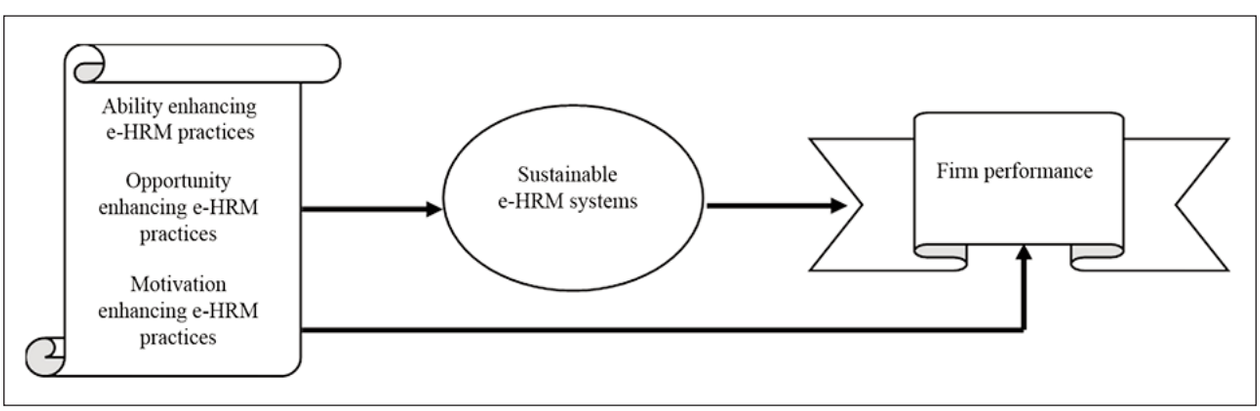

Fig. 1. Conceptual framework

for completeness. The experts have recommended minor language adjustments to improve e-HRM practices and the company's performance. This study used a convenient sampling technique to collect data from respondents. A total of 615 questionnaires were distributed among respondents, and 373 questionnaires were returned from respondents. After scrutiny, some responses needed to be completed, appropriate, and excluded from the final sample. Now there were 365 appropriate replies considered for the last analysis with a response rate of 59.34%.

INSTRUMENT DEVELOPMENT

This study used firm performance as DV and nine items adapted from [45]. In addition, we used three independent variables, i.e., six items adapted from [45] and [46] to measure AEHRM. Seven items were adapted from [45] and [46] to compute OEHRM, four items were utilized for MEHRM from the prior study of [45] and [46], and the four items were used for mediating variable SEHRM and these items were obtained from the study of [47].

DATA ANALYSIS

Statistical model applied

This study uses a partial miniature square modelling technique rather than other co-variance-based techniques such as LISREL and AMOS. PLS-SEM is the method of choice for our investigation since it lends itself to confirmatory and exploratory study types [48]. Covariance-based and partial least square SEM are the two techniques for structural equation modelling (SEM). PLS is generally utilized for hypothesis validation, whereas covariance-based (CB)-SEM is most useful for expanding on existing hypotheses. The PLS-SEM approach would consist of two stages: the first would be weighing, and the second would be measuring. PLS-SEM is excellent for a multiple-order, multi-variables model. PLS-SEM can benefit just as much from analysing small data sets. PLS-SEM makes it possible to quickly determine the model's parameters. Version 3.9 of Smart PLS was used to carry out the analysis presented here [49]. The value of Cronbach Alpha for each construct must be more significant than 0.70 to be considered valid [48]. As a result, every one of the values is more than 0.7.

Scale reliability for each item and Cronbach's alpha are examples of convergent validity measurements [48]. In the opinion of the knowledgeable party, CR and AVE should have values more than or equal to 0.7 and 0.5 correspondingly. Employing the test's composite reliability and average variance extracted scores, we calculated the test's convergent validity [50]. An unacceptable degree of convergent validity and internal consistency has been demonstrated in table 1 by the average variance derived from all indicators above 0.50 and the composite reliability exceeding 0.70. Therefore, a combined dependability rating of not less than 0.70 is deemed acceptable and a positive predictor of intra-organizational consistency [48]. Likewise, a composite reliability value of 0.70 or above is considered satisfactory. In addition, convergent validity is supported by average variance extracted scores greater than 0.50. This is because the scores suggest that the required signals

Table 1

DISCRIMINANT VALIDITY

Fornell–Larcker criterion						Heterotrait–monotrait (HTMT) ratios					
Indicator	SE	AE	OE	ME	FP	Indicator	SE	AE	AE	ME	FP
SE	0.751					SE	0.671				
AE	0.679	0.759				AE	0.839	0.731			
OE	0.629	0.621	0.691			OE	0.829	0.669	0.809		
ME	0.631	0.631	0.531	0.781		ME	0.711	0.769	0.799	0.709	
FP	0.589	0.581	0.539	0.651	0.741	FP	0.791	0.681	0.881	0.801	0.781

Table 2

HYPOTHESIS TESTING

Hypothesis		Ptah coefficient (t-value)	Confidence interval	F square	P values	Accepted
H1a	AE→SE	0.419(9.213)	0.141 to 0.209	0.219	0.000	Yes
H1b	AE→FP	0.281 (4.991)	0.051 to 0.111	0.069	0.000	Yes
H2a	OE→SE	0.210 (4.791)	0.031 to 0.061	0.051	0.000	Yes
H2b	OE→FP	0.161 (3.209)	0.011 to 0.041	0.031	0.001	Yes
H3a	ME→SE	0.229 (4.919)	0.029 to 0.069	0.061	0.000	Yes
H3b	ME→FP	0.049 (4.918)	–0.011 to 0.011	0.059	0.023	Yes
H4	SE→FP	0.321 (4.101)	0.059 to 0.141	0.091	0.000	Yes

clarified a specific construct with more than 50% variance [51].

Two methods, namely the Fornell–Larcker criteria and the heterotrait–monotrait (HTMT) method, are utilized to ascertain the discriminant validity [48]. This signifies that the model is valid regarding its ability to discriminate between groups [28]. According to table 2, the top value of the variable with the highest correlation is the discriminant validity that was produced. In addition, the HTMT ratios need to be lower than 0.85, but values in the range of 0.90 to 0.95 are acceptable [48]. The results of this study's classification are presented in table 2, which reveals that every HTMT ratio is less than 0.90, providing further evidence to support the claim that discriminant validity was achieved.

In this investigation, the VIF values were computed to check the collinearity concerns with the Framework. According to the experts, if the Variance Intensity Function (VIF) value is less than 5, there are no collinearity concerns in the data [48]. According to the findings of the analysis, the values of the items' inner VIF range from 1.321 to 1.876. Therefore, there is no evidence of a collinearity issue with the data presented in this study, and the findings are consistent. The early results give a suitable model whenever R2 is more than 0.5. A value of R Square larger than 0.5 on each exogenous construct indicates that the model has solid predictive accuracy. The model appears to have a high degree of predictive power based on the Q2 values of all five latent variables [48].

Table 2 depicts that SE positively enhances FP with values (β = 0.321, t-value = 4.101, p = 0.000). Table 2 explains that AE is an important factor in improving SE and the values are (β = 0.419, t-value = 9.213, p = 0.000). Furthermore, the table depicts the positive impact of AE on FP with the results (β = 0.281, t-value = 4.991, p = 0.000). Moreover, according to the table results, OE significantly influences SE (β = 0.229, t-value = 4.919, p = 0.000). Another relationship of OE towards FP is significant (β = 0.049, t-value = 4.918, p = 0.023). The next relationship of the impact of OE on SE is also positive (β = 0.210, t-value = 4.791, p = 0.000). In the end, OE positively improves FP (β = 0.161, t-value = 3.209, p = 0.000). In conclusion, table 2 expresses that all the hypotheses are approved.

Mediation analysis

Utilizing the VAF approach, we discovered the mediating function that SE plays between AE, OE, ME, and firm performance [48]. When the value of the VAF is more than 80 percent, complete mediation has occurred. The value of the VAF that is more than 20% but less than 80% suggests that there was some mediation of the effects of mediation, while the value of the VAF that is less than 20% indicates that there was no mediation. The findings demonstrate that SE is a partial mediator of the link between AE and FP concerning the direct effect. This study's results reveal a partial role for Se in mediating the association between AE and FP, with a partial mediation effect of 71.29% for both the direct and indirect impacts of VAF on t-values and p-values. The variance measures an indirect effect's magnitude accounted for (VAF). According to table 3, when OE and FP are linked, SE partially mediates this association with a direct impact of 0.161 and a direct effect of 0.059 with a VAF of 51.91%. FP and ME had a 55.10% direct and indirect influence on VAF (β = 0.049, t-value = 4.919, p-value = 0.000), with SE mediating the link in part (β = 0.069, t-value = 4.081, p-value = 0.000). Partial mediation showed where the direct and indirect effects are essential.

DISCUSSION

The findings highlight E-HRM practices and systems that enhance employee performance and provide the groundwork for a company's long-term success. The strategic and long-term features of e-HRM are crucial markers of the system's usefulness. EHRM (e-HRM) has transformed manual processes into automated services that create more money and profit and provide businesses and organizations with a competitive edge [33]. The literature describes a range of strategies for ensuring HRM programs' long-term survival. Using is one of the simplest methods to comprehend the concept of long-term employment [4]. This strategy has proven effective in Western Europe and has the potential to have a substantial influence from a SEHRM perspective [19]. Sustainable employability refers to a person's skill to utilize their mental and physical talents to do certain activities in a coordinated manner. This is the first research of its sort to investigate the nature of the connection between the factor mentioned above and the development and maturation of enterprises in general. The statistical validation of the model demonstrates that organizations benefit from good e-HRM practices and long-term e-HRM systems. The current era of digitization shows a fundamental shift in the context of many human resources practices, such as electronic selection, electronic recruiting, and electronic remuneration, which has completely altered the notion of managing

Table 3

MEDIATION EFFECTS						
Relationship	**Direct effect**	**Indirect effect**	**Total effect**	**VAN**	**Interpretation**	**Findings**
AE→SE→FP	0.049 (4.919)	0.069 (4.081)	0.069 (4.081)	55.10	Partial Mediation	H5a, Accepted
OE→SE→FP	0.161 (3.209)	0.059 (3.099)	0.059 (3.099)	51.91	Partial Mediation	H5b, Accepted
ME→SE→FP	0.281 (4.991)	0.129 (4.039)	0.129 (4.039)	71.29	Partial Mediation	H5c, Accepted

human resource operations. It has also been discovered that there needs to be a connection between opportunities to improve e-HRM practices and the long-term sustainability of e-HRM systems [24]. However, because it is common knowledge that there is a cost associated with every opportunity, improving e-HRM operations comes with advantages and disadvantages [10]. One of technology's most significant unintended consequences is the deterioration of the natural environment and the incapacity to maintain it. The use of EHRM strategies may have unintended consequences for corporations as well as workers. These consequences may include compromising privacy norms and adding an unnecessary burden [8]. The company's viability over time will be improved as a direct result of completing this procedure.

THEORETICAL IMPLICATIONS

The global supply chain network has been disrupted as a result of COVID-19. The persistent nature of this pandemic has educated us on several important topics. Businesses that have transitioned to digital technology have shown improved performance and increased viability over the long run [14]. Companies unable to withstand the pandemic either downsized their workforce or laid off employees to remain profitable. This has a significant influence both on the morale of the present workers and their performance on the job [1]. e-HRM solutions can be utilized at this time of unpredictability to construct capacities and systematize workforce management [16]. When we looked at the available materials, we realized how important it is to implement effective e-HRM practices that increase employees' capacity and motivation, in addition to other e-HRM practices. We learned this from implementing effective e-HRM practices that increase employees' ability and motivation. These flexible talents are necessary for a firm to flourish in today's unstable economic climate and boost its performance. The power of businesses and organizations to combine and match their existing resources to cultivate new talents that can be used for further investigation of new avenues for long-term growth is the most critical factor determining the viability of these entities over the long term. The problem impacts organizations and businesses of all types; even those run purely for profit [37]. The outcomes of this study positively impact the management of information systems and human resources.

PRACTICAL IMPLICATION

The role will give executives access to the most vital information they can take away. Sustainable EHRM systems for recruitment, selection, training, and performance assessment can help enhance E-HRM processes. Executives need to be aware of the relevance of the capabilities of e-HRM practices to maintain employee engagement and excitement about their jobs. According to the findings presented in this article, E-HRM practices can provide chief executive officers with a better understanding of how to support their workers. Finally, executives need to be aware of the direct connection between their firms' success and the sustainable implementation of e-HRM systems. Maintaining a sustainable way of life is nec- essary in the uncertain modern world. Therefore, companies must emphasize comprehending and beginning the e-HRM operations before they can be implemented.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Big data analytics, artificial intelligence, and cloud computing are just a few examples of the technologies developed as part of Industry 4.0. These technologies are helping to improve the e-HRM system to better meet the diverse requirements of various businesses. The entire workforce needs to be educated on modern HRM systems, and training is required. It is highly recommended that upcoming scholars devote significant time and energy to studying environmentally friendly EHRM systems. The research might be expanded to examine how using a sustainable EHRM platform can improve operational efficacy. In addition, prospective researchers can investigate how businesses might implement ethical EHRM systems throughout people's life cycles, from hiring to firing. It is also encouraged to look at how data and theories from other areas can explain the achievements of EHRM.

CONCLUSION

In the following research initiatives, it would be beneficial to discuss some of the benefits that may be gained via e-HRM. The quality of the information that is made available to each department in an organization is critical to the success of that department. The field of HRM is not an exception to this requirement. By handling information in an electronic format, the company will be able to utilize its various resources, such as time and money, in a far more effective manner. The human resources department's workload is increased due to the significant number of administrative responsibilities that must be fulfilled. On the other hand, due to the digitalization of HR-related processes, human resource professionals can reduce the amount of work they need each day. There are several benefits associated with EHRM, one of which is the acceleration of duties related to human resources, such as exchanging information on employee personnel data. This sort of labour will take considerable time if carried out traditionally. For example, the design of metrics to measure a company's human resources has been a time-consuming effort for any company. On the other hand, the digitalization of human resource measurements makes it possible to do computations in a more time-efficient manner. However, training is required to guarantee that every staff member is conversant with the HRM systems on the cutting edge of

technology. Future researchers are strongly encouraged to do more in-depth investigations on long-term e-HRM systems. It is possible to broaden the scope of an inquiry into how an EHRM system could improve environmental performance. For example, future research may look at how businesses utilize ethical e-HRM systems in hiring and firing processes for workers. It is also advised that you consider the benefits of e-HRM from the point of view of many disciplines to get the whole picture.

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Comparative Investment decisions in emerging textile and FinTech industries in India using GARCH models with high-frequency data

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ABSTRACT – REZUMAT

Comparative Investment decisions in emerging textile and FinTech industries in India using GARCH models with high-frequency data

The domestic textiles and apparel industry stood at $152 billion in 2021, growing at a CAGR of 12% to reach $225 billion by 2025. The textiles and apparel industry in India has strengths across the entire value chain from fibre, yarn, and fabric to apparel. On the other hand, many FinTech companies gained enough importance and attention during the Demonetization and COVID-19 pandemic situation where most people are dependent and prefer cashless payments and receipts over hard cash payments and receipts. Due to the growth of FinTech companies in India, consumer lending FinTech companies in India make up 17% of total FinTech enterprises. Many angel investors are coming forward to invest in such FinTech companies as this industry has much potential to grow in future. As there is enough scope for the expansion of FinTech companies in India, retail investors come forward to invest in the stocks of listed FinTech companies. As retail investors always look forward to returns either in the form of dividends or appreciation of stock prices, it is also necessary to analyse and model the stock price volatility of FinTech companies in India before investing. Hence, this research study is an attempt to use high-frequency data i.e. 1-minute closing prices, to formulate suitable GARCH (Generalised Autoregressive Conditional Heteroscedasticity) models for stock price volatility of listed textiles and FinTech companies that could also capture the asymmetric volatility if it exists due to third phase of COVID-19 pandemic and Russia-Ukraine war. The results concluded that there is a presence of positive shocks which might be due to the third wave of the COVID-19 pandemic that might have again shot the demand for financial products and services of these FinTech companies namely Paytm and PolicyBazaar and there is no negative shock of Russia-Ukraine war.

Keywords: *textile industry of India, FinTech companies, asymmetric volatility, high-frequency data, Indian Stock Market, GARCH models*

Deciziile de investiții comparative în industriile emergente din domeniile textil și FinTech din India folosind modele GARCH cu date de înaltă frecvență

Industria internă din domeniul textil și cel de îmbrăcăminte s-a situat la 152 de miliarde de dolari în anul 2021, crescând cu un CAGR (rata de creştere anuală compusă) de 12% pentru a ajunge la 225 de miliarde de dolari până în 2025. Industria textilă și de îmbrăcăminte din India are puncte forte de-a lungul întregului lanț valoric, de la fibre, fire, materiale textile până la îmbrăcăminte. Pe de altă parte, multe companii FinTech au câștigat suficientă importanță și atenție în timpul situației generate de procesul de demonetizare și de pandemia COVID-19, în care majoritatea persoanelor au depins de conjunctură și au preferat plățile și încasările fără numerar în detrimentul plăților și încasărilor în numerar. Datorită creșterii companiilor FinTech în India, companiile de creditare FinTech din India reprezintă până la 17% din totalul întreprinderilor FinTech. Mulți așa-numiți investitori "îngeri" se preocupă să investească în astfel de companii FinTech, deoarece această industrie are mult potențial de dezvoltare în viitor. Întrucât există suficientă sferă de extindere a companiilor FinTech în India, investitorii de retail se vor prezenta pentru a investi în acțiunile companiilor FinTech listate. Deoarece investitorii din zona de retail așteaptă întotdeauna cu nerăbdare obținerea de profituri, fie sub formă de dividende, fie sub formă de apreciere a prețurilor acțiunilor, este, de asemenea, necesar să se analizeze și să modeleze volatilitatea prețului acțiunilor companiilor FinTech din India înainte de a se investi. Prin urmare, acest studiu de cercetare este o încercare de a utiliza date de înaltă frecvență, adică prețuri de închidere la intervale de 1 minut, pentru a aplica modele GARCH (adică modelul generalizat autoregresiv condiţional heteroscedastic) adecvate pentru volatilitatea prețului acțiunilor la companiile din domeniul textil și FinTech listate, care ar putea capta și volatilitatea asimetrică dacă aceasta există datorită celei de-a treia faze a pandemiei COVID-19 și războiului dintre Rusia și Ucraina. Rezultatele empirice au condus la concluzia că există o prezență de șocuri pozitive care s-ar putea datora celui de-al treilea val al pandemiei COVID-19, care ar fi putut afecta din nou cererea de produse și servicii financiare ale acestor companii FinTech și anume Paytm și PolicyBazaar și nu există un șoc negativ cauzat de războiul dintre Rusia și Ucraina.

Cuvinte-cheie: *industria textilă din India, companii FinTech, volatilitate asimetrică, date de înaltă frecvență, piața bursieră din India, modele GARCH*

INTRODUCTION

The domestic textiles and apparel industry stood at $152 billion in 2021, growing at a CAGR of 12% to reach $225 billion by 2025. The textiles and apparel industry in India has strengths across the entire value chain from fibre, yarn, and fabric to apparel. The organized textile industry in India is characterized by the use of capital-intensive technology for the mass production of textile products and includes spinning, weaving, processing, and apparel manufacturing. On the other hand, technological advances are not new to finance, digital innovation has brought major improvements in the connectivity of systems, in computing power and cost, and in newly created and usable data. These improvements have alleviated transaction costs and given rise to new business models and new entrants [1]. These new entrants are termed as FinTechs. In this digital era, many FinTech start-ups have been started and flourished in India. FinTech, as the name suggests, is the amalgamation of finance and technology. FinTech experienced the most remarkable expansion only after the global financial crisis in 2008. Therefore, it is a rather new area that is growing very fast and has not been fully explored yet [2]. A lot of players in the market are using technology to simplify financial services like lending, insurance, investment, trading, budgeting, and a lot more. This leads to the smooth and efficient functioning of financial services provided by traditional banks and insurance companies. Many FinTech companies gained enough importance and attention during the Demonetization and COVID situation where most people are dependent and prefer cashless payments and receipts over hard cash payments and receipts. Paytm is one the emerging examples of it. As the FinTech sector expands, many players in India are focusing on niche sectors. Consumer lending FinTech companies in India make up 17% of total FinTech enterprises. From business loans to consumer loans, the demand for credit in India is ever-increasing. Moreover, the banks are also tying up with such FinTech companies to provide better facilities, like Paytm which helps in achieving frictionless payments by reducing manual intervention by customers for cards and net banking transactions. Many angel investors are coming forward to invest in such FinTech companies as this industry has much potential to grow in future. Few FinTech companies have reached a certain height by expanding their operations and registering themselves in stock exchanges. Now the point of discussion is that there is enough scope for expansion of FinTech companies in India, should the retail investors come forward to invest in the stocks of listed FinTech companies.

For investing in the stocks of FinTech, it is necessary to analyse the stock price volatility of listed Textile Companies and FinTechs. Again, in recent years, there has been a significant increase in both high-frequency trading (HFT) and algorithmic trading (AT) activity in financial markets. Most of the transaction volume in developed markets is created by HFT [3]. The question arises, to facilitate high-frequency trading (HFT) and algorithmic trading (AT), can the high-frequency data be used to frame suitable volatility models for FinTech companies so the retail investors could forecast the volatility of stock prices of FinTechs for investment? This paper is an attempt to use high-frequency data to formulate suitable GARCH (Generalised Autoregressive Conditional Heteroscedasticity) models for listed textiles and FinTech companies that could capture the asymmetric volatility if any and forecast volatility accordingly if the companies have adequate time series data points.

REVIEW OF LITERATURE

Many studies have already been done in the area of FinTech Companies. This review of literature is divided into 4 sections. The first section deals with a few important different studies on Textile Industry. The next section deals with the growth of FinTech. The third section specifically deals with the studies related to FinTechs and the stock market. The last section deals with the investment using GARCH models.

Present scenario, prospects and determinants of textile industry growth

A study attempted to measure the changes and instabilities in employment and the number of apparel factories in Bangladesh after the MFA phase-out based on secondary data from 1998 to 2011 using different statistical techniques [4]. Moreover, a study from India where the authors discussed the impacts of cotton yarn price volatility on handloom weavers and the public and private interventions that have been employed to address them [5].

Present scenario, prospects and determinants of fintech growth

A study explores the current state and prospects of FinTech in the Middle East and North Africa (MENA) region whose financial systems are not deepening, by applying descriptive, inductive and analytical methodologies [6]. Again a review paper consists of burgeoning literature on FinTech and FinTech-enabled services, focusing on the opportunities and risks for banks by using high-quality bank-level data from 115 countries around the world for the past 16 years and computing statistical moments of some key indicators of the changing banking landscape in the FinTech era and found that FinTech lenders will replace banks, perhaps because banks are developing their own FinTech platforms or working with FinTech start-ups [7]. Similarly, a paper aims to find out the main factors that determine the change in the number of FinTech companies in Lithuania and predict the future development of this sector and found that 8 out of 17 factors indicate economic conditions, 4 out of 9 factors indicating business environment and 7 out of 14 other factors are major factors [2]. Likewise, a study covers the development, opportunities, and challenges of financial sectors because of

new technologies in India. This chapter throws light on opportunities that emerged because of demographic dividend, high penetration, and access to the latest and affordable technology, affordable cost of smartphones, and government policies such as Digital India, Startup India, and Make in India. Lastly, this chapter portrays the untapped potential of FinTech in India [8]. Apart from that, a paper describes the key role of FinTech regulation to manage the risks, and keep the balance and stability of the FinTech ecosystem from the highest impact of risks' in this industry by taking 3 variables i.e. namely Risk Construct, Financial Regulation Construct and FinTech Ecosystem Constructs by taking interview from 150 FinTech industry Stakeholders in Indonesia using purposive sampling and found that COVID-19 pandemic has a positive influence on startups FinTech companies [9]. Besides that research showed that FinTechs are bringing about economically meaningful changes in the production of financial services, with implications for the industrial structure of finance. Regulatory and supervisory policy tools will have to adapt. Existing regulatory perimeters may not adequately cover emerging providers of financial services, and new players may pose challenges to day-to-day financial supervision [1]. Furthermore, a study attempts to determine whether FinTech is a threat to global banking and found that the average cost of sending remittances and the role of banks in sending remittances have been declining [10]. Likewise, a paper has presented the main risk concerns that arise with the development of the most important financial technologies, and has suggested research directions in risk measurement models, appropriate to manage and mitigate the involved risks like a strict collaboration and open discussion between academics, FinTech experts, and regulators can help move us ahead in this direction, developing FinTech risk management models that, while limiting the negative impact of disrupting technologies, encourage their development [11, 12].

FinTech and stock market

Now some of the important studies related to FinTech and Stock market. A paper analyses two indices of public FinTech firms i.e. one for the United States and another for Europe by computing the ΔCoVaR of the FinTech firms against the financial system to measure their impact on systemic risk and found that FinTech firms do not contribute greatly to systemic risk [13]. Again, a study tries to find out the effect of FinTech funding frequency and value on retail banks' stock returns listed on the Indonesia Stock Exchange and found that FinTech funding frequency does not affect retail banks' stock returns [14]. Similarly, a study examines the effects of high-frequency trading (HFT) and algorithmic trading (AT) activities, which represent important technological developments in financial markets in the past two decades, on Borsa Istanbul in terms of volatility by using GJR-GARCH-in-Mean and I-GARCH models during pre and post period of implementation of BISTECH project, a technology transformation program, which is a stock market transaction system that was put into operation in 2015, along with Genium INET software and other technological components [3]. Furthermore, a study analyses the impact of the COVID-19 pandemic on the dynamics of volatility spillovers in financial markets, focusing on innovative assets, such as a FinTech index and Bitcoin, and traditional assets, such as gold, oil, global equities, and the USD and found that bursts of volatility spillovers between the FinTech index, Bitcoin, and traditional assets are associated with the outbreak of this global pandemic [15].

Retail investment and GARCH models

The research applied the E-GARCH model approach to data from 2015 to 2018, to explore the influence of investor sentiment on the return rate of the Shanghai Composite Index [16]. Again, a paper investigates whether changes in a firm's investor following can influence volatility in the French stock market. By defining a novel proxy of investor following, the paper contributes to the emerging literature on the impact of information technology on financial markets [17, 18]. Many research questions have been raised while studying the existing literature of various researches related to textiles, FinTech, the stock market and FinTech and GARCH model – there are very few studies related to FinTech and the stock market. Moreover, there is not enough research on the stock price volatility of Textiles and FinTech Companies in India. Can it be possible to use the High-frequency data to formulate a suitable GARCH model for listed textiles and FinTech companies in India? Can these formulated GARCH models also grasp the leverage effect of events that took place from December 2021 to July 2022? Hence related stocks Whether COVID-19 affected the stock price volatility of Indian Banks? Now it will be interesting to find out the answers to this research questions through this study. As high-frequency data are not available for textiles, investment in FinTech could be a wise decision; hence, the objectives are made accordingly.

OBJECTIVES OF THE STUDY

- To analyze the volatility of the stock price of listed FinTech Companies in India namely One 97 Communications Ltd (Paytm), PB FinTech Ltd. (Policy Bazar) and Niyogin FinTech Ltd.
- To formulate a suitable GARCH Model for each listed FinTech Company that could grasp their volatility.

HYPOTHESES OF THE STUDY

- H_{0A}: The high-frequency data i.e. 1-minute closing price data of three listed FinTech companies under BSE, from 1st December 2021 to 31st July 2022 are stationary in nature.
- H_{0B}: There is no ARCH effect on the stock price volatility of 3 listed FinTech Companies under BSE from December 2021 to July 2022.

- H_{0C}: There is no leverage effect on the stock price volatility of each 3 listed FinTech Companies under BSE from December 2021 to July 2022.

MATERIALS AND METHODS

The study is Empirical in nature. The study is based on High-frequency secondary data. The secondary data involves the 1-minute closing prices of listed FinTech companies on BSE.

There are only three listed companies on BSE namely One 97 Communications Ltd (Paytm), PB FinTech Ltd. (PolicyBazaar) and Niyogin FinTech Ltd. The 1-minute data is for 8 months which ranges from 1st December 2021 to 31st July 2022 that have been extracted and downloaded from www.moneycontrol.com. Wherever required, an attempt has been made to make the unbalanced data into balanced data i.e. 5 days a week. There are only 3companies listed on BSE which is specifically recognised as FinTech Industry which are considered for this study. The total sample size is 1,95,144 i.e. 3 FinTech companies of 65,048 observations each [19]. For the application of GARCH, Log Returns have been calculated to make the data stationary and Augmented Dickey Fuller Test (ADF) has been employed to check whether the data is stationarity in nature. Different GARCH models have been trailed and tested based on various statistical parameters to find a suitable GARCH model for each FinTech company. After formulating the models, the models have been used to predict the volatility for the period last 15 trading days of the selected trading period i.e. 16thJuly, 2022 to 31st July, 2022. To formulate models and forecast the volatility of selected FinTech stocks, E-Views 10 has been used.

SIGNIFICANCE OF THE STUDY

The affairs of the study could provide a feasible volatility model for each selected textiles and FinTech stocks that can assist the investors having basic knowledge on algorithms, to run the developed models to study and forecast the volatility of these stocks. This may enable them to take a calculated risk. Through this study the price volatility of listed textiles and FinTechs could be judged by taking into consideration the positive or negative news or leverage effect of different important events on the price volatility which could help the scholars and researchers to go through a proper study to develop suitable volatility predicted models in future as well. In addition to that, the research could highlight the impact of important events on the price volatility of commodities under the energy sector, to the policymakers as well, which may help them to formulate relevant counter policies to avoid inflation.

DATA ANALYSIS, RESULTS AND DISCUSSION

The reason for selecting GARCH models over ARCH is because the major limitations of the ARCH Model suppose that the variance or heteroscedastic of tomorrow's return is an equally weighted average of the residuals squared from the last 22 days. The assumption of equal weights looks ill-favoured, as one may think that the more recent events would be more significant and therefore should have more weight [20]. To the contrary GARCH has diminishing weights that now decline to zero. It provides parsimonious models that are soft to estimate and, even in its simplest form, has proven astonishingly successful in forecasting conditional variances [7]. The simple GARCH model i.e. GARCH (1,1) is depicted below:

$$h_t = \varphi + \theta_1 h_{t-1} + b_1 u_{t-1}^2 \quad (1)$$

where h_t is variance or returns, φ – Constant, θ – GARCH effects, h_{t-1} – past values of itself, u_{t-1}^2 – past values of the shocks captured by the lagged spared error terms.

The EGARCH model is distinct from the GARCH variance structure because of the log of the variance [21]. In addition to that, the advantage of using EGARCH is that the positivity of the parameters is assured as it will be working with the log of the variance [22]. The following formula is for the EGARCH model:

$$\log(h_t) = \varphi + \sum_{i=1}^{q} \eta_i \left| \frac{u_t - i}{\sqrt{h_t - i}} \right| + \sum_{i=1}^{q} \lambda_i \frac{u_t - i}{\sqrt{h_t - i}} + \\ + \sum_{k=1} \theta_k \log(h_{t-k}) \quad (2)$$

where $\log(h_t)$ is a log of variance or log returns, φ – Constant, η_i – ARCH Effects, λ_i – Asymmetric effects, θ – GARCH effects.

The threshold GARCH (TGARCH) is similar to the GJR model, different only because of the standard deviation, instead of the variance, in the specification [23]. The following formula is for TGARCH(1,1) model:

$$h_t = \varphi + \theta_1 h_{t-1} + b_1 u_{t-1}^2 + \gamma_1 u_{t-1}^2 D_{t-1} \quad (3)$$

where h_t is variance or returns, φ – Constant, θ – GARCH effects, D_t – value of 1 (bad news) for $u_t < 0$, γ – Asymmetric effects or leverage term, b_1 – good news (positive shock) has an impact of b_1, b_{1+} γ_1 – Impact of Bad news.

To choose an appropriate model, the results of the formulated models with three different distributions need to be analysed. The standard way to select a model is the coefficients, ARCH and GARCH should be significant and there should not be the existence of Heteroscedasticity and autocorrelation after framing the model. In addition to that, the model with lesser AIC (Akaike Information Criterion) and SIC (Schwartz Information Criterion) is better and a model with higher Log Likelihood statistics, R squared and Adjusted R Squared is better [24]. The following section deals with a brief description of three FinTech companies under BSE as of 31st March 2022 and the tables representing the results of different models. The major obstacle in predicting the volatility of textile companies is the unavailability of high-frequency

data due to which only FinTechs are considered feasible investments.

About three listed FinTech companies in India

One 97 Communications Ltd (Paytm)

One 97 Communications Ltd (Paytm) is India's leading digital ecosystem for consumers and merchants, according to RedSeer. It offers payment services, commerce and cloud services, and financial services to 337 million consumers and over 21.8 million merchants registered with it, as of June 30, 2021. Paytm was launched in 2009, as a "mobile-first" digital payments platform to enable cashless payments for Indians, giving them the power to make payments from their mobile phones. Starting with bill payments and mobile top-ups as the first use cases, and Paytm Wallet as the first Paytm Payment Instrument, the company has built the largest payment platform in India based on the number of consumers, number of merchants, number of transactions and revenue as of March 31, 2021, according to RedSeer. As per the Kantar BrandZ India 2020 Report, the "Paytm" brand is India's most valuable payments brand, with a brand value of US$ 6.3 billion, and Paytm remains the easiest way to transact across multiple methods.

PB FinTech Ltd. (Policybazar)

PB FinTech Ltd. launched Policybazaar, its flagship platform, in 2008 to respond to Consumers' need for more awareness, choice and transparency and create a consumer-pull-based, provider-neutral model for insurance distribution. In 2014, PB FinTech Ltd. launched Paisabazaar to transform how Indians access personal credit by accentuating ease, convenience and transparency in selecting a variety of personal loans and credit cards. According to Frost & Sullivan, Paisabazaar was India's largest digital consumer credit marketplace with a 53.7% market share, based on disbursals in Fiscal 2021. In Fiscal 2020, Policybazaar was India's largest digital insurance marketplace among all online insurance distributors with a 93.4% market share based on the number of policies sold.

Furthermore, in Fiscal 2020, Policybazaar constituted 65.3% of all digital insurance sales in India by number of policies sold (including online sales done directly by insurance companies and by insurance distributors).

Niyogin FinTech Ltd.

Niyogin FinTech Limited operates as a non-banking finance company. The Company offers loans, finance, and investment, as well as lending and allied activities to micro, small, and medium enterprises. Niyogin FinTech serves customers in India. Niyogin believes in superior execution leveraging cutting-edge technology, innovative risk management and strong on-ground connections. To give small businesses access to a holistic support system that is cost-efficient through innovative technology and a committed network of partners with a vision to be the country's best small business-centric organization, empowering customers through an ecosystem of

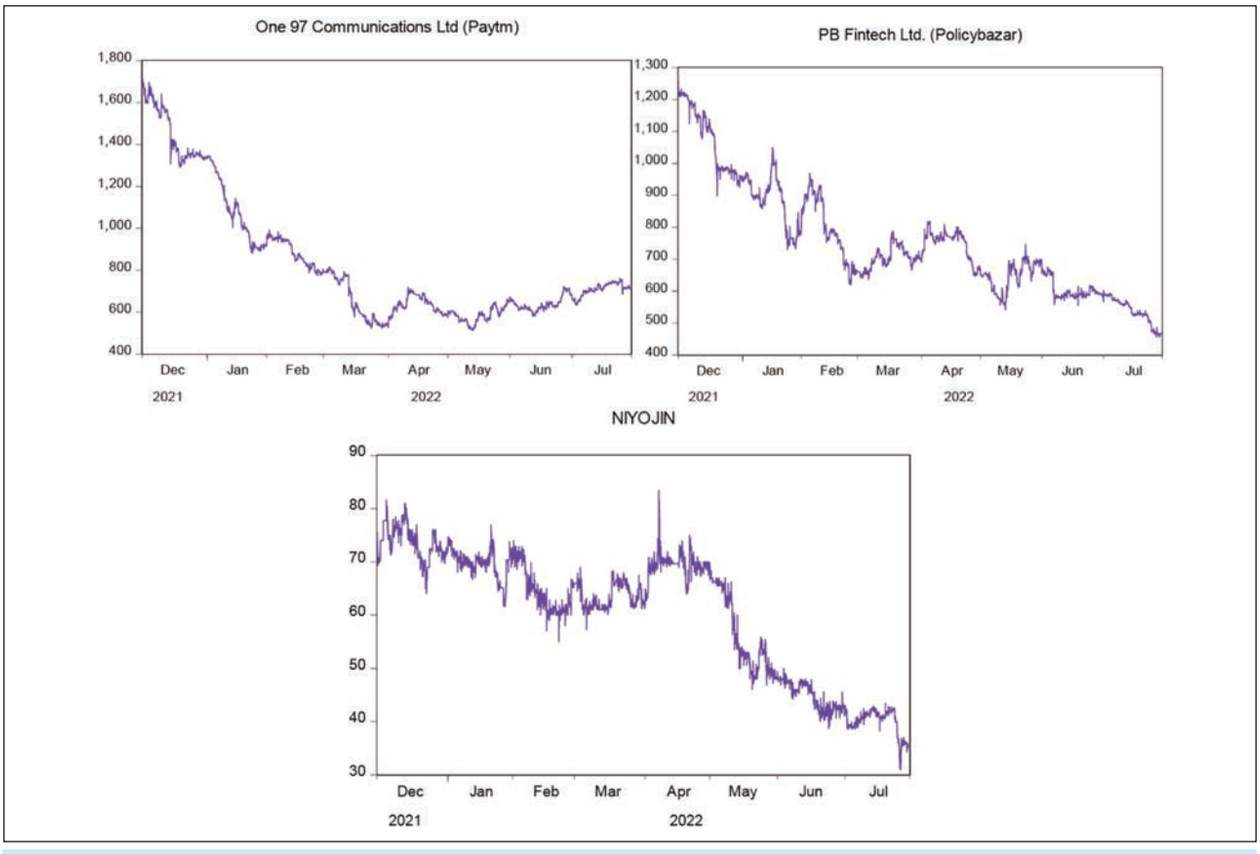

Fig. 1. Graphs Representing Stock Prices of Paytm, PolicyBazaar and Niyojin FinTech Companies from 1st December 2021 to 31st July 2022 (*Source: Authors' Formulation using EVIEWS 10*)

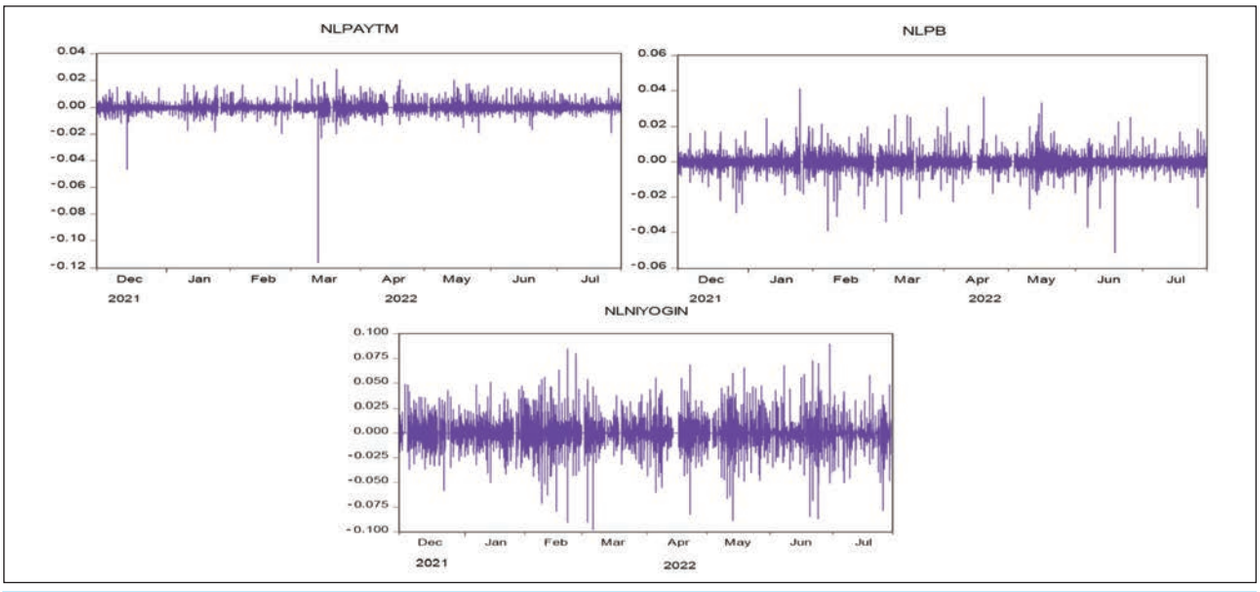

Fig. 2. Graphs Representing Log Returns of Paytm, PolicyBazaar and Niyojin FinTech Companies from 1st December 2021 to 31st July 2022 (*Source: Authors' Formulation using EVIEWS 10*)

products, partnerships, technology and exceptional customer experience.

For the application of GARCH, Log Daily Returns have been calculated to make the data stationary. Again the graphs of log returns have been plotted for visualization. Augmented Dickey Fuller Test (ADF) will be applied to check whether the data is stationarity in nature.

The stationarity of log returns series of the above FinTech companies have been examined with the help of a unit root test named Augmented Dickey Fuller Test with the inclusion of test equations as Intercept, Trend and Intercept and None and found stationary. After visualising the above graphs of log returns of all the FinTech companies, it can be said that there is the existence of volatility clustering in the data of all companies i.e. huge variations in log returns followed by huge variations in log returns and small variations in log returns followed small variations in log returns. Moreover, it can also be observed there were certain abnormal variations in the returns of the stocks of the selected companies. These variations indicate that there might be the existence of asymmetricities which should be statistically checked while framing a suitable GARCH model. Moreover, the data of all selected companies are leptokurtic or highly peaked which have been checked with the values of the coefficients of Skewness, Kurtosis and Jarque-Bera Statistics.

Testing ARCH effect

To apply any GARCH Model it is also mandatory to inspect the presence of the ARCH effect within the data i.e. price volatility of three listed FinTechs. The following table is based on testing the presence of ARCH effects in data related to the price volatility of the 3 FinTechs taken into study.

Table 1 reveals the results of the Heteroscedasticity Test of Paytm, PolicyBazaar and Niyogin which could show the presence of ARCH effect in the data. The ARCH effect can be judged from lag range multiplier (LM) statistics which is shown in the form of

Table 1

RESULTS OF HETEROSKEDASTICITY TEST TO EXAMINE ARCH EFFECTS ONE 97 COMMUNICATIONS LTD. (PAYTM)			
Heteroskedasticity Test: ARCH			
F-statistic	114.7372	Prob. F(1,65042)	0.0000
Obs*R-squared	114.5387	Prob. Chi-Square(1)	0.0000
PB FinTech Ltd.			
Heteroskedasticity Test: ARCH			
F-statistic	1271.304	Prob. F(1,65043)	0.0000
Obs*R-squared	1246.971	Prob. Chi-Square(1)	0.0000
Niyogin FinTech Ltd.			
Heteroskedasticity Test: ARCH			
F-statistic	3710.881	Prob. F(1,65043)	0.0000
Obs*R-squared	3510.700	Prob. Chi-Square(1)	0.0000

Table 2

DECISION TABLE FOR SELECTING SUITABLE GARCH (1,1), TGARCH (1,1) & EGARCH (1,1) MODEL FOR ONE 97 COMMUNICATIONS LTD (PAYTM)

Statistics	GARCH (1,1)			TGARCH			EGARCH		
	Normal Distribution	Student t's Distribution	Generalised Error Distribution	Normal Distribution	Student t's Distribution	Generalised Error Distribution	Normal Distribution	Student t's Distribution	Generalised Error Distribution
Significant Coefficients	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ARCH Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GARCH Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	340071.0	359204.3	358891.0	340331.3	NA	358534.2	339582.0	359291.9	358237.6
AIC	–10.45633	–11.04461	–11.03498	–10.46430	NA	–11.02397	–10.44126	–11.04727	–11.01486
Schwartz IC	–10.45563	–11.04377	–11.03414	–10.46346	NA	–11.02300	–10.44042	–11.04629	–11.01388
Heteroscedas-ticity (ARCH LM-Test)	No	No	No	No	No	No	No	No	No
Autocorrelation (Correlogram of Residuals)	No	No	No	No	No	No	No	No	No

Observed R Squared. The Observed R-squared statistics of all these three companies are considered significant as their probability value is less than 0.05. Moreover, the F statistics are also significant as its significant value is less than 0.05. This proves that there is an existence of ARCH effect in the stock price volatility of all these 3 companies which indicates GARCH models are suitable for the data.

The table 2 reveals that Coefficients, ARCH Effect and GARCH are significant in all three GARCH (1,1), all the three EGARCH (1,1) and all the three TGARCH (1,1) models with Normal Distribution Error Construct, with Student t's Distribution Error Construct and with Generalised Error Distribution Construct. After framing the above models, there is no Heteroscedasticity (which has been checked with the help of the ARCH LM Test) and no Autocorrelation (which has been checked with the help of a cor-relogram of residuals and squared residuals) in any of the nine models. While comparing the AIC and SIC of all the above nine models, it has been found that EGARCH with Student t's distribution has the lowest AIC (–11.04727) and SIC (–11.04629) as compared to the other eight models. This model also has the highest Log-Likelihood (359291.9). Hence, this is considered as the most suitable model. The result of the selected EGARCH (1,1) Model for One 97 Communications Ltd (Paytm) is mentioned in the table given below.

Table 3

RESULTS OF EGARCH (1,1) MODEL WITH STUDENT'S T DISTRIBUTION CONSTRUCT FOR ONE 97 COMMUNICATIONS LTD (PAYTM)

Dependent Variable: NLPAYTM
Method: ML ARCH - Student's t distribution
Date: 09/11/22 Time: 16:43
Sample (adjusted): 12/01/2021 09:17 7/29/2022 15:29
Included observations: 65045 after adjustments
Convergence achieved after 24 iterations
Presample variance: backcast (parameter = 0.7)
LOG(GARCH) = C(3) + C(4)*ABS(RESID(–1)/@SQRT(GARCH(–1))) + C(5)*RESID(–1)/@SQRT(GARCH(–1)) + C(6)*LOG(GARCH(–1))

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	–1.67E-05	1.17E-07	–143.1913	0.0000
NLPAYTM(–1)	–0.127766	0.003290	–38.83038	0.0000
Variance Equation				
C(3)	–0.360869	0.006121	–58.95468	0.0000
C(4)	0.215254	0.003599	59.81152	0.0000
C(5)	0.059267	0.001967	30.13622	0.0000
C(6)	0.983256	0.000329	2989.062	0.0000
T-DIST. DOF	2.934953	0.036506	80.39625	0.0000
R-squared	–0.019382	Mean dependent var		–1.37E-05
Adjusted R-squared	–0.019397	S.D. dependent var		0.001663
S.E. of regression	0.001679	Akaike info criterion		–11.04727
Sum squared resid	0.183283	Schwarz criterion		–11.04629
Log likelihood	359291.9	Hannan-Quinn criterion		–11.04697
Durbin-Watson stat	1.731277			

The above table shows the results of the selected EGARCH(1,1) model with Student t's distribution Construct for One 97 Communications Ltd (Paytm). The results are classified into two parts. The upper part shows the mean equation and the lower part represents the variance equation. In the mean equation, the constant (C) is significant as the probability value is less than 0.05 and even the co-efficient of the first lag [NLPAYTM(–1)] is also significant as it is probability value is also less than 0.05.

In the case of the variance equation, C(3) is the constant, C(4) is the GARCH Coefficient, C(5) is the Asymmetric Coefficient, and C(6) is the GARCH Coefficient. All the coefficients of the variance equation are significant as their probability values are less than 0.05. The coefficient of an asymmetric term is positive, i.e. 0.06 approx. and it is also statistically significant even at the 1% level, which indicates that for this stock there are asymmetries. Hence, this model seems fit to the stock price data of Paytm and would be suitable for forecasting the stock price volatility of the company.

Table 4 reveals that Coefficients, ARCH Effect and GARCH are significant in two out of three GARCH (1,1), all three EGARCH (1,1) and all the three TGARCH (1,1) models with Normal Distribution Error Construct, with Student t's Distribution Error Construct and with Generalised Error Distribution Construct. After framing the above models, there is no Heteroscedasticity (which has been checked with the help of the ARCH LM Test) and no Autocorrelation (which has been checked with the help of a correlogram of residuals and squared residuals) in any of the nine models. While comparing the AIC and SIC of all the above nine models, it has been found that EGARCH with Generalised Error Distribution has the lowest AIC (–11.05742) and SIC (–11.05644) as compared to the other eight models. This model also has the highest Log-Likelihood (359627.4). Hence, this is considered as the most suitable model. The result of the selected EGARCH (1,1) Model for PB FinTech Ltd is mentioned in the table 5.

Table 5 shows the results of the EGARCH(1,1) model with a Generalized error distribution Construct for PB FinTech Ltd. The results are classified into two parts. The upper part shows the mean equation and the lower part represents the variance equation. In the mean equation, the constant (C) is significant as the probability value is less than 0.05 and even the co-efficient of the first lag [NLPB(–1)] is also significant as it is probability value is also less than 0.05.

In the case of the variance equation, C(3) is the constant, C(4) is the ARCH Coefficient, C(5) is the Asymmetric Coefficient, and C(6) is the GARCH Coefficient. All the coefficients of the variance equation are significant as their probability values are less than 0.05. The coefficient of an asymmetric term is positive, i.e. 0.0675 approx. and it is also statistically significant even at the 1% level, which indicates that for this stock there are asymmetries. Hence, this model seems fit to the stock price data of PB FinTech Ltd. and would be suitable for forecasting the stock price volatility of the company.

Table 6 reveals that Coefficients, ARCH Effect and GARCH are significant in one out of the three GARCH (1,1), two out of the three EGARCH (1,1) and one out of the three TGARCH (1,1)models with Normal Distribution Error Construct, with Student t's Distribution Error Construct and with Generalised Error Distribution Construct. After framing the above models, there is no Heteroscedasticity (which has

Table 4

DECISION TABLE FOR SELECTING SUITABLE GARCH (1,1), TGARCH (1,1) & EGARCH (1,1) MODEL FOR PB FINTECH LTD

Statistics	GARCH (1,1)			TGARCH (1,1)			EGARCH (1,1)		
	Normal Distribution	Student t's Distribution	Generalised Error Distribution	Normal Distribution	Student t's Distribution	Generalised Error Distribution	Normal Distribution	Student t's Distribution	Generalised Error Distribution
Significant Coefficients	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ARCH Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GARCH Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	335904.6	353381.1	357740.5	335915.4	352922.1	NA	336670.6	356756.2	359627.4
AIC	–10.32806	–10.86539	–10.99943	–10.32836	–10.85125	NA	–10.35158	–10.96913	–11.05742
Schwartz IC	–10.32737	–10.86455	–10.99859	–10.32753	–10.85027	NA	–10.35075	–10.96816	–11.05644
Heteroscedasticity (ARCH LM-Test)	No	No	No	No	No	No	No	No	No
Autocorrelation (Correlogram of Residuals)	No	No	No	No	No	No	No	No	No

been checked with the help of thve ARCH LM Test) and no Autocorrelation (which has been checked with the help of a correlogram of residuals and squared residuals) in any of the nine models. While comparing the AIC and SIC of all the above nine models, it has been found that GARCH with Student t's distribution has the lowest AIC (–15.53218) and SIC (–15.53134) as compared to the other five models. This model also has the highest Log-Likelihood (505159.1). Hence, this is considered as the most suitable model. The result of the selected GARCH (1,1) Model for Niyogin Ltd. is mentioned in the table 7.

Table 5

RESULTS OF EGARCH (1,1) MODEL WITH GENERALIZED ERROR DISTRIBUTION CONSTRUCT FOR PB FINTECH LTD.

Dependent Variable: NLPB
Method: ML ARCH - Generalized error distribution (GED)
Date: 09/11/22 Time: 17:25
Sample (adjusted): 12/01/2021 09:17 7/29/2022 15:30
Included observations: 65046 after adjustments
Convergence achieved after 65 iterations
Presample variance: backcast (parameter = 0.7)
LOG(GARCH) = C(3) + C(4)*ABS(RESID(–1)/@SQRT(GARCH(–1))) + C(5)*RESID(–1)/@SQRT(GARCH(–1)) + C(6)*LOG(GARCH(–1))

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	–1.88E-05	3.53E-08	–532.8613	0.0000
NLPB(–1)	–0.082177	0.002025	–40.59007	0.0000
Variance Equation				
C(3)	–0.256660	0.003214	–79.85324	0.0000
C(4)	0.231130	0.002641	87.50845	0.0000
C(5)	0.067419	0.001663	40.54481	0.0000
C(6)	0.991904	0.000128	7750.765	0.0000
GED PARAMETER	0.703055	0.002162	325.1633	0.0000
R-squared	–0.002960	Mean dependent var		–1.51E-05
Adjusted R-squared	–0.002975	S.D. dependent var		0.001810
S.E. of regression	0.001812	Akaike info criterion		–11.05742
Sum squared resid	0.213656	Schwarz criterion		–11.05644
Log likelihood	359627.4	Hannan-Quinn criterion		–11.05711
Durbin-Watson stat	1.883933			

Table 7 shows the results of the GARCH(1,1) model with Student t's distribution Construct for Niyogin FinTech Ltd. The results are classified into two parts. The upper part shows the mean equation and the lower part represents the variance equation. In the mean equation, the constant (C) is significant as the probability value is less than 0.05 and even the co-efficient of the first lag [NLNIYOGIN(–1)] is also significant as its probability value is also less than 0.05.

In the case of variance equation, C is the Constant, RESID(–1)^2 is the ARCH co-efficient,

RESID(–1)^2*(RESID(–1)<0) is the asymmetric co-efficient, and GARCH(–1) is the GARCH co-efficient. Only the ARCH and GARCH coefficients are significant in the variance equation as their probability values are less than 0.05. The coefficient of an

Table 6

DECISION TABLE FOR SELECTING SUITABLE GARCH (1,1), TGARCH (1,1) & EGARCH (1,1) MODEL FOR NIYOGIN FINTECH LTD

Statistics	GARCH (1,1)			TGARCH (1,1)			EGARCH (1,1)		
	Normal Distribution	Student t's Distribution	Generalised Error Distribution	Normal Distribution	Student t's Distribution	Generalised Error Distribution	Normal Distribution	Student t's Distribution	Generalised Error Distribution
Significant Coefficients	No	Yes	No	Yes	Yes	No	Yes	No	No
ARCH Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GARCH Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	279704.6	505159.1	331723.2	279804.3	468946.4	313122.6	280159.9	427838.1	304919.6
AIC	–8.600056	–15.53218	–10.19946	–8.603091	–14.41870	–9.627512	–8.614025	–13.15472	–9.375291
Schwartz IC	–8.599358	–15.53134	–10.19863	–8.602253	–14.41772	–9.626535	–8.613187	–13.15375	–9.374314
Heteroscedasticity (ARCH LM-Test)	No	No	No	No	No	No	No	No	No
Autocorrelation (Correlogram of Residuals)	No	No	No	No	No	No	No	No	No

Table 7

RESULTS OF GARCH (1,1) MODEL WITH STUDENT'S T DISTRIBUTION CONSTRUCT FOR NIYOGIN LTD.

Dependent Variable: NLNIYOGIN
Method: ML ARCH - Student's t distribution
Date: 09/11/22 Time: 22:22
Sample (adjusted): 12/01/2021 09:17 7/29/2022 15:30
Included observations: 65046 after adjustments
Failure to improve Likelihood after 66 iterations
Presample variance: backcast (parameter = 0.7)
GARCH = C(3) + C(4)*RESID(–1)^2 + C(5)*GARCH(–1)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	8.14E-09	1.61E-09	5.056414	0.0000
NLNIYOGIN(–1)	0.412086	0.002888	142.6697	0.0000
Variance Equation				
C	1.85E-15	9.87E-17	18.74773	0.0000
RESID(–1)^2	0.604497	0.006569	92.01715	0.0000
GARCH(–1)	0.276554	0.000526	525.6451	0.0000
T-DIST. DOF	2.780253	0.005127	542.3203	0.0000
R-squared	–0.237692	Mean dependent var		–1.11E-05
Adjusted R-squared	–0.237711	S.D. dependent var		0.004582
S.E. of regression	0.005098	Akaike info criterion		–15.53218
Sum squared resid	1.690554	Schwarz criterion		–15.53134
Log likelihood	505159.1	Hannan-Quinn criterion		–15.53192
Durbin-Watson stat	2.774798			

asymmetric term is negative, i.e. –0.0082 and it is not statistically significant even at the 5% level, which indicates that for this stock there are no asymmetries due to the pandemic COVID-19. Hence, this model seems fit to the stock price data of Niyogin FinTech Ltd. and would be suitable for forecasting the stock price volatility of the company.

Forecasting of stock price volatility and returns of three listed companies

The suitable GARCH model that has been formulated for each listed FinTech company has been used to forecast stock price volatility and returns. A selected GARCH Model has been formulated taking into consideration the data for 7 months 15 days (01/12/2021 to 15/07/2022) and then forecasting has been done for the remaining 15 days (16/07/2022 to 31/07/2022. The forecasting graphs are mentioned in figure 3. In figure 3, the forecasting graph of Paytm shows that there were negligible fluctuations in the returns but so far as the volatility is concerned high fluctuations can be seen during the 25th to 29th moderate levels of fluctuations on other days and the possibility to continue in future as well. Similar case with the returns and stock price volatility of Niyogin Ltd. – no fluctuations in returns but high volatility throughout the forecasting period which may continue in the future too. Hence, these two stocks i.e. Paytm and Niyogin should not be considered for retail investment. On the contrary, the forecasting graphs of PB FinTech Ltd. seem much more stable as its returns have no fluctuations and even the volatility has been slowed down to a little towards the end

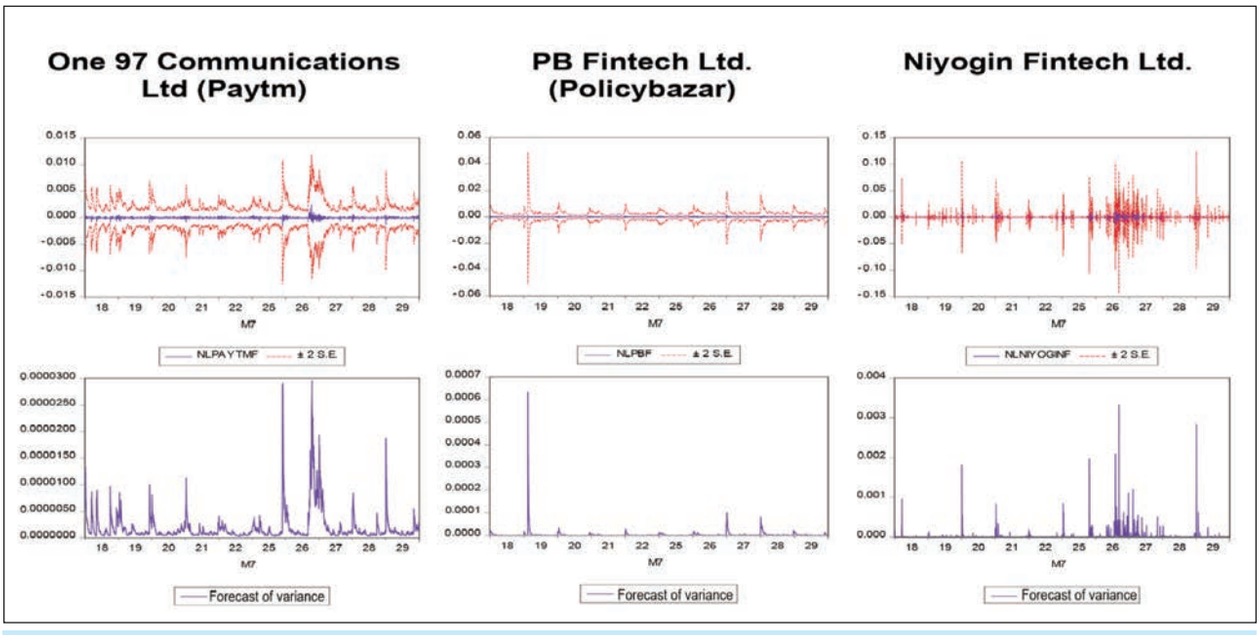

Fig. 3. Forecasting Graphs of Stock Price Volatility and Returns of One 97 Communications Ltd (Paytm), PB FinTech Ltd. (Policybazar) &Niyogin FinTech Ltd. (*Source: Authors' Formulation using EVIEWS 10*)

of the forecasting period and hence can be considered by retail investors.

CONCLUSIONS

From the above results and discussion, it can be observed that EGARCH (1,1) with Student t's Distribution Model is the suitable volatility model for One 97 Communications Ltd (Paytm)to grasp the volatility along with the leverage effect during those eight months i.e. 1st December 2021 to 31st July 2022, as it has highest log likelihood and lowest AIC and Schwartz IC with all significant coefficients. Similarly, EGARCH (1,1) with a Generalised Error Distribution Model is the suitable volatility model for PB FinTech Ltd. (Policy Bazar) to grasp the volatility along with the leverage effect during those eight months, i.e. 1st December 2021 to 31st July 2022 as the model has highest log likelihood and lowest AIC and Schwartz IC with all significant coefficients. This implies that there is an existence of asymmetricity in the stock price volatility of Paytm and Policy Bazar. The point of discussion is the asymmetricity coefficient in the models. The asymmetricity coefficient (λ) is positive and also statistically significant in both the above EGARCH models which implies that the good news (positive shocks) generates larger volatility than the bad news (negative shocks). The presence of positive shocks might be due to the third wave of COVID-19 which might have again shot the demand for financial products and services of these FinTech companies. Paytm might get more demand for cashless receipts and payments while PolicyBazaar might be able to provide many insurance via digital mode. On the other hand, for Niyogin FinTech Ltd., the simple GARCH model i.e. GARCH (1,1) is suitable to grasp the volatility during those eight months. There is no existence of any leverage effect or any effect of positive and negative news on the stock price volatility of Niyogin FinTech Ltd. The non-existence of asymmetricity in the stock price volatility of Niyogin, even during the third wave might be due non exposure of any positive or negative news to the nature of services provided by them during that period. Moreover, the positive asymmetricity coefficient of both the EGARCH models for Paytm and PolicyBazaar and the absence of leverage effect in the stock price volatility of Niyogin also inferred that the war between Ukraine and Russia did not adversely affect the stock price volatility of these listed FinTech companies. Hence, it could be concluded that investment in FinTechs is more feasible than textiles in India at present. These statistical models with the use of high-frequency data can also lead future researchers to develop different models for forecasting using the high-frequency data that can be used even for Algo Trading. Moreover, further research can also be done on removing the noise from the high-frequency data to make the short-term forecasting models more accurate.

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Evaluation of the comfort properties of functional knitted fabrics for people with special needs

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ABSTRACT – REZUMAT

Evaluation of the comfort properties of functional knitted fabrics for people with special needs

In this study, several comfort properties of knitted fabrics were investigated. Seven types of knitted fabrics made of combinations of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) were produced. The knitted samples were subjected to several comfort tests, including air permeability, thermal resistance and water vapour resistance assessments. To determine the correlations among the comfort properties of the fabric, fabric structural properties, such as fabric weight and fabric thickness, were considered. Moreover, statistically significant differences were found in terms of dry thermal resistance, water vapour resistance and air permeability depending on the structural parameters of the fabric.

Keywords: *knitted fabrics, thermal comfort, air permeability, water vapour resistance, thermal resistance*

Evaluarea proprietăților de confort ale tricoturilor funcționale pentru persoanele cu nevoi speciale

În acest studiu, au fost investigate mai multe proprietăți de confort ale tricoturilor. Șapte tipuri de tricoturi au fost realizate din combinații de fibre naturale (de exemplu, bumbac, lână și bambus), fibre artificiale (de exemplu, modal) și fibre sintetice (de exemplu, poliester și acrilice). Probele tricotate au fost supuse mai multor teste de confort, inclusiv permeabilitatea la aer, rezistența termică și evaluările rezistenței la vapori de apă. Pentru a determina corelațiile dintre proprietățile de confort ale tricoturilor, au fost luate în considerare proprietățile structurale ale materialelor, cum ar fi masa și grosimea. În plus, s-au constatat diferențe semnificative statistic în ceea ce privește rezistența termică uscată, rezistența la vapori de apă și permeabilitatea la aer în funcție de parametrii structurali ai tricotului.

Cuvinte-cheie: *tricoturi, confort termic, permeabilitate la aer, rezistență la vapori de apă, rezistență termică*

INTRODUCTION

Herein, we analyse and evaluate the comfort properties of knitted fabrics used for functional clothing items. These items are guaranteed to meet the performance and/or functionality requirements of people with special needs, such as elderly people, people with atypical conformations, people who work under variable temperature conditions, and infants and young children. For these groups of people, the comfort of clothing is crucial. Clothing comfort can be divided into four categories: psychological, thermophysiological, sensorial (tactile) and garment fit comfort [2]. The thermophysiological comfort of clothing is influenced by internal heat exchange, air permeability and moisture evaporation. This type of comfort is achieved when the exchange of heat and humidity between the body and environment through clothing occurs under conditions in which the thermal and moisture management of the body is balanced and when a microclimate arises next to the skin [4–5]. The indicators that define thermophysiological comfort are thermal insulation capacity, air permeability, vapour permeability and water impermeability. Much research has focused on the improvement of thermal comfort performance in clothing. Özkan et al. investigated the thermophysiological comfort properties of polyester knitted fabrics. They found that textured polyester yarn knitted fabrics showed the highest air permeability values than moisture management polyester in the same yarn count and knit structure. Also, lower filament number fabrics show higher thermal resistance values in the same yarn count of fabrics [5].

The sensorial comfort of clothing is a result of the interactions among the fabric, human skin, the human sensory system and the atmospheric conditions, resulting in at least one of the following feelings: softness, stiffness, smoothness, itchiness, prickliness, warmth, and coolness.

Psychological comfort is determined by the mental state of the wearer, which is contributed to by their confidence in their appearance, their style of dressing, whether the style conforms to that of their location, whether the general style is in agreement with that of the wearer in terms of their socioeconomic

status, and whether the style is in agreement with that of their acquaintances, including their colleagues, friends, and associates [3].
People with special needs still want to be fashionable, even if they often need to wear clothes that can hide specific body parts affected by disability and transformation, such as weight gain and skin sensitivity. The comfort of knitted fabric depends mainly on the basic properties of the yarn, the knitting structure, the weight and thickness of the knitted fabric and the presence of chemical treatments. Research has shown that it is impossible to obtain all the comfort requirements needed for clothing products intended for a certain group of users by using only one type of yarn [6–8]. A combination of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) is an optimal solution. An example of this combination is COOLMAX (polyester with channels), which has excellent moisture-wicking capacity. Modal, which is a form of regenerated cellulose, is more biodegradable and softer than viscose, and it is stronger, lighter, more breathable, and 50% more absorbent than cotton. Many researchers investigated the properties of knitted or woven fabrics made of regenerated cellulosic fibres. Sarioglu et al. investigated some comfort properties of different woven fabrics produced from cotton and polyester fibres blended with varying ratios of regenerated cellulosic fibres. The authors concluded that fibre type, fibre blend components and blend ratio have a significant effect on some comfort properties such as air permeability, wicking rate and absorption ratio. However, those parameters did not have any significant effect on the water vapour permeability [6]. Çeven et al. investigated some comfort properties such as thermal property, water vapour permeability, water vapour resistance, air permeability and bursting strength of single jersey knitted fabrics made of different raw materials including combed cotton, carded cotton, Cupro, TencelTM, Modal and Umorfil® yarn. They found that the regenerated cellulosic yarn type of knitted fabrics and the process type (untreated greige fabric or dyed fabric) were generally significant [8]. Kumar et al. investigated moisture management properties and drying behaviour of various knitted fabrics produced by changing the blend percentage of wool/acrylic, the number of filaments in polypropylene yarn and the structure of the knitted fabric. The authors concluded that the higher wool content in fabrics gives better moisture management and drying behaviour.
Polypropylene fabrics having a high number of filaments in the constituent yarn show better moisture management and drying behaviour than wool/acrylic fabrics [9]. Knitted fabrics are preferred by people with special needs, as these fabrics have greater elasticity and stretchability than woven fabrics. These materials provide unrestricted freedom of movement and transmission of body vapour to the next textile layer in the clothing system [1].
The objective of this study is to investigate the thermophysiological comfort properties of different fabrics knitted from combinations of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) for people with special needs (e.g., elderly people, people with disabilities, and people who work in variable temperature conditions). According to the test results, some evaluations are made regarding the knitted fabrics, such as thermal resistance, air permeability, and water vapour resistance.

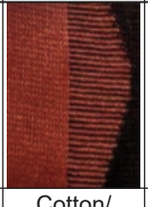
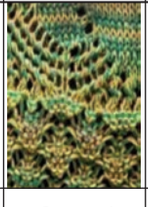
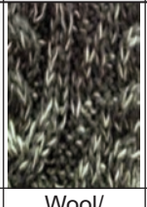
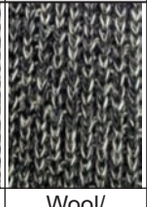
MATERIALS AND METHODS

Materials

In this study, seven knitted fabrics with fibres of varying compositions and knit structures were manufactured by Datsa Textil S.R.L. on the flat knitting machine CMS 530 ki. Detailed construction parameters are given in table 1.

Table 1

CONSTRUCTION PARAMETERS OF KNITTED FABRICS

Sample cod	A	B	C	D	E	F	G
Appearance							
Fibre type	Cotton/ acryl/ bamboo	Cotton/ acryl	Wool/ cotton/ modal/	Wool/ cotton/ modal/	Wool/ cotton/ modal/	Wool/ acryl/ Coolmax	Wool/ acryl/ Coolmax
Knit structure	Single jersey	Single jersey and openwork	Rib 1x1	1x1 Rib	1x1 Rib	Honeycomb	Honeycomb
Gauge of knitting machine	E 7.2	E 7	E 2.5	E 7	E 7	E 10	E 10
Fabric mass per unit area (g/m^2)	329.6	541.5	509.5	764	728.4	511.8	537
Fabric thickness (mm)	1.8	4.68	4.64	5.61	5.39	4.19	3.08

Methods

Before testing, all fabric samples were conditioned in a standard atmosphere for 24 hours at a temperature of 20±2°C and a relative humidity of 65±2%.

Two physical parameters of the developed knitted fabrics fabric thickness (mm) and fabric mass per unit area were evaluated according to the SR EN ISO 5084 and SR EN 12127 test methods, respectively.

Comfort properties including air permeability (l/m^2/s), thermal resistance (m^{2}K/W) and water vapour resistance (m^{2}Pa/W) were measured.

Air permeability has been described as the rate of airflow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. Air permeability tests of the knitted fabrics were performed according to the SR EN ISO 9237 test method using a head area of 20 cm^2 and differential pressure of 100 Pa. Air permeability was measured on a TexTest air permeability tester (model FX 3300).

Many of the test methods to measure thermophysiological, comfort try to mimic the heat and mass transfer from the human skin to the environment through the textile layers. One of the most widely used methods is the sweating-guarded hot plate to measure the water vapour resistance or the thermal resistance of material samples.

The thermal resistance, R_{ct}, is a quantity specific to textile materials that determines the dry heat flux between the two faces of a material relative to the area and temperature gradient. In addition, this parameter determines the heat insulation characteristics of a textile material. The higher the thermal resistance is, the lower the heat loss. Water vapour resistance, R_{et}, is a quantity specific to textile materials that determines the latent evaporative heat flux between the two faces of a material relative to the area and water vapour pressure gradient.

Each fabric sample was tested by using a sweating-guarded hot plate to evaluate the dry thermal resistance (R_{ct}) and water vapour resistance (R_{et}) characteristics, according to the SR EN ISO 11092 test method. The sweating-guarded hot plate consists of an electrically heated plate, which is located in a climatic chamber. Square samples are put onto the plate, and air at a defined temperature, relative humidity and velocity (1 m/s) is blown tangentially from a fan over the sample. The plate is heated to 35°C and the measuring surface is surrounded by a guard heated to the same temperature to avoid heat loss.

To analyse the obtained experimental data, a single factor analysis of variance (ANOVA) was applied. The null hypothesis was as follows: *There are significant differences between all analysed parameters of the knitted fabrics for people with special needs.*

RESULTS AND DISCUSSION

The experimental data analysed for the knitted fabric samples are mass per unit area, thickness, air permeability, water vapour resistance and thermal resistance.

The statistical parameters and interpretations of the experimental data for the physical and comfort properties of the knitted fabrics are illustrated in figures 1–5 and tables 2–5.

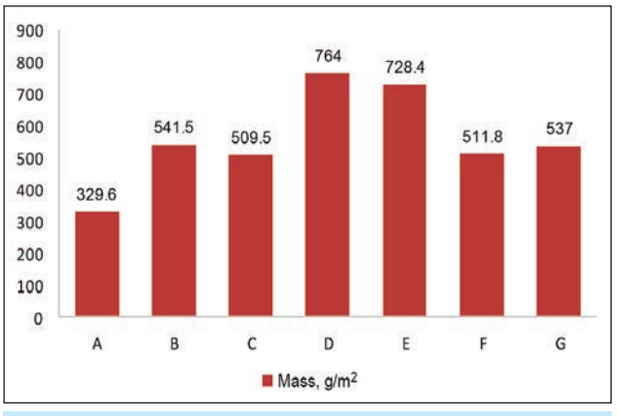


Fig. 1. Averages of experimentally determined values for mass (g/m^2)

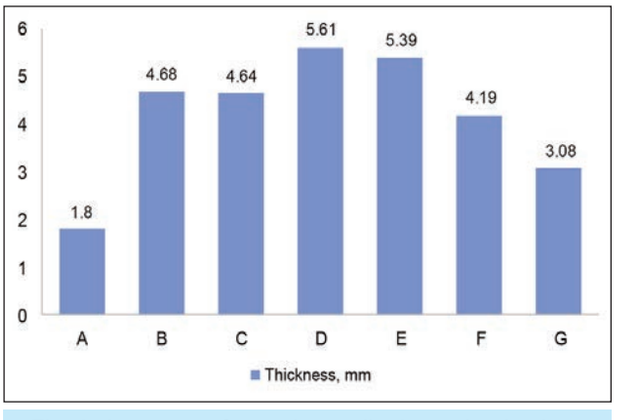


Fig. 2. Averages of experimentally determined values for thickness (mm)

Table 2

STATISTICAL PARAMETERS OF EXPERIMENTAL DATA FOR THICKNESS

Thickness (mm)	A	B	C	D	E	F	G
Mean	1.798	4.676	4.642	5.606	5.386	4.186	3.06
Standard Error	0.060117	0.089252	0.196962	0.057671	0.096312	0.042024	0.010488
Median	1.85	4.74	4.68	5.61	5.33	4.14	3.05
Standard Deviation	0.134425	0.199575	0.44042	0.128957	0.21536	0.093968	0.023452
Sample Variance	0.01807	0.03983	0.19397	0.01663	0.04638	0.00883	0.00055

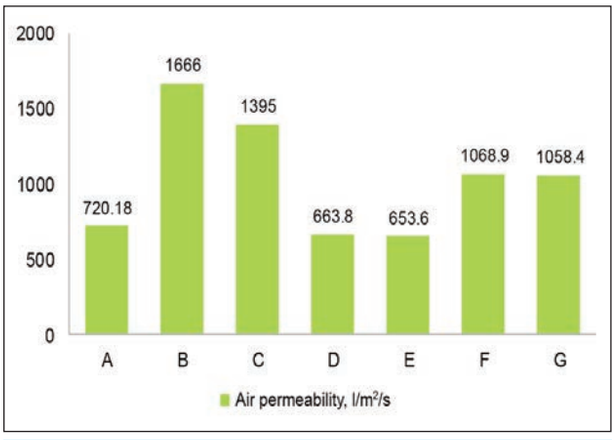


Fig. 3. Averages of experimentally determined values for air permeability (l/m^2/s)

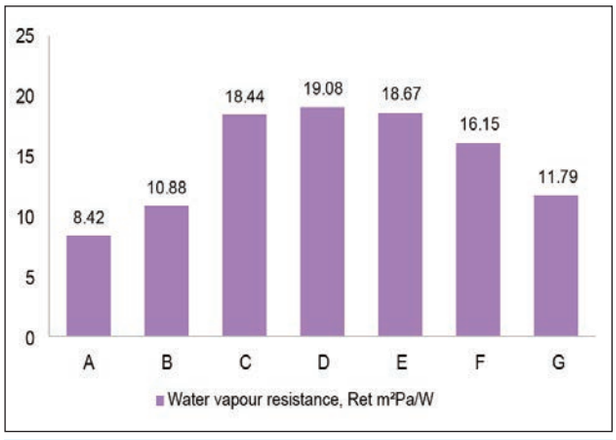


Fig. 4. Averages of experimentally determined values for water vapour resistance R_{et} (m^{2}Pa/W)

Table 3

STATISTICAL PARAMETERS OF THE EXPERIMENTAL DATA FOR AIR PERMEABILITY							
Air permeability (l/m^2/s)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Mean	720.16	1666	1395	663.8	653.6	1068.9	1058.4
Standard Error	62.00293	83.30933	16.21042	6.621178	5.641513	12.84476	17.97232
Median	646	1720	1410	665	648	1070	1045
Standard Deviation	196.0705	263.4472	51.26185	20.938	17.84003	40.61869	56.83348
Sample Variance	38443.63	69404.44	2627.778	438.4	318.2667	1649.878	3230.044
Maximum	1133.6	2020	1460	701	682	1140	1150

Table 4

STATISTICAL PARAMETERS OF EXPERIMENTAL DATA FOR WATER VAPOUR RESISTANCE							
Water vapour resistance R_{et} (m^{2}Pa/W)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Mean	8.42	10.984	18.437	19.078	18.671	16.225	11.791
Standard Error	0.003944	0.00718	0.069635	0.01052	0.018705	0.081025	0.01402
Median	8.42	10.985	18.385	19.08	18.685	16.14	11.78
Standard Deviation	0.012472	0.022706	0.220204	0.033267	0.059151	0.256223	0.044335
Sample Variance	0.000156	0.000516	0.04849	0.001107	0.003499	0.06565	0.001966

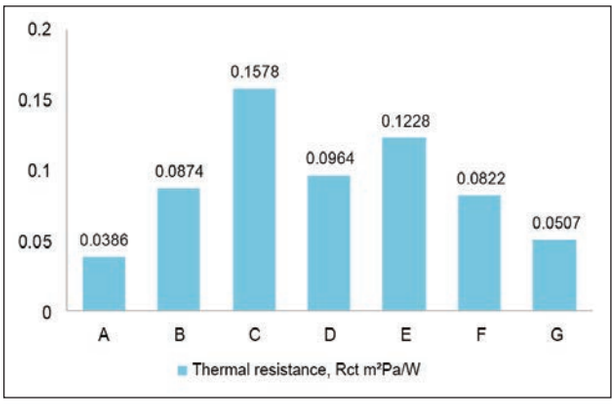


Fig. 5. Averages of experimentally determined values for thermal resistance R_{ct} (m^{2}K/W)

The ANOVA test is conducted to evaluate the statistical hypotheses. In addition, averages, variances (dispersions), proportions, and other statistical tools are implemented to form frequency distributions with known patterns (tables 6 and 7).

We test the null hypothesis, in which we predicted the absence of any interactions among the variables. If the *P* value is lower than 5%, the null hypothesis can be rejected. Thus, there are interactions between the analysed variables. Next, we analyse the correlations among some of the experimentally determined values.

The equation of the correlation coefficient, r = *CORREL*(*X, Y*), is as follows:

Table 5

STATISTICAL PARAMETERS OF EXPERIMENTAL DATA FOR THERMAL RESISTANCE							
Thermal resistance R_{ct} (m^2K/W)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Mean	0.03862	0.08743	0.1572	0.09636	0.111802	0.0822	0.05073
Standard Error	3.59E-05	6.84E-05	0.000653	9.33E-05	0.011065	8.56E-05	0.000117
Median	0.0386	0.08745	0.15785	0.09625	0.1228	0.08215	0.0508
Standard Deviation	0.000114	0.000216	0.002063	0.000295	0.034991	0.000271	0.000371
Sample Variance	1.29E-08	4.68E-08	4.26E-06	8.71E-08	0.001224	7.33E-08	1.38E-07

Table 6

SUMMARY			
Groups	**Sum**	**Average**	**Variance**
Mass (g/m^2)	3921.8	560.2571429	21467.16619
Thickness (mm)	29.39	4.198571429	1.807114286
Air permeability ($l/m^2/s$)	7225.88	1032.268571	151962.0962
Water vapour resistance, R_{et} (m^2Pa/W)	103.43	14.77571429	18.91569524
Thermal resistance, R_{ct} (m^2Pa/W)	0.6359	0.090842857	0.001660453

Table 7

STATISTICAL ANOVA OF THE THERMOPHYSIOLOGICAL COMFORT						
Source of variation	**SS**	**df**	**MS**	**F**	**P value**	**F crit**
Between groups	6021801.931	4	1505450.483	43.39724982	4.62E-12	2.689628
Within groups	1040699.921	30	34689.99738			

Note: SS – sum square, df – degree of freedom

$$Correl(X, Y) = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} \quad (1)$$

The correlation coefficient *r* has values between –1 and 1.

A brief interpretation of the coefficient *r* is as follows:

- *r* [0; 0.2] – very weak, nonexistent correlation
- *r* [0.2; 0.4] – weak correlation
- *r* [0.4; 0.6] – reasonable correlation
- *r* [0.6; 0.8] – high correlation
- *r* [0.8; 1] – very high correlation (very tight relationship between variables)

Thus, we determine the value of the correlation coefficient for the following parameters given in table 8.

Table 8

VALUES OF THE CORRELATION COEFFICIENT	
Average values correlation	**r**
Mass – Thickness	0.8752
Mass – Air permeability	–0.2902
Mass – Water vapour resistance	0.7559
Mass – Thermal resistance	0.4265
Thickness – Air permeability	0.0680
Thickness – Water vapour resistance	0.8316
Thickness – Thermal resistance	0.7290
Air Permeability – Water vapour resistance	–0.2145
Air Permeability – Thermal resistance	0.2922
Water Vapour Resistance – Thermal resistance	0.7825

CONCLUSION

In this study, the thermophysiological comfort properties of seven different knitted fabrics made of combinations of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) were investigated. All fabrics were compared in terms of their thermal resistance, water vapour resistance and air permeability. The correlation coefficients were analysed to identify the strengths and impacts of the relationships.

The air permeability values of the fabrics used in the experiments were compared, as shown in figure 3. The lowest air permeability value was observed in sample E, which had the second highest thickness and fabric mass per unit area among the experiments. The highest air permeability value was observed in sample B, which had the third highest thickness and fabric mass per unit area. According

to the correlation coefficients obtained r = 0.2902, r = 0.2145 and r = 0.2922, air permeability was weakly correlated with the fabric mass per unit area, water vapour resistance and thermal resistance,

The thermal resistance properties of the fabrics used in the experiments were found, as shown in figure 5. The highest thermal resistance value was seen in sample C, which had the fourth-highest thickness and the sixth-highest fabric mass per unit area value among the evaluated specimens. The lowest thermal resistance value was observed in sample A, which had the seventh-highest thickness and fabric mass per unit area among the tested specimens. The correlation coefficient obtained, r = 0.4265, indicated a reasonable correlation between thermal resistance and fabric mass per unit area. Furthermore, r = 0.7290 indicated a high correlation between thermal resistance and thickness.

The water vapour resistance properties of the fabrics used in the experiments were found, as shown in figure 4. The highest water vapour resistance was observed in sample D, which had the highest thickness and fabric mass per unit area value. The lowest thermal resistance value was observed in sample A, which had the lowest thickness and fabric mass per unit area value. The correlation coefficients obtained were as follows: r = 0.7559, which indicated a high correlation between water vapour resistance and fabric mass per unit area; r = 0.8316, which indicated a very high correlation between water vapour resistance and thickness; and r = 0.7825, which indicated a high correlation between water vapour resistance and thermal resistance.

The results of this study showed that there were statistically significant differences in dry thermal resistance, water vapour resistance and air permeability depending on the structural parameters of a knitted fabric.

ACKNOWLEDGEMENTS

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INFORMATION FOR AUTHORS

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

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