Investigation of atmospheric plasma in textile finishing

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ABSTRACT – REZUMAT

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This study aims to investigate the usability of plasma pretreatment before bleaching in textile finishing. Atmospheric pressure air plasma treatment was applied to 100% cotton rib raw fabrics. Samples were bleached at three different temperatures (90–100–110°C) and two different duration (30–60 minutes). Hydrophilicity and whiteness values, which were intended to be imparted to the sample by bleaching, were measured. Bleached samples were pre-mordanted using Potassium aluminium sulfate (alum) and dyed using chlorophyll natural dye. Colour measurements of the dyed samples were made. Air plasma applied to the fabrics has shortened the samples' sinking time and improved their hydrophilicity. While bleaching temperature has an effect on the whiteness measured after bleaching, the effect of plasma treatment has not been statistically significant. Colour and K/S values were measured after dyeing 5% and 10% pre-mordanted samples with chlorophyll natural dye. It's been found that the colour values are similar, and there is no statistical difference observed between the K/S values.

Keywords: *pretreatment, dyeing, hydrophility, whiteness, colour*

Investigarea plasmei atmosferice în finisarea materialelor textile

Scopul acestui studiu este de a investiga utilitatea pretratării cu plasmă înainte de albire în finisarea materialelor textile. Tratamentul cu plasmă de aer la presiune atmosferică a fost aplicat tricoturilor patent din bumbac brut 100%. Probele au fost albite la 3 temperaturi diferite (90–100–110°C) și 2 durate diferite (30–60 minute). Au fost măsurate valorile hifrofiliei și gradului de alb care urmau să fie conferite probei prin albire. Probele albite au fost premordansate cu sulfat de potasiu și aluminiu (alaun) și vopsite cu colorant natural de clorofilă. Au fost efectuate măsurători ale culorii probelor vopsite. Plasma de aer aplicată pe tricoturi a scurtat timpul de scufundare a probelor și a îmbunătățit hidrofilia acestora. În timp ce temperatura de albire are un efect asupra gradului de alb măsurat după albire, efectul tratamentului cu plasmă nu a fost semnificativ din punct de vedere statistic. Culoarea și valorile K/S au fost măsurate după vopsirea cu colorant natural de clorofilă a probelor premordansate 5% și 10%. S-a constatat că valorile culorii sunt similare și nu se observă nicio diferență statistică între valorile K/S.

Cuvinte-cheie*: pretratament, vopsire, hidrofilie, grad de alb, culoare*

INTRODUCTION

Some dyeing production requires heavy metals like mercury, chromium, cadmium, lead, or arsenic. About 70% of dyes used in fabric dyeing are incompletely absorbed by the fabric, leading to their discharge into wastewater. Untreated wastewater release poses risks to humans and animals throughout the food chain. Adopting eco-friendly wastewater treatment is crucial for conserving and restoring water resources [1]. Sustainability in all applied fields, particularly in textiles, is to protect our globe, environment, and community, where green-dyed products are playing their role [2]. The surface modification of textile fibres plays a crucial role in delineating their moisture management, dyeing properties, and overall performance. Given that these surface attributes directly influence the hygroscopic tendencies of fibrous substrates, various techniques have been developed for the surface modification of textiles.

Microwave technology is used in textile finishing and the extraction of natural pigments from plants. It accelerates chemical reactions, improves pigment dispersion, and enhances dye adsorption onto fibres. This method improves dyeing conditions, fastness, and colour yield while reducing mordant and solvent usage, providing economic and time-saving benefits [3–5]. Literature studies have focused on determining optimum dyeing conditions by combining different dyeing parameters with mw irradiation. MW radiation is used to investigate the natural dyeing potential of tea leaves [5]. arjun bark [6], acid red 138 [7], cassia obovata [8], red sandal wood (RSW) [4], and cassia fistula pods [3]. The main application areas of ultrasound technology in textile and apparel can be listed as follows: pre-treatment, washing, dyeing, ultrasound drying, use of ultrasound waves in various painting methods, and ultrasonic stitches in garments. Cavitation, generated within the liquor, is the main contributor to the effects of ultrasound in wet finishing procedures. Cavitation occurs due to the explosion of small energetic bubbles formed due to the movement of ultrasound waves in the liquor. As a result of cavitation occurring at the solid/liquid interface, an increase in mass transfer from liquid to solid is observed [9]. Studies on ultrasonic radiation have focused on improving dyeing conditions and investigating the use of bio-mordants. In their study, Adeel et al. applied US to silk material for 60 minutes [10], while Adeel et al. applied US radiation to silk material for 30 minutes [2], and Azeem et al. applied US radiation to wool material for 15–60 minutes [11]. Here, the processing time is longer than other surface modification techniques. Ultraviolet (UV) waves have shorter wavelengths than visible light. Scientists have divided the ultraviolet part of the spectrum into three: near UV, far UV and very far UV. It is expressed in terms of the wavelength energy of UV light. While UV A and UV B are used in lighting systems in industry, UV C is used in surface modification. [12]. As we move from visible light to UV radiation, the wavelength decreases while the energy and frequency increase. This change allows the beam to penetrate surfaces more effectively. These beams are undetectable and non-ionizing. When non-ionizing rays are absorbed by molecules, they cannot ionise them into positive or negative ions [13]. Under aerobic conditions, UV light (100–400 nm) oxidises fibre surfaces, forming reactive groups like carboxyl, aldehyde, hydroxyl, and carbonyl. This enhances dye-fibre affinity, improving natural dyeing efficacy [14]. In their study, Adeel et al. reduced the dyeing temperature by exposing the polyester fabric and dye solution to Ultraviolet radiation for 30–45 minutes [15]. Haggag et al. dyed silk fabric with mulberry leaf extract. High colour strength and satisfactory fastness towards light, washing, perspiration and crocking were achieved [16]. UV polymer technology on textiles faces challenges in formulation, component selection, and surface integration. Textile's high hydrophilicity enables liquid polymer penetration, altering inner layers. Concerns include residual odours, garment use restrictions, and polymer effects on texture and drape, with excessive cross-linking stiffening the fabric, reducing comfort [12].

Gamma rays, emitting high-energy photons, penetrate deeply. Being electrically neutral and massless, they don't alter the nucleus. Typically, gamma emission follows alpha and beta decay. Despite travelling far in air and lead, they're not fully absorbed. Examples of gamma-emitting substances are caesium (Cs-137), krypton (Kr-88), and cobalt (Co-60) [17]. Gamma rays from isotopes like Cs-137 or Co60 produce ionising radiation, interacting with fabric surfaces to create free radicals, altering surface properties and chemical composition [14]. Gamma radiation can crosslink and graft polymers by generating radicals on substrate surfaces in the presence of oxygen. These radicals react with atmospheric oxygen to form functional groups needed for grafting, altering fundamental properties due to deep penetration and causing material degradation due to gamma rays' exceptional penetrative ability [13]. Gamma radiation is applied to dye powders and textile materials at different doses. Batool et al. stated that the best-absorbed dose for cotton fabric and chicken gizzard leaf powder was 10 kGy. They revealed the optimum conditions for dyeing [18]. In their study, Bhatti et al. found that the best dose applied to sdelulosic fabric and Vat Green 1 dye was 6 kGy [19]. Gulzar et al. observed that 20 kGy is the optimum absorbed dose for surface modification of cotton [20]. Khan et al. indicated that gamma-ray treatment of 15 kGy was the effective absorbed dose for extraction of dye and surface modification of cotton fabric [21]. In addition to optimising dyeing conditions, microwave technology finds applications in the reuse and recycling of textile wastewater, as well as in the sterilisation processes of textiles [22]. Plasma, the "fourth state of matter", is an electrically neutral ionised gas with a significant number of charged particles that are not bound to an atom or molecule. Plasma technology can assist in designing and removing natural or synthetic grease and wax from textile fibres, increasing the dyeing rates of textile polymers, and improving the diffusion of dye molecules into fibres to increase colour intensity and wash fastness. This treatment promotes surface modification of polymeric/textile substrates, improves hydrophilic properties (chemical changes) and increases the surface properties (physical changes) of fibres/textile substrates. This surface modification increases the dyeability of the fibre and is an effluent-free and environmentally friendly process [1]. Plasma treatment stands out as one of the most promising technologies, serving as an alternative for several wet processes in textiles while concurrently diminishing energy, water, and chemical usage. Through meticulous choices in plasma gas and processing conditions, a spectrum of surface modifications becomes achievable, encompassing tasks such as contamination removal, bond breaking (resulting in the creation of free radicals), crosslinking, etching (yielding surface roughness), functionalisation, polymerisation, and post-irradiation grafting [23]. Through the utilisation of the plasma process, textile fibres can acquire characteristics such as wettability [24–28], thermal comfort [29], desizing&decoloration [30–32], flame retardant [33], water proof&oil repellent [34–38], antibacterial properties [39, 40] and anti-static properties [41]. Atmospheric plasma treatment is based on the principle of ionising the oxygen and nitrogen in the air and applying it to the surface. The plasma ionisation process is the disintegration of gases under the influence of high voltage by passing them between two electrodes and the transformation of gas atoms into ions with a high energy effect [42]. Atmospheric Pressure Plasma Treatment (APPT) causes the oxygen content on the surface of cotton fibres to increase [43]. Oxidation of the cotton fibre surface caused by reactive oxygen species adds new oxygen-containing functional groups such as -OH and -C-O, greatly increasing the adhesion force between the polymer surface and water molecules [44]. Air plasma increases hydrophilicity in cotton fabrics [45]. There are various studies in the literature on the investigation of the dyeability of different fibres with plasma treatment

[46–54]. The possibility of using atmospheric pressure plasma as a dry process to remove foreign substances and yellowness in 100% raw cotton knitted fabrics was investigated in a study. They stated that atmospheric pressure plasma treatment can effectively remove impurities in 100% raw cotton knitted fabrics and significantly increase the water absorption property [55]. Plasma treatment was applied to raw cotton fabrics with different combinations of plasma parameters using helium and oxygen gases in another study. They stated that the wettability of raw cotton fabrics increased significantly after plasma treatment and gave better results than traditional desizing and cleaning [56]. Argon and air-atmospheric plasma were treated to knitted and naturally coloured cotton fabrics. Researchers stated that atmospheric plasma treatments could alter the surface of naturally coloured cotton fabrics without significant loss in colour strength or fastness and thermal properties [57]. In another study, researchers applied low-pressure non-equilibrium gaseous plasma to raw cotton fabrics to enhance the adsorption of natural dyes and improve the ultraviolet (UV) protection factor. They stated that the ultraviolet protection factor (UPF) was found above 50, indicating excellent protection due to improved adsorption of the dye on samples treated with ammonia plasma [58]. Haji et al. were dyed wool fibres using grape leaves. To improve the dyeability, wool fibres were pre-treated with oxygen plasma. The results revealed that plasma treatment has partially removed the surface scales of wool and enhanced the penetration of the natural dye into the fibres. Plasma treatment power showed the highest effect on fibre modification [54].

This study aims to investigate the effect of atmospheric plasma treatment on the hydrophilicity, whiteness value after bleaching and colour values of fabrics after dyeing.

MATERIALS AND METHODS

Materials

100% carded cotton ring spun yarn with Ne 20/1 yarn count was knitted with flat knitting machines of 10 gauge thus, 100% cotton 1 × 1 rib fabrics were used in the study. Hydrogen peroxide 35% EMPLURA® (Sigma-Aldrich, Germany), Sodium Hydroxide EMSURE® (Sigma-Aldrich, Germany), Oil remover soap BELFİX BTD (Belice Chemical, Türkiye), Anti-crease agent BELFALT OYT (Belice Chemical, Türkiye), Ion trapping BELPİN RT (Belice Chemical, Türkiye), Wetting agent BELWETT HM-Y (Belice Chemical, Türkiye), Peroxide stabiliser BAY STAP-CH (Bayka Chemical, Türkiye), Anti-peroxide DK ANP 4 (Derin Chemical, Türkiye), Aluminum potassium sulfate (Carlo Erba Reagents GmbH, Germany), Chlorophyll S-10 (Tito Co. Ltd., Türkiye) liquid was provided.

Methods

Within the scope of this study, fabrics treated with atmospheric plasma were bleached and subsequently dyed with chlorophyll natural dye. Initially, atmospheric air plasma was applied to the samples at various speeds, and SEM analyses were conducted to observe changes in the surface morphology of the fibres. Hydrophilicity and whiteness values of the bleached fabrics were measured. Finally, the bleached fabrics were dyed using chlorophyll natural dyestuff, and colour measurements of the dyed samples were taken (figure 1).

Atmospheric pressure plasma

Atmospheric pressure plasma jet (APJ) treatments were applied to 100% cotton knitted fabrics at Plasmatreat GmbH. The objective was to activate the surface of cotton fabrics and enhance their hydrophilicity using atmospheric pressure air plasma. Table 1 outlines the parameters of the atmospheric pressure plasma treatment.

Openair® plasma systems operate at atmospheric pressure and generate plasma by spraying it onto the

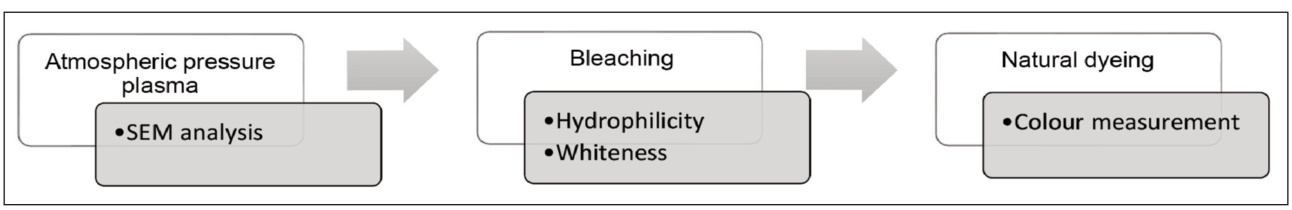


Fig. 1. Flow chart

Table 1

PARAMETERS OF THE ATMOSPHERIC PRESSURE PLASMA							
Jet	**Voltage (V)**	**Frequency (kHz)**	**Power (Watt)**	**Distance (mm)**	**Pressure (bar)**	**Ionisation gas**	**Speed (m/min)**
RD1010	280	21	600	10	3	Air	5
RD1010	280	21	600	10	3	Air	10

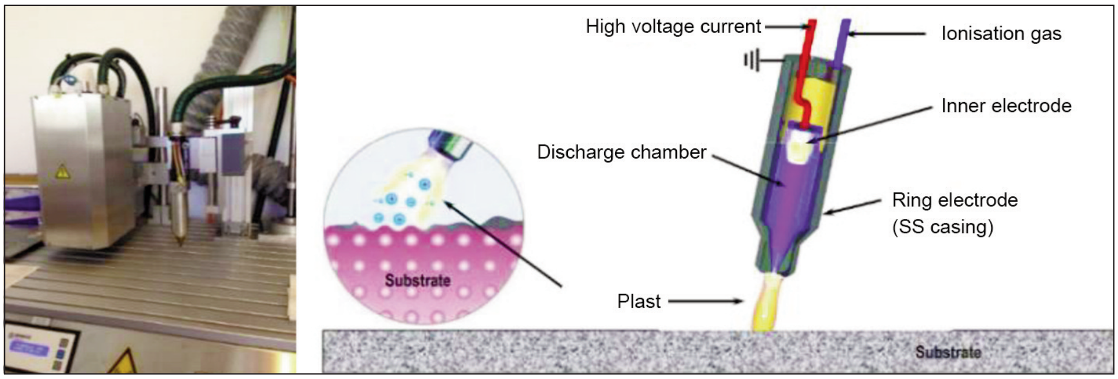


Fig. 2. Atmospheric Pressure Plazma (APJ) (Openair®plazma) [59]

fabric with the help of a jet-fired arc and processing gas, typically air. This plasma contains a sufficient level of induced particles to initiate the desired effect on the surface (figure 2).

Bleaching process

The bleaching processes were applied to cotton fabrics using the exhaust method. This involved treating the fabrics with a solution containing 6% H2O2, 4g/l (46°Be) NaOH, 0.5 g/l oil remover soap, 0.5 g/l anti-creasing agent, 0.8 g/l ion trapping agent, 0.5 g/l wetting agent, and 0.8 g/l peroxide stabiliser in a laboratory-type machine, with a liquor ratio of 20:1. The bleaching process was conducted at three different temperatures and two different durations. The parameters of the bleaching process and the corresponding sample codes are presented in table 2.

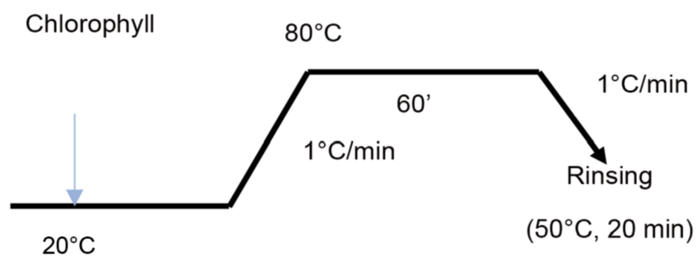
After the bleaching processes, the samples were rinsed for 10 minutes. At the end of the bleaching process, anti-peroxide treatments were applied to remove peroxide residues remaining on the samples. These processes were carried out for 20 minutes at 50°C in a liquor prepared using 0.2 g/l catalase enzyme and 0.5 cm^3/l acetic acid. Hydrophilicity assessments of the samples were conducted using the sinking method. A sample measuring 5 cm × 5 cm was immersed in pure water, and the stopwatch was initiated upon contact with the water. The stopwatch was stopped when the sample was completely submerged in water, and the sinking times were recorded. Whiteness values (Berger) of the samples were measured with a spectrophotometer (Datacolor).

Natural dyeing

After the pre-mordanting process, dyeing processes utilising 10% owf chlorophyll were conducted at 80°C for 60 minutes, with a liquor ratio of 30/1. The dyeing liquors, prepared at a room temperature of 20°C, were contained in tubes. The pH value of the dye bath was measured as 11.02. The exhausting apparatus was programmed according to the diagram illustrated in figure 3. The dyeing liquors were gradually heated to 80°C, increasing by 1°C per minute.

Table 2

BLEACHING PROCESS PARAMETERS AND SAMPLE CODES			
Sample code	**Plasma type**	**Temperature (C°)**	**Time (min)**
R-90-30	Reference (plasma free sample)	90	30
A5-90-30	Air plasma (5 m/min)		
A10-90-30	Air plasma (10 m/min)		
R-100-30	Reference (plasma free sample)	100	
A5-100-30	Air plasma (5 m/min)		
A10-100-30	Air plasma (10 m/min)		
R-110-30	Reference (plasma free sample)	110	
A5-110-30	Air plasma (5 m/min)		
A10-110-30	Air plasma (10 m/min)		
R-90-60	Reference (plasma free sample)	90	60
A5-90-60	Air plasma (5 m/min)		
A10-90-60	Air plasma (10 m/min)		
R-100-60	Reference (plasma free sample)	100	
A5-100-60	Air plasma (5 m/min)		
A10-100-60	Air plasma (10 m/min)		
R-110-60	Reference (plasma free sample)	110	
A5-110-60	Air plasma (5 m/min)		
A10-110-60	Air plasma (10 m/min)		



Natural dyestuff	Amount (%owf)
Chlorophyll	10
Liquor ratio	30/1

Fig. 3. Dyeing diagram

The temperature was maintained at 80°C for 60 minutes while the dyeing process occurred.
Subsequently, the bath was cooled to 50°C, emptied, and the samples were rinsed under tap water for 2 minutes. Colour measurements of the dyed samples were conducted using a spectrophotometer (Datacolor).

RESULTS AND DISCUSSION

SEM Analysis

Figure 4 illustrates that the surface morphology of cotton knitted fabric undergoes changes when exposed to air plasma, and these changes become more pronounced with longer treatment times. From the SEM images, it is evident that the surface of the plasma-treated sample fabrics has undergone significant modification, in contrast to the reference samples, which exhibit a smoother surface texture. The plasma-treated samples display notable microcracks on their surfaces. These surface modifications due to plasma treatment were further confirmed through subsequent hydrophilicity tests, which demonstrated an increase in the hydrophilicity of the fabrics following air plasma treatment. The modification occurring on the surface of the sample treated with plasma at a speed of 5 m/min was more intense (figure 4). Therefore, it can be concluded that as the contact time of the plasma treatment with the sample fabric increases, the hydrophilicity of the sample fabric also increases.

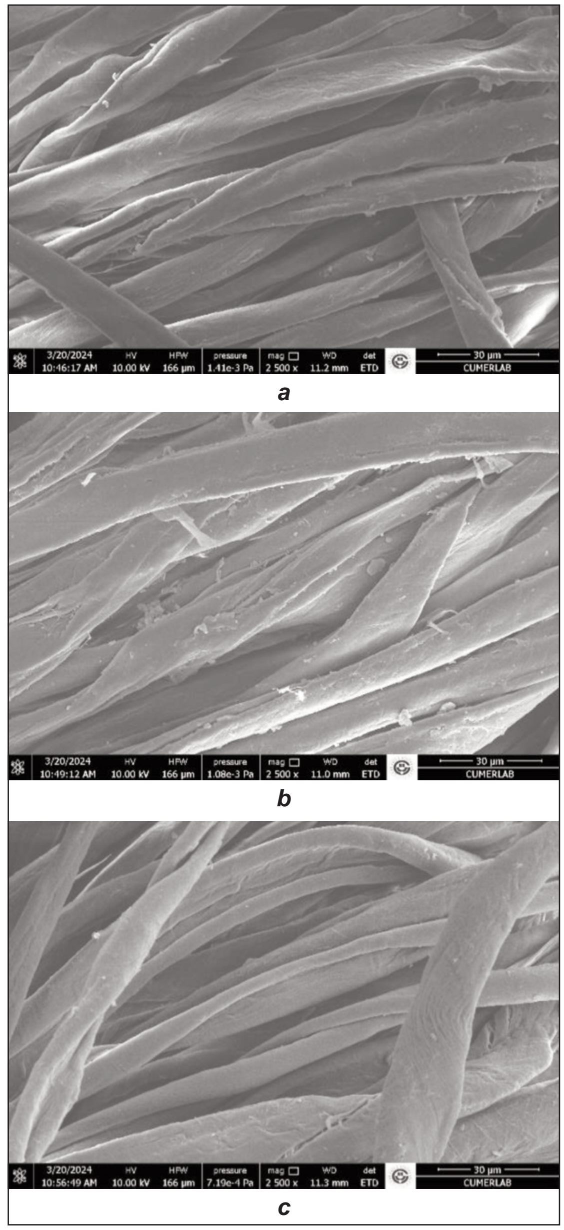


Fig. 4. SEM İmages: *a* – reference (plasma-free); *b* – air plasma (5 m/min); *c* – air plasma (10 m/min)

Hydrophilicity results

The hydrophilicity of the samples was assessed using the sinking method. Sinking times, measured according to this method, are presented in figure 5. As anticipated, sinking times decreased with increasing temperatures for bleached samples at equivalent temperatures and durations. Significantly reduced sinking times were observed for plasma-treated samples compared to the reference (plasma-free) sample treated under identical temperature and time conditions. The plasma treatment effectively enhanced the fabric’s hydrophilicity.
Analysis of variance was performed for the dependent variable hydrophilicity, taking plasma type and temperature as independent variables (table 3). No statistical difference was observed between the subgroups of the temperature variable in terms of hydrophilicity (batma süresi) values obtained at the end of the 30-minute bleaching process. However, a statistical difference was found between subgroups of plasma type at the end of the 30-minute bleaching process. A notable decline was observed in similar samples with rising temperatures. However, plasma pretreatment led to a significant reduction in sinking times. It is observed that there is a statistical difference

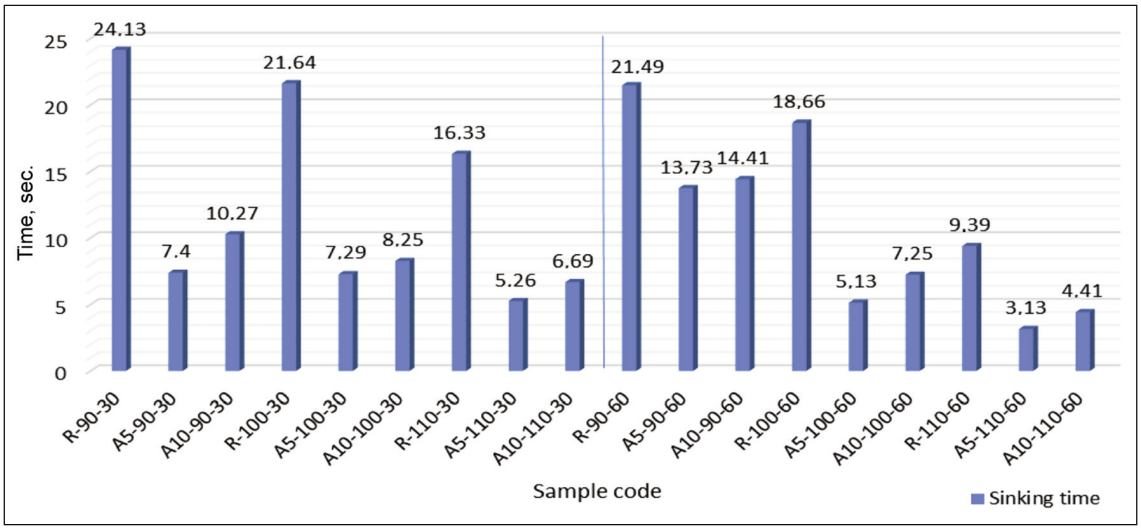


Fig. 5. Hydrophilicity test results (sinking time)

Table 3

ANALYSIS OF VARIANCE

Duration	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	R square	Adjusted R Squared
30 minutes	Temperature	31.483	2	15.741	6.552	0.055	0.976	0.951
	Plasma type	351.685	2	175.842	73.189	0.001		
60 minutes	Temperature	179.330	2	89.665	20.687	0.008	0.950	0.899
	Plasma type	147.388	2	73.694	17.002	0.011		

between the subgroups of the temperature variable and the subgroups of the plasma type variable in terms of hydrophilicity values obtained at the end of the 60-minute bleaching process. Increasing the temperature and applying plasma pretreatment during the 60-minute bleaching process significantly reduced the sinking time of the samples.

The Tukey HSD test was employed as a post hoc test to examine differences between subgroups. In the output of homogeneous subsets, the subgroups of the temperature variable were consolidated into a single subset after 30 minutes of bleaching (table 4). Plasma-treated samples were grouped into one subset, while the reference sample appeared in a separate subset. Consequently, it can be inferred that the plasma treatment influences the hydrophilicity values after 30 minutes of bleaching (table 5). Sinking data measured after bleaching at 100°C and 110°C were aggregated into the same subset, while sinking data measured after bleaching at 90°C were presented in a distinct subset. Hence, it can be deduced that the hydrophilicity values of the samples bleached at 110°C and 100°C for 60 minutes are similar, and these two groups do not exhibit statistically significant differences (table 6).

It can be concluded that there is no statistical difference between the hydrophilicity values of the samples treated with plasma at a speed of 5 m/min for 60 minutes and those treated at a speed of 10 m/min for 60 minutes.

Berger whiteness index results

Whiteness measurements of the samples were conducted using the Berger whiteness index. Plasma

Table 4

SUBSETS OF TEMPERATURE FOR 30 MINUTES

Temperature	30 minutes	
	N	Subset
		1
110°C	3	9.4267
100°C	3	12.3933
90°C	3	13.9333
Sig.		0.05

Table 5

SUBSETS OF PLASMA TYPE FOR 30 MINUTES

Plasma type	30 minutes		
	N	Subset	
		1	2
Air plasma 5	3	6.65	
Air plasma 10	3	8.4033	
Plasma free	3		20.7
Sig.		0.429	1

Table 6

SUBSETS OF TEMPERATURE FOR 60 MINUTES			
Temperature	60 minutes		
	N	Subset	
		1	2
110°C	3	5.6433	
100°C	3	10.3467	
90°C	3		16.5433
Sig.		0.104	1

Table 7

SUBSETS OF PLASMA TYPE FOR 60 MINUTES			
Plasma type	60 minutes		
	N	Subset	
		1	2
Air plasma 5	3	7.33	
Air plasma 10	3	8.69	
Plasma free	3		16.5133
Sig.		0.723	1

pretreatment applied to the samples did not result in a consistent increase or decrease in whiteness values (figure 6). When the Berger whiteness index values obtained after the pretreatment process for 30 and 60 minutes were compared, the whiteness index values were higher in the bleaching process for 60 minutes, as expected. No significant difference was observed between plasma-treated samples bleached at the same temperature and time and the reference sample. However, a notable increase in whiteness values was observed when the bleaching temperature was raised to 110°C for both 30 and 60 minutes of bleaching.

Analysis of variance was conducted for the dependent variable whiteness, with plasma type and temperature as independent variables. A statistical difference was found between the subgroups of the temperature variable regarding the whiteness values obtained after the bleaching process for both 30 and 60 minutes (p value < 0.05). However, there was no statistical difference observed in the subgroups of the plasma type concerning the whiteness values obtained after the bleaching process for 30 and 60 minutes (p value > 0.05) (table 8). Although the plasma process did not demonstrate a statistically significant effect on the whiteness values, the temperature variable notably influenced the whiteness values statistically.

Tukey HSD test was used as a post hoc test to see the differences between subgroups. In the homogeneous

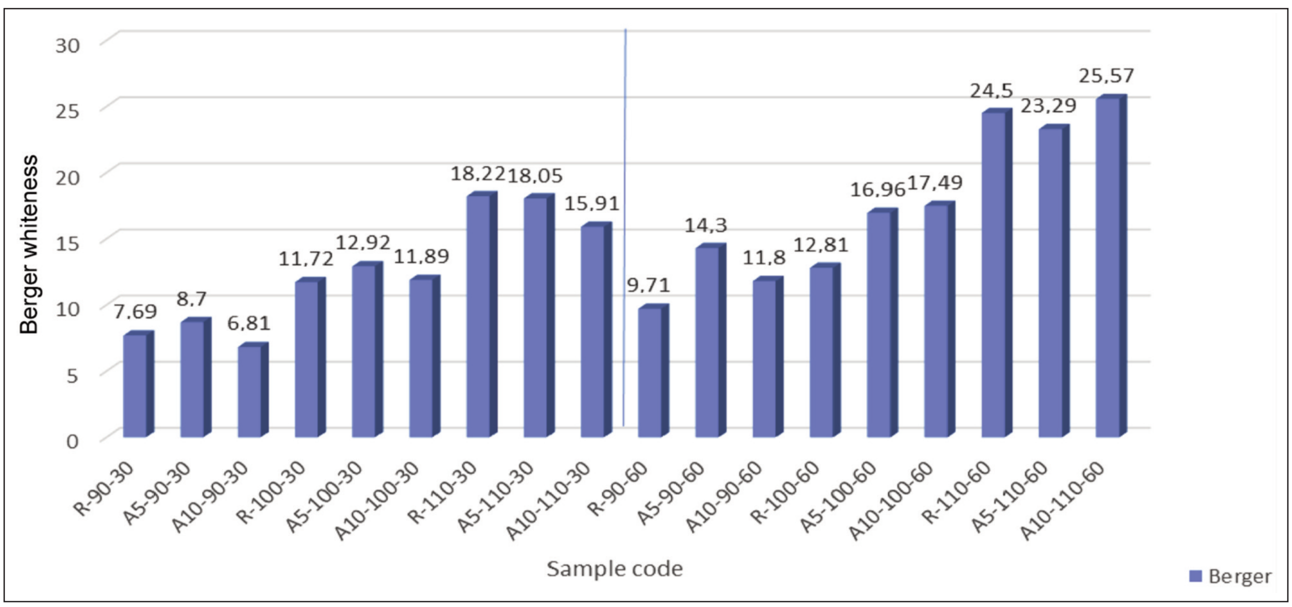


Fig. 6. Berger whiteness ındex values

Table 8

ANALYSIS OF VARIANCE								
Duration	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	R square	Adjusted R Squared
30 minutes	Temperature	140.272	2	70.136	172.497	0.000	0.989	0.978
	Plasma type	4.321	2	2.160	5.313	0.075		
60 minutes	Temperature	246.924	2	123.462	37.528	0.003	0.952	0.904
	Plasma type	13.140	2	6.570	1.997	0.250		

Table 9

SUBSETS OF TEMPERATURE FOR 30 MINUTES				
Temperature	**30 minutes**			
	N	**Subset**		
		1	**2**	**3**
90°C	3	7.7333		
100°C	3		12.1767	
110°C	3			17.3933
Sig.		1.000	1.000	1.000

Table 10

SUBSETS OF PLASMA TYPE FOR 30 MINUTES		
Plasma type	**30 minutes**	
	N	**Subset**
		1
Air plasma 10	3	11.5367
Plasma free	3	12.5433
Air plasma 5	3	13.2233
Sig.		0.067

Table 11

SUBSETS OF TEMPERATURE FOR 60 MINUTES			
Temperature	**60 minutes**		
	N	**Subset**	
		1	**2**
90°C	3	11.9367	
100°C	3	15.7533	
110°C	3		24.4533
Sig.		0.126	1.000

Table 12

SUBSETS OF PLASMA TYPE FOR 60 MINUTES		
Plasma type	**60 minutes**	
	N	**Subset**
		1
Plasma free	3	15.6733
Air plasma 5	3	18.1833
Air plasma 10	3	18.2867
Sig.		0.291

subsets output, the subgroups of the temperature variable were divided into three subsets (table 9). The temperature had a statistical effect on whiteness values after 30 minutes of bleaching. Subgroups of the plasma type were collected in a single subset. From this, it was concluded that the plasma treatment did not affect the whiteness values after 30 minutes of bleaching (table 10). After 60 minutes of bleaching, 90°C and 100°C of the subgroups of the temperature variable were collected in the same subset, while 110°C was put in a different subset. It was concluded that the 110°C subgroup is statistically different (table 11). Since all subgroups of the plasma type variable were collected in a single subset after 60 minutes of bleaching, it was concluded that there was no statistical effect of the plasma treatment on whiteness (table 12).

Colour measurements

Colour measurements of the samples were measured according to the CIE lab system. Colour and K/S values of 5% and 10% pre-mordanted samples were found to be close to each other (table 13).

Table 13

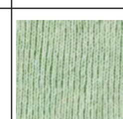
COLOUR MEASUREMENT												
Sample code	**%5 mordan**						**%10 mordan**					
	L	**a**	**b**	**Δe**	**K/S**	**Sample**	**L**	**a**	**b**	**Δe**	**K/S**	**Sample**
R-90-30	71.58	–6.40	12.46	1.38	7.17		68.04	–7.50	13.51	1.43	5.15	
A5-90-30	70.62	–6.34	12.89	0.93	6.84		69.65	–7.82	12.43	2.24	6.00	
A10-90-30	72.22	–6.13	12.12	1.64	7.64		70.92	–7.54	12.39	2.32	6.52	
R-100-30	69.58	–7.49	12.70	1.57	5.96		70.26	–7.76	12.14	2.43	6.23	

Table 13 (continuation)

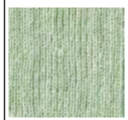
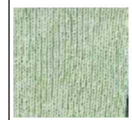
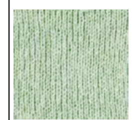
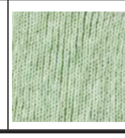
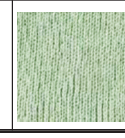
Sample code	%5 mordan						%10 mordan					
	L	a	b	Δe	K/S	Sample	L	a	b	Δe	K/S	Sample
A5-100-30	69.47	–7.46	12.68	1.53	5.93		69.80	–7.73	12.32	2.24	6.12	
A10-100-30	69.84	–7.67	12.62	1.79	6.05		69.96	–8.03	12.28	2.51	6.03	
R-110-30	70.48	–7.73	12.95	1.85	6.00		71.68	–8.09	12.18	2.96	6.67	
A5-110-30	70.24	–7.37	12.88	1.52	5.08		69.37	–8.43	13.10	2.48	5.57	
A10-110-30	69.95	–8.01	13.12	1.99	5.70		70.21	–8.72	13.36	2.8	5.54	

Table 14

INDEPENDENT SAMPLES TEST							
Value	t	df	Sig. (2-tailed)	Mean difference	Std.Error difference	95% Confidence interval of the difference	
						Lower	Upper
KS	–0.184	34	0.855	–0.04000	0.21723	–0.48146	0.40146

The difference between the K/S values of the samples premordanted using 5% and 10% owf of potassium aluminium sulfate (alum) was examined with the Independent Samples t-test (table 14). No statistical difference was observed between K/S values (p value > 0.05).

CONCLUSION

This study aimed to investigate the usability of plasma pretreatment before bleaching in textile finishing. Atmospheric pressure air plasma treatment was applied to 100% cotton rib raw fabrics. SEM analyses were performed to see the effect (surface characterisation) of the plasma treatment on the fabrics. According to the SEM analysis results, it was concluded that slow application of plasma pretreatment (5 m/min) causes more intense surface modification and microcracks on the sample surface.

Then, samples were bleached at three different temperatures (90°C – 100°C – 110°C) and two different times (30–60 minutes). Hydrophilicity and whiteness values, which were intended to be imparted to the sample by bleaching, were measured. The sinking times of plasma-treated samples decreased significantly compared to the reference (plasma-free) sample treated at the same temperature and time. Plasma treatment enhanced the fabric's hydrophilicity. Statistical analysis further confirmed that plasma treatment influenced the hydrophilicity values of samples bleached at various temperatures for 30 and 60 minutes. When comparing the whiteness values of samples bleached at various temperatures for 30 and 60 minutes, both the plasma-treated samples and the reference sample were statistically grouped. Therefore, plasma pretreatment did not have a significant effect on the whiteness values of the samples. Nevertheless, statistically significant differences emerged in the whiteness values of samples bleached at 90°C – 100°C and 110°C compared to those bleached for 30 minutes. Similarly, a statistical discrepancy was observed among samples bleached for 60 minutes, particularly with a temperature increase to 110°C within the same group as those at 90°C and 100°C. The whiteness data obtained after bleaching at 90°C, 100°C, and 110°C for 30 minutes were categorised into different subsets. For the bleaching process conducted within 30 minutes, it was observed that each temperature level exerts an influence on whiteness. However, with the extension of bleaching time to 60 minutes, the whiteness data obtained after bleaching at 90°C and 100°C were grouped into the same subset, whereas the whiteness data obtained after bleaching at 110°C were placed in a separate subset. Consequently, it is evident that the temperature variable significantly impacts whiteness.

Bleached samples were pre-mordanted using Potassium aluminium sulfate (alum) and dyed using chlorophyll natural dye. Colour measurements of the dyed samples were made. Chromaticity coordinates (L*, a*, b*) and Kubelka-Munk (K/S) values of the samples showed negligible difference. An investigation of the difference between the K/S values of samples subjected to pre-mordanted utilising 5% and 10% on weight of fabric (owf) of potassium aluminium sulfate (alum) was conducted employing the Independent Samples t-test (Table X). No statistical difference was observed between K/S values (p value > 0.05).

In this study, the usability of atmospheric pressure air plasma in textiles was investigated. Plasma pretreatment was applied to textile materials as a pre-treatment before bleaching and natural dyeing processes. Plasma pretreatment induced modifications on the fabric surface. The integration of plasma technology in textile dyeing is expected to reduce both chemical and water consumption required for subsequent processes such as bleaching and dyeing. Consequently, the amount of wastewater discharged into the environment is anticipated to decrease, along with a reduction in energy consumption.

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