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EVALUATION OF THE QUALITY OF CELLULOSE SEMI-FINISHED PRODUCTS FROM TECHNICAL HEMP AND THE POSSIBILITY OF THEIR FURTHER USE

OPTIMIZATION OF RAWHIDE COLLAGEN DEFIBRILLIZATION PROCESS

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ABSTRACT

The paper features the rawhide collagen defibrillization process in the elastic leather materials manufacturing. Optimal colloid-chemical properties of semi-processed products were defined by way of using mathematical optimization of rowhide liming process. It was found that during the alkaline treatment of raw material (in the operating temperature range) the degree of defibrillation of raw material raises (in proportion to the derm collagen swelling) with increase in the ratio of process solution to the mass of raw material, and the extremum of hydrothermal stability and leather yield can be estimated. It was also shown that the degree of swelling decreases with a decreasing ratio of sodium sulphide and sodium hydrosulphide, and the leather area yield reaches the maximum value at the equal proportion of these reagents. Multicriteria optimization of rawhide liming process using the Harrington's desirability function was carried out. The developed technology of soaking and liming was tested under production conditions. The above-mentioned low-waste technology provides elastic leather materials with a yield increase by 3.5%, which meet the industry standards requirements.

KEYWORDS

Defibrillization; Derm collagen; Rawhide; Liming; Swelling; Multicriteria optimization; Desirability function.

INTRODUCTION

The collagen is a widespread biopolymer, which is part of the animal skins, and is part of their internal organs. Collagen and collagen-derived products are widely used in different industries such as light and food industries, medicine, etc. [1, 2]. The fibrillar collagen of animal skin is 90% of the dry weight of the dermis, and under the action of chemical reagents changes the structure and properties in the process of forming the finished material. Thus, it is important to remove unstructured components of the dermis, that is various cells [3], surrounded by plasma membranes consisting of lipids up to 45% of their mass and more than 50% of proteins that mainly have globular structure. In the processes of soaking, liming, alkaline treatment (unhairing), reliming, enzyme treatment (softening) and acid-salt treatment (pickling) unstructured components are replaced by technological solutions. It is especially important to investigate such a substitution in the case of soaking and liming processes, in which soluble proteins, mucopolysaccharides, some lipid inclusions, and preservative chemicals are removed. Conversely, the derm collagen restores the water balance of raw materials and under the action of alkaline reagents the mass of raw materials increases, collagen is defibrillazed. Further, amide intermolecular bonds are destroyed with the formation of ionized amine and carboxyl side chain groups that increases the chemical activity of collagen for the efficient subsequent technological processes' implementation.

Leather and fur materials quality depends on the rawhide type and processing technique. Given the rawhide quality [4], the multi-stage colloid-chemical and mechanical working operations, there is a necessity for effective use of a wide range of chemical reagents at all technological stages and especially in soaking and liming processes of collagen-derived raw materials. However, considering the significant cost of environmentally hazardous reagents at soaking and liming stages [5], it is reasonably required to minimize reagent costs with the most efficient use of raw materials.

Due to the amphoteric nature, the derm collagen changes its properties in the technological processes depending on the pH of working solution [6]. According to the impact on the swelling of the derm

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collagen spatial structure, the alkaline reagents form a row KOH> NaOH> $Ba(OH)_2$> $Ca(OH)_2$. However, according to the chemical interaction degree with collagen, chemical reagents can be arranged in the following sequence: $Ca(OH)_2$> $Ba(OH)_2$> KOH> NaOH> Na_2S> NH_4OH, and according to the unstructured components removal degree, the above mentioned reagents have the reverse sequence. It should be noted that strong base solutions can cause significant collagen destruction. In particular, a 10% NaOH solution at a temperature of 18-20°C causes the collagen destruction, which reaches 24%, in two days [7]. Moreover, even in weak alkali solutions, telopeptides with amino acid residues of tyrosine are cleaved, which indicates the collagen destruction. In contrast to strong base, the use of calcium hydroxide hydrolysis collagen destruction is significantly reduced. Thus, in a saturated 0.13% calcium hydroxide solution, the collagen destruction is only 12% upon contact of the components for 120 days [8]. Notably, in an alkaline condition, there is ammonia cleavage from aspartic and glutamic acid residues observed, as well as ionic and hydrogen bonds rupture, destruction of cross-molecular and intra-molecular bonds, that leads to the release of blocked amino, carboxyl and hydro groups. In addition, the formation of free amino and carboxyl groups can occur due to the covalent bonds' breakdown in the collagen molecule main chains, along with the removal of guanidine group of arginine. The course of these side reactions is much slower than the interaction of alkalis with carboxyl groups in the side radicals of collagen macromolecules.

The authors of [9] assumed that using saturated solutions of calcium hydroxide only provides a more pronounced effect of fibrillar separation of the derm collagen structure if alkali solutions with a significant solids content (4.0-4.5% of calcium hydroxide by rawhide weight) are used. This effect can be explained by action of the dispersed calcium hydroxide particles on the collagen structure and other proteins. It can be considered that smaller amount of dispersed alkali in liming processes [10] maintains not only to obtain high-quality leather, but also reduces wastewater pollution.

The saline agents adding in the alkaline working solution reduce the hydrolyzing effect on collagen, while swelling decreases it, depending on the type of salt alkaline-salt treatment [7]. Reich [11] showed that the active groups of collagen also adsorb neutral salts while changing its swelling degree. There are three groups of salts according to the watering degree. Strong swelling of the derm collagen is caused by rhodanates, iodides, chlorates, salts of barium, calcium, magnesium and lithium, which is expressed in a significant fibril thickening and reducing, and decreasing their denaturation temperature. The impact of the second group salts is determined by their concentration in solution: low concentrations of sodium chloride cause significant swelling whereas large concentrations cause collagen dehydration. Salts of the third group - sulfates, thiosulfates and carbonates have a dehydrating ability and do not show increased adsorption.

Over sodium hydroxide, the calcium hydroxide solubility decreases and the working solution reduces the chemical activity. This also occurs when calcium hydroxide is used in combination with one of the exacerbating salts: potassium or sodium, which form insoluble calcium salts. When insoluble salt ($CaCO_3$, CaC_2O_4) sets up, there is a direct dependence between the salt concentration and the liming solution properties. If salt is sparingly soluble, for example $CaSO_4$, CaS_2O_3 or $Ca(C_2H_3O_2)_2$, or salt ($CaCl_2$) soluble in the sodium chloride presence in the skin, then with increasing the salt amount, the maximum alkalinity is quickly reached. In this case, the double salts ($CaCO_4 \cdot Na_2SO_4$) formation is possible [8]. The use of sodium hyposulfite in the liming solution is advantageous because it eliminates the insoluble compounds formation and leads to a controlled increase in the liming solution alkalinity.

The globular protein body is removed at the soaking stage because it is contained in a tissue saline solution. This process can be intensified by the surfactants use. Fibrils dispersion depends on the removal completeness of globular proteins and polysaccharides as they contribute to cell adhesion [12]. Surfactants used in soaking and liming processes are multifunctional. They promote diffusion of electrolytes into the dermis by reducing the surface tension at the interface, increasing the water content in the dermis, and have a dispersing effect on the substances removed and plasticizing effect on the derm collagen fibrillar structure. When using sulfonol in a soaking solution with a concentration of more than 2 g/dm^3, the hexoses yield increased by almost 8 times in the treatment solution, and proteins increased by 4 times. A similar effect on polysaccharides is achieved at the liming stage with the non-ionic surfactants use along with a slight yield of soluble proteins and oxyproline.

The interfibrillar matter removal from the dermis structure enables to separate its fibrils and increase the collagen reactivity. At the same time partial disorientation of fibrillar structure elements with decrease in its durability is reached. Further, the hydration and swelling degree of the neutralized dermis increases, the collagen destruction degree caused by enzymes increases [13]. It is important to consider that an effective removal of unstructured derm components, in particular polysaccharides and proteoglycans, is observed at the rawhide alkaline treatment stage due to enzymatic rawhide rehydration when used of sodium sulphide and calcium hydroxide in existing technologies [14]. The study of the collagen structure at eight stages of fresh ovine skins processing into dry crust leather using small-angle X-ray scattering is devoted to paper [15].

The authors defined a dependence between the structure stability and the collagen fibrils orientation index from its hydration degree. In the liming process, the cross-links are destroyed, which destabilizes the collagen structure [16], its fibrils are stretched and slightly straightened by reducing the collagen D-gap [17].

Thus, despite the significant number of works devoted to the influence of different chemical reagents and collagen structure on the rawhide liming process as well as on the semi-finished product properties obtained, there is virtually no scientific justification for effective soaking and liming processes. This is especially true to minimize the cost of environmentally hazardous reagents.

RESEARCH PROBLEM

The aim of the work was to establish the dependence between the effective rawhide use with a set of colloidal chemical properties of the semi-finished product at the soaking-liming stage. The following tasks were solved:

- colloid-chemical properties determination of alkaline treated semi-finished product;
- rawhide liming technology optimization;
- testing of the developed rawhide soaking-liming process.

MATERIALS AND METHODS

The cattle hide sulphide liming process and effective rawhide use were studied. The wet salted extreme light steer hides, fleshed until complete subcutaneous tissue removal, weighing 19-21 kg were used for the study. Rawhide samples with an area of 5 dm^2 taken from the central (butt) and peripheral (belly) areas were soaked in a wooden drum with a volume of 18 dm^3 at a working solution ratio to semi-finished product equal to 1.3:1 with float ratio (FR) 1.3 at a temperature of 27-29°C with the addition of 0.5% Na_2CO_3 by rawhides weight for 6 hours. Drum rotation speed during soaking-liming processes was 3-4 min^{-1} for 50% of the total time with a frequency of 0.5 h of rotation and rest. After soaking, the rawhide was washed twice at FR 2.0 with a water change after 0.5 h.

Natural water ISO 5667-11-2013, sodium sulphide GOST 596-89, sodium hydrosulphide TU 2153-541-05763441-2012 and calcium hydroxide VP-K-G DSTU B B.2.7-90:2011 were used for liming. Note: The names of state and industrial standards, which guide research and industrial production, are given for reference.

The influence of the liming process factors on the semi-finished product formation was determined by liming process physico-chemical and technological properties. Elastoplastic properties of the semi-finished product in compression strain were measured by an indicator gauge with a division value of 0.01 mm according to the standard method described in [18]. Swelling of the limed semi-finished product was expressed as an increased percentage in thickness after washing to the soaked rawhide thickness. Residual engineering strain was measured after unloading the sample after 0.5 hours. Hydrothermal stability was determined by the sample initial length reduction when semi-finished product heated in water or a glycerine and water mixture by weighting ratio 4:1 with a speed of 2-3 ºC/min according to DSTU 2726-94. The porosity of rawhides, limed semi-finished product after alcohol-ether dehydration, and the leather after conditioning at a temperature of 20 ± 2°C and humidity of 65 ± 5% was set by the ratio of pore volumes and sample elongation at rapture of 9.81 MPa on the rupture machine RT- 250M (belt A) and at a deformation rate of 80 mm/min according to the methods indicated in [18, 19]. To render gelatin, limed samples were used from the rump washed for 24 h under flowing water. The rendered gelatin amount obtained from the semi-finished product was set at a temperature of (65±0.1) ºC for 1.5 h on a photoelectrocalorimeter "FEK-56M" according to the calibration graph "Optical density of gelatin solution - the percentage of semi-finished product dry residue" at a 520 nm wavelength and the standard distilled water. The yield area was set by the leather area elongation after drying and moisturizing processes to the soaked rawhide area.

PRELIMINARY STUDIES OF LIMING PROCESS

The soaked samples of raw materials were subjected to liming for 12 hours at the temperature of the process suspension 27-29 °C [20], at the float ratio 0.5-3, at a concentration of sodium sulphide and calcium hydroxide of 8 g/dm^3 and 7 g/dm^3, respectively.

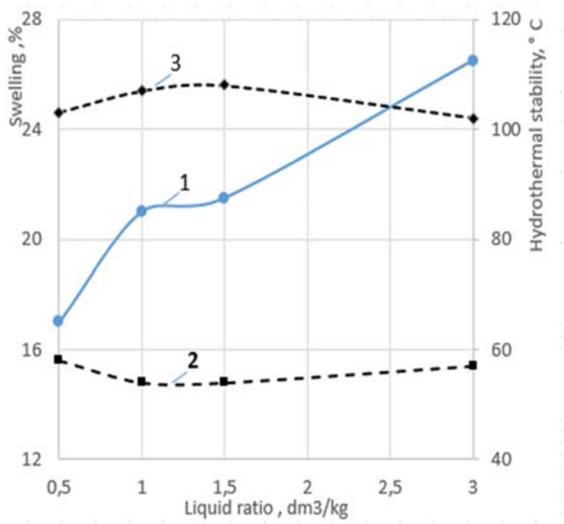


Figure 1. Change in swelling and temperature of hydrothermal stability depending on the values of the float ratio. **Note.** Curve 1 corresponds to the swelling process, curve 2 describes the change in the hydrothermal stability of the limed semi-finished product, curve 3 describes the change in the hydrothermal stability of the tanned semi-finished product.

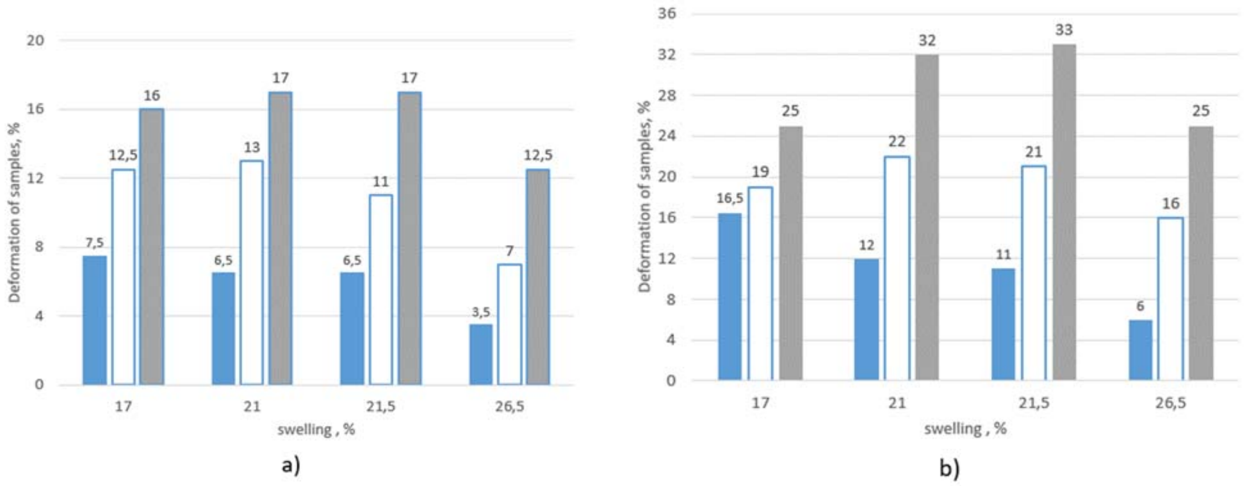


Figure 2. Dependence of deformation of limed semi-finished product on swelling. **Note 1.** Visualization is presented for different topographic areas of the the semi-finished product: (a) corresponds to the butt, (b) corresponds to the belly; **Note 2.** Stress values (kPa) are color marked: 1 is blue, 3 is white, 5 is gray.

The subsequent washing with a water change lasted 40 minutes. To determine the yield of the area, the resulting semi-finished product was subjected to reliming with ammonium sulfate at a temperature of 28-30 °C followed by washing, pickling and tanning with basic chromium sulfate with a basicity of 38-42% and a consumption of 1.6% by weight of limed sheared skin. The following drying and wetting processes and operations were performed according to the current technology [21].

The studies of the deformation properties of the limed semi-finished product under compression showed the following results (see Figure 1) depending on water consumption. The decrease in float ratio was followed by the reduction of the limed hide collagen swelling. The hydrothermal stability of the tanned semi-finished product acquires the maximum value at the minimum value of the hydrothermal stability of the limed semi-finished product.

When compressing the limed semi-finished product, there was an increase in its deformation capacity at low pressure (Figure 2). With increasing compression stress at higher values of the float ratio, the deformation of the semi-finished product increases even more. The described phenomenon is especially characteristic of areas with a loose structure (Figure 2(b)). With increasing compression stress, the samples obtained at the values of the float ratio 1.0-1.5 have the maximum deformation.

The behaviour of the conditional permanent deformation of the samples of the limed semi-finished product depending on the values of the float ratio (Figure 3) is similar to that described above. The yield of the hide area increases therewith. Reducing the float ratio when liming to a value of 0.5 leads to the limed semi-finished product with lower swelling and lower area yield. This can be explained by insufficient defibrillation of the middle of corium, i.e., a lower degree of fibrillar dispersion of collagen.

Therefore, to obtain a semi-finished product with the maximum yield of the area, the float ratio must be in the range of 1-1.5; this contributes to the optimal swelling of the limed semi-finished product.

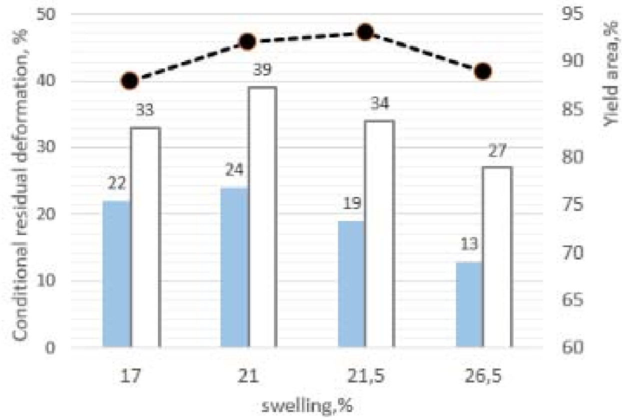


Figure 3. The dependence of the conditional permanent deformation of the limed semi-finished product and the yield of the hide area on the degree of swelling of the semi-finished product. **Note.** Topographic areas of hide correspond to the color of the columns: the butt – blue columns, the belly – white columns; the dotted curve describes the change in area yield.

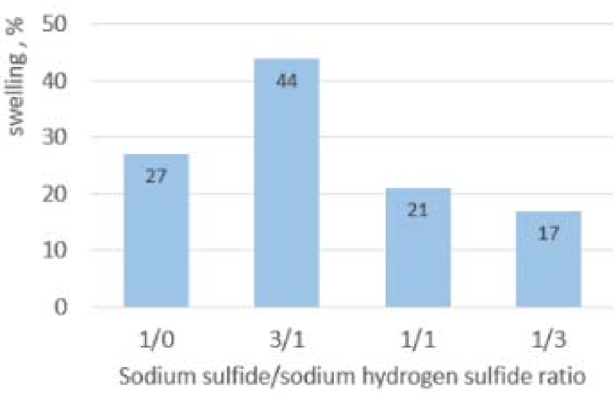


Figure 4. Dependence of the degree of swelling on the sodium sulphide to sodium hydrosulphide ratio.

Table 1. Characteristics of process factors.

Description	Value of factors		
	X_1	X_2	X_3
Middle level	1.16	1.00	12.0
Variability interval	0.2	0.22	4.0

To reduce the consumption of environmentally hazardous sodium sulphide during liming, the effect of the ratio of sodium sulphide and sodium hydrosulphide on the swelling of dermal collagen was studied (Figure 4). The increased consumption of sodium hydrosulphide contributes to reducing the degree of swelling. When the value of the ratio of sodium sulphide to sodium hydrosulphide equaled 1/3, incomplete dehumidification of hide was observed. Therefore, the optimal content of sodium hydrosulphide in the liming solution to obtain the maximum yield of the hide area should be at least 50%.

Thus, the limed semi-finished product with optimal elastic-plastic properties and moderate swelling can be obtained by carrying out soaking and liming processes at a stable temperature of 27-29 °C and at a reduced consumption of chemical reagents in accordance with current technologies, with water consumption ratio 1.0-1.5 relative to the weight of raw materials. This creates the conditions for more uniform swelling of individual topographic areas of the corium collagen, which facilitates the action of chemical reagents on the structure of the corium. The result was a more uniform defibrillation of elementary fibers and fibrils of the corium collagen.

OPTIMIZATION OF THE RAW HIDES LIMING PROCESS

Obtaining the mathematical model

Optimization of the raw hides liming process requires the development of the properly specified model based on the principles of an active experiment design. As a result of the preliminary analysis of the object of research, the factors influencing the liming process and the quality characteristics of the liming process were selected. The following parameters were chosen as factors: X_1 (% by weight of raw materials) – the total consumption of alkaline reagents (the alkaline reagents Na_2S and NaHS were dosed in equal proportions 1/1), X_2 (% by weight of raw materials) – consumption of calcium hydroxide, and X_3 (hours) – liming process duration. The response values were: the consumption of raw materials per 1 m^2 of product – y_1, kg/m^2; swelling of the semi-finished product – y_2, % by weight of soaked raw materials; stretch elongation at 9.81 MPa – y_3, %.

For the experiment, 20 trial amounts of 8 samples, measuring 150 by 160 mm and 3.0–3.5 mm thick, were used. The samples were obtained from the butt topographic area of two wet salted extreme light steer hides. The samples were completed in batches by the method of asymmetric fringe [18]. The hypodermis tissue of the hides was removed using a shaving machine. Processing of each batch of samples was completed by chrome tanning. After aging and squeezing, the samples were subjected to splitting to a thickness of 1.5 mm and brought to the finished form by the technology of production of elastic leather [20].

The experiments were performed according to a pre-built experimental design. The zero level of the factors of the studied process and their interval of variation are given in Table 1.

The specificity of the experimental studies was that at the beginning a 23 full factorial design was implemented. Since the first-order mathematical models and incomplete quadratic models based on the results of a full factorial design turned out to be inadequate, it was decided to switch to second-order experimental designs. To make optimum use of the results of the experiments already performed, the classic central composite rotatable plan [22] with six experimental points in the center of the domain under study and with axial "star value" of 1.682 was chosen from the second-order plans (Table 2). The selected plan has a significant advantage over the central orthogonal plan: the information surface of the rotatable plan is close to spherical, as a result of which the accuracy of the output variable in all directions at the same distance from the center of the domain under study is almost the same. Therefore, the compositional plan makes it possible to minimize errors in the definition of the response variable associated with the inadequacy of the presentation of the results of the study of the process using the model in the form of a second-order polynomial.

After processing the response values, the coefficients of regression mathematical models (polynomials of the second degree $\hat{y}_j = f(x_i)$ were obtained:

$$\begin{cases} \hat{y}_1 = 6.5509 - 0.0673x_1 - 0.1053x_2 - 0.1163x_3 + 0.0538x_1x_2 - 0.0062x_1x_3 + \\ +0.0438x_2x_3 + 0.1148x_1^2 + 0.0353x_2^2 + 0.0883x_3^2; \\ \hat{y}_2 = 20.3670 + 2.6459x_1 + 1.7140x_2 + 2.8156x_3 + 0.1250x_1x_2 - 0.1250x_1x_3 + \\ +0.0438x_2x_3 + 0.1148x_1^2 + 0.0353x_2^2 + 0.0883x_3^2; \\ \hat{y}_3 = 34.7190 + 3.8241x_1 + 5.0721x_2 + 5.1487x_3 + 0.3750x_1x_2 + 0.3750x_1x_3 + \\ +0.375x_2x_3 + 3.6488x_1^2 - 2.4117x_2^2 - 3.2954x_3^2, \end{cases} \quad (1)$$

s.t. $\hat{y}_j$are predicted response values for the j-th model.

Table 2. Experimental design and the obtained response values.

#	Factor Values						Response Values		
	Coded			Uncoded (natural)					
	x_1	x_2	x_3	X_1	X_2	X_3	y_1	y_2	y_3
1	–	–	–	0.96	0.78	8.00	7.21	14.0	12.0
2	+	–	–	1.36	0.78	8.00	6.93	19.0	18.0
3	–	+	–	0.96	1.22	8.00	6.78	17.0	21.0
4	+	+	–	1.36	1.22	8.00	6.71	23.0	27.0
5	–	–	+	0.96	0.78	16.00	6.98	20.0	20.0
6	+	–	+	1.36	0.78	16.00	6.67	25.0	26.0
7	–	+	+	0.96	1.22	16.00	6.72	24.0	29.0
8	+	+	+	1.36	1.22	16.00	6.63	29.0	38.0
9	$-\alpha$	0	0	0.8236	1.00	12.00	6.87	17.0	19.0
10	$+\alpha$	0	0	1.4964	1.00	12.00	6.77	26.0	34.0
11	0	$-\alpha$	0	1.16	0.63	12.00	6.74	19.0	21.0
12	0	$+\alpha$	0	1.16	1.37	12.00	6.45	24.0	39.0
13	0	0	$-\alpha$	1.16	1.00	5.27	7.03	15.0	17.0
14	0	0	$+\alpha$	1.16	1.00	18.73	6.46	23.0	38.0
15	0	0	0	1.16	1.00	12.00	6.57	20.5	34.0
16	0	0	0	1.16	1.00	12.00	6.44	21.5	35.0
17	0	0	0	1.16	1.00	12.00	6.5	21.0	37.0
18	0	0	0	1.16	1.00	12.00	6.45	20.0	35.0
19	0	0	0	1.16	1.00	12.00	6.55	21.5	32.0
20	0	0	0	1.16	1.00	12.00	6.59	21.0	33.0

Note 1. # is number of experimental run. **Note 2.** The signs "+" and "-" indicate the corresponding levels of change of technological factors: the upper +1 and lower -1; α indicates the special “axial” value of distance from the center of the domain under study.

The statistical study of the obtained models showed that they adequately describe the process of liming of raw hides and therefore can be used to further search for optimal parameters of the liming process.

Multi-objective optimization of liming technology using Harrington's desirability function

Multi-objective optimization is the search for solutions that in the multidimensional space of objective functions are acceptable and close to the optimum of all criteria simultaneously [23]. In contrast to the single-objective optimization problems [24], multicriteria optimization solves the issues related to the contradiction of individual optimality criteria.

In the study presented the optimization strategy on the basis of the generalized criterion of desirability was applied. This strategy is to reduce the multi-objective problem to a certain generalized criterion (i.e., to the single-objective problem) with its subsequent optimization. The generalized desirability criterion is a weighted product of partial desirability criteria, which, in their turn, are normalized estimates of the state of the studied system, presented in fractions of a scale unit (from 0.0 to 1.0) and obtained from target functions by encoding these functions based on a special “scale of preferences”.

Harrington's desirability function was used in this study, which showed sufficient efficiency compared to other desirability functions [25]. The effectiveness of the desirability-based approach compared to other multi-purpose optimization strategies has been confirmed by numerous studies [26–29]. It should be noted that the optimization of the generalized desirability criterion may be accompanied by computational difficulties due to the complex structure of this criterion. The search process is partially simplified by preliminary visual analysis of response surfaces, which provides a priori information about the most "promising" ranges of factor space [30].

The numerical solution of a complex nonlinear optimization problem requires the use of special methods for finding the global extremum, for example, the use of random search methods. Given this, the authors conducted a multi-goal optimization that combines the desirability function with the genetic algorithm [31] as an evolutionary method of global nonlinear optimization. Therefore, the optimization of liming technology was performed according to the following procedure:

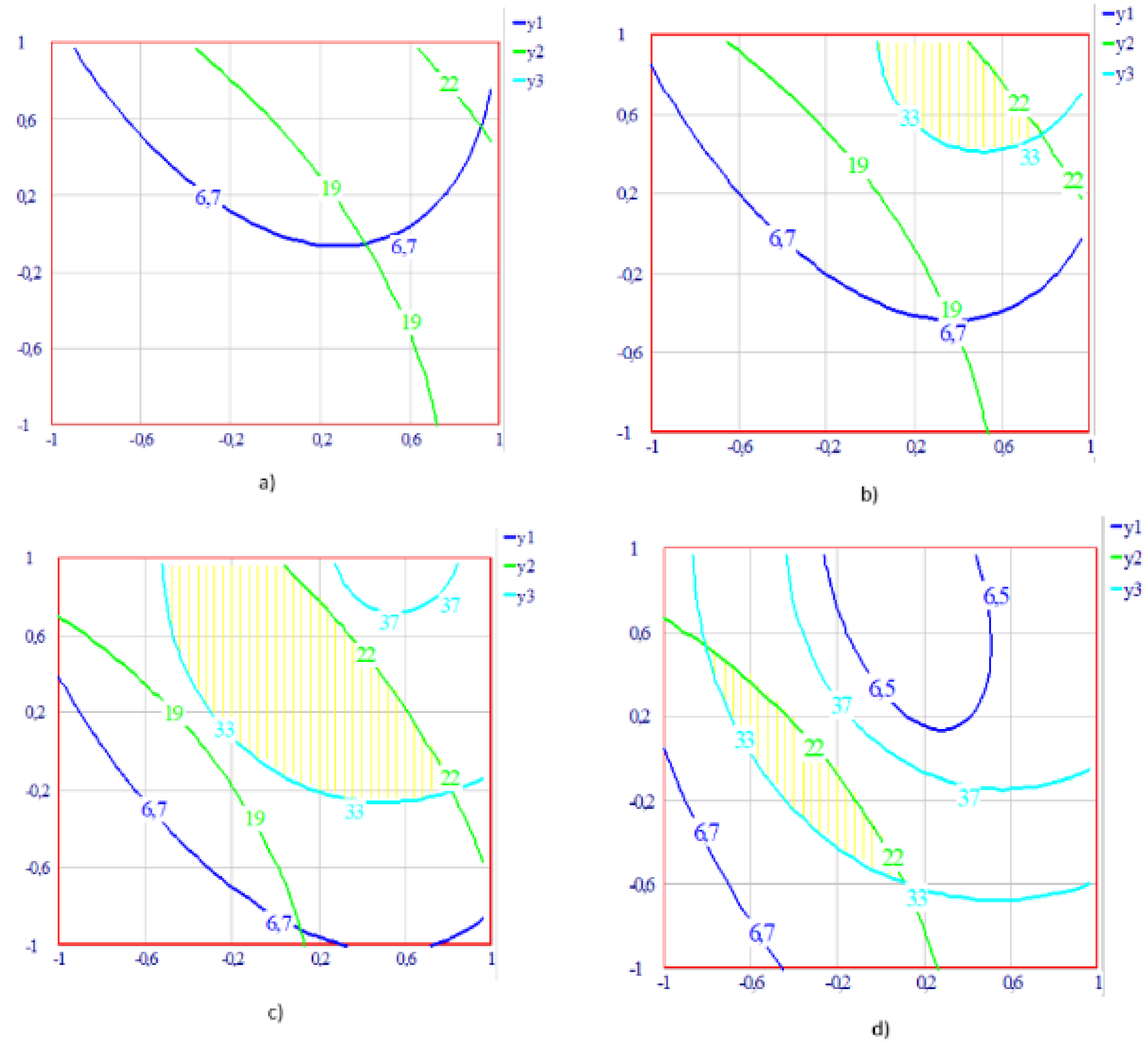


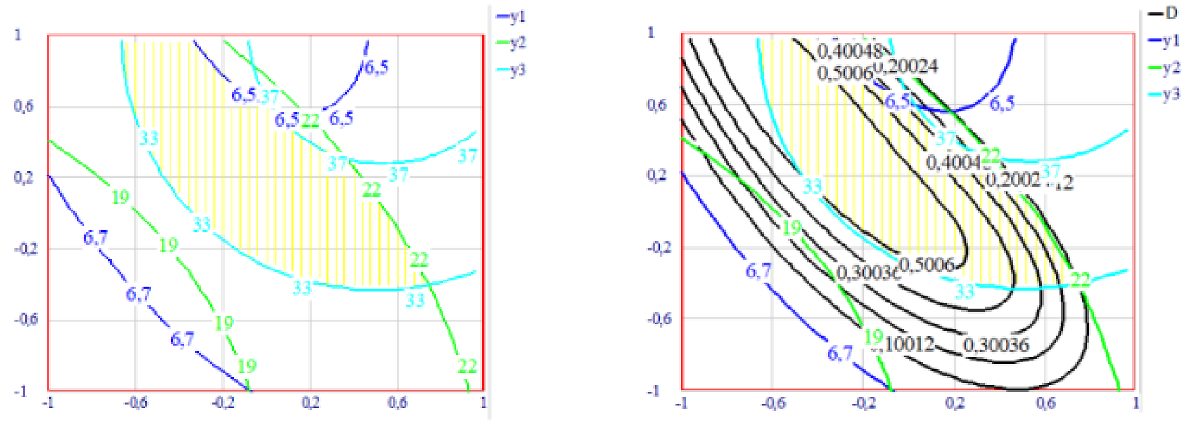
Figure 5. Response graphs of hide liming process. **Note 1.** Factor x_3 was fixed at the level of: a) –0.8; b) –0.6; c) –0.2; d) 0.9. **Note 2.** The compromise area is marked in yellow.

1. Preliminary visual analysis of response surfaces.
2. Construction of a generalized criterion using the Harrington desirability function.
3. Search for the optimum of the generalized criterion of desirability function and decision-making based on the results of optimization. This procedure uses a genetic algorithm of the GENOCOP type [32], which with sufficient probability guarantees the achievement of the global optimum of the generalized criterion of desirability.

The analysis of response surfaces (Figures 5, 6) included simultaneous visualization and study of graphs for all criteria, i.e., construction and study of projections of target surfaces y_1, y_2 and y_3 on the x_1-x_2 plane. During the analysis, the value of the factor x_3 consistently varied within the applicable domain of this factor. The analysis showed that the maximum value of the area of the compromise area can be achieved in the range of change of the factor $x_3 \in$ [-0,6, 0,6] (Figures 5(c), 6(a)). At the same time, as the factor x_3 moves away from the medium level, the area of the compromise region decreases (Figures 5(b), 5(d)) until it disappears (Figure 5(a)).

As a result of the analysis of response surfaces, the range of factors variation during multicriteria optimization of the liming process was previously determined to reduce the number of calculations: $x_1 \in$[-0.6, 0.9], $x_2 \in$[-0.5, 1], $x_3 \in$[-0.6, 0.6]. The subsequent numerical search for the extremum based on the desirability function (Figures 5b, 6b) confirmed that these intervals were chosen correctly.

For parametric identification of partial desirability criteria according to a priori data, reference marks on the desirability scale were set (Table 3). The reference marks establish a correspondence between the "less desirable" and "more desirable" key values of the response variables y_i (i=1, 2, 3) and the values of desirability.



a) b)

Figure 6. Response graphs of the multi-goal optimization problem in the neighborhood of the extremum. **Note 1.** The compromise area is marked in yellow. **Note 2.** The factor x_3 is fixed at the average level; a) compromise area, b) correlation of the compromise area with the desirability function D isolines.

Table 3. Reference marks on the desirability scale for the response variables

Response values	**Desirability**		
	"bad" (d_i=0,2)	***"good" (d_i=0,8)***	***"bad" (d_i=0,2)***
y_1	–	6.47	6.58
y_2	17	21	26
y_3	32	36	–

It should be noted that for variables y_1 and y_3 one-sided desirability profiles were applied, while for variable y_2 a two-sided profile was applied, since the desired range of existence of the variable y_2 was known.

After determining the partial desirability criteria di (*i*=1, 2, 3) a generalized desirability criterion (2) was constructed:

$$D = \sqrt[3]{d_1 \cdot d_2 \cdot d_3} \qquad (2)$$

The maximum value of the generalized desirability criterion D = 0,707 corresponds to the compromise-optimal values of the factors in the coded form: x_1 = –0.1233, x_2 = 0.4405, x_3 = 0.0497.

Therefore, based on the results of optimization of the liming process of wet salted extreme light steer hides, the following values of the consumption of chemical reagents (% by weight of raw materials) were recommended: hydrosulphide and sodium sulphide 0.57; calcium hydroxide 1.10. The recommended process duration is 12.2 hrs. The consumption of raw material of 6.5 kg per 1 m^2 of product, as well as a degree of swelling of 21% by weight of raw materials and stretch elongation 36.0% at 9.81 MPa, can hereby be achieved.

THE TESTING OF THE DEVELOPED TECHNOLOGY

The industrial testing of the developed low-waste technology of soaking and liming was carried out in the "Chinbar" stock company (Kyiv City, Ukraine), in the production of elastic leather for shoe uppers from wet salted extreme light steer hides. All soaking and liming processes were carried out in the liming drum "Volcano" manufactured by "Olcina" (Spain) at a speed of 3-4 min^{-1} at a stable temperature. Soaking of raw materials was carried out in accordance with the regime described above (in the section "Materials and methods of research"). The following mixture (% by weight of raw material) was used for liming: sodium hydrosulphide – 0.57, sodium sulphide – 0.57, calcium hydroxide – 1.1. The spent technological solution had the following characteristics: pH equal to 11,5-12,0 and density equal to 1.020-1.035 g / cm^3. After washing at a float ratio of 2 for 40 min, the limed semi-finished product was subjected to fleshing and splitting.

Before the reliming, using ammonium sulfate 1.6–1.8%, the splitted semi-finished product is washed at float ratio 1.2 for 20 minutes. The semi-finished product then undergoes bating, washing and pickling processes at a float ratio of 0.6. The characteristics of the spent solution were as follows: the pH value is 2.9–3.4 and the density is 1.027 g / cm^3. Tanning of the obtained semi-finished product is carried out with basic chromium sulfate with a basicity of 38–42% with a consumption of 1.8 in terms of Cr_2O_3 using the spent solution. The tanning agent is dosed in two stages with an interval of 2 hours.

Further technological processes and operations were performed according to the current technology [21] which acts as a reference technology. The results of determining the physicochemical properties of the obtained hides are shown in Table 4.

Table 4. Conditions for soaking and liming processes and hide properties.

Effectiveness measure	Technology	
	offered	*pre-existing*
Float ratio, [dm^3] per 1 kg of raw material, when soaking	–	1.5
Float ratio, [dm^3] per 1 kg of raw material, when liming	1.3	1.5
Float ratio, [dm^3] per 1 kg of raw material, when calcinationing	–	1.5
Consumption of materials, [%] by weight of raw materials	2.7	8.8
Process temperature [ºC]	27–29	20–22
Duration of the process [hours]	17–19	40.0
The degree of swelling of the sheared skin [%]	21.0	26.0
The degree of rendering of gelatin, [%] of the dry residue	9.0	12.0
Enzyme-thermal stability [min]	55.0	52.0
Porosity of raw material [%]	44.0	44.0
Porosity of sheared skin [%]	52.0	50.0
Porosity of product [%]	54.0	53.0
Hydrothermal stability of raw material [ºC]	65.0	65.0
Hydrothermal stability of sheared skin [ºC]	56.0	54.0
Loose grain hides [%]	–	18.0
Consumption of raw materials, [kg/100 m^2]	647.2	669.5
Yield of hide area [%]	92.5	89.0

The hides obtained by the developed technology are characterized by savings of natural raw materials (3.5% yield higher) and the absence of loose grain defects. This is confirmed by the higher resistance of the limeless semi-finished product of the developed technology to the melting of gelatin and the smaller amount of its swelling. At the same time, the developed technology is characterized by significantly lower consumption of environmentally hazardous chemical reagents and reduced duration of the technological process.

CONCLUSIONS

The process of defibrillation of raw hide collagen in the production of elastic skins has been studied. The study involved determining the optimal parameters of the liming process of the semi-finished product, which provides the best colloid-chemical properties of the mentioned semi-finished product. It was found that during the caustic treatment of raw materials with an increase in the ratio of process medium to its mass from 0.5 to 3.0 (at a temperature of 27–29 °C), the degree of defibrillation increases corresponding to the swelling of derm collagen. In this case, the hydrothermal stability and the yield of the hide area approaches 107 ºC and 92% of the area of the soaked raw material, respectively. It is shown that in the case of a decrease of the Na_2S/NaHS ratio, the degree of swelling decreases, and the area yield reaches the maximum value at a ratio of these reagents 1/1 and the optimal degree of defibrillation of the derm collagen. Multigoal optimization of raw leather liming process using the Harrington desirability function was performed. According to the results of optimization, the optimal values of technological factors of the process (the total consumption of reagents) were established: hydrosulphide and sodium sulphide – 0.57, calcium hydroxide – 1.1 (% by weight of raw materials).

The optimized soaking and liming technology was tested under industrial conditions, in the production of shoe upper leather. The analysis of the results of practical evaluation showed that the implementation of the optimized technology (in comparison with the current technology) provides the reduction of environmentally hazardous reagents consumption by more than three times, as well as the halving of the duration of leather raw materials caustic treatment. At the same time, the low-waste technology ensures the production of elastic leather materials that meet the requirements of state standards of Ukraine, with an increase in the area by 3.5%.

The developed technology of leather soaking and liming can be used in the development of innovative processes for the production of leather materials from the wide range of raw hides and skins.

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FORMATION OF COMPLEX 3D SURFACES SCANS FOR GARMENT CAD

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ABSTRACT

Algorithms for building scans of complex surfaces of the human body based on three-dimensional measurements were founded. A mathematical model of the surface was developed, followed by the definition of triangulation parameters. The accuracy of building sweeps followed by pattern making depends on the direction and number of geometric elements. The obtained data should be used to improve garment CAD for pattern making for individual consumers.

KEYWORDS

3D Surface; Scans; Garment CAD; Pattern making; Kinect device.

INTRODUCTION

The human body is a complex geometric shape, which is an individual feature for each individual person. In addition, the asymmetry of the right and left parts of both a typical and atypical figure can be of varying degrees. Anthropometric standards reveal certain unified features that can be separated into separate groups. Such features are reduced to geometric measurements. One of the main requirements for clothing that is designed and manufactured for a specific person is a quality fit, which in many cases determines the proximity of the surface of the clothing to the surface of the human body. For this reason, the corresponding part of the clothing in the design process should have the appearance of a three-dimensional figure spread over a plane. Pattern sweeps are commonly known as garment elements in various garment design systems. The implementation of known methods in modern garment CAD did not expand fundamentally their capabilities in obtaining particularly accurate pattern drawings taking into account the plasticity of the figure.

The theory of three-dimensional design opens up new perspectives for improving the methods of graphic reproduction of the surface of the human body, and the functioning of modern systems of automated clothing design cannot be effective without solving the problems of information support. Initial anthropometric information about the surface of the figure of garment consumers in the form of their digital models for 3-CAD/CAM expands the possibilities of using computer systems in the design preparation of production. The methods of 3D clothing modelling provide a new level of design activity by using graphic software packages for modelling 3D space and 3D printing of design objects.

Digital 3D technologies, primarily three-dimensional scanning technologies, open up new opportunities for more accurate garment pattern making. Despite the considerable amount of research in this direction, there remains a complex of problems that determines the features of anthropometry of individual areas of the human body surface, as well as practical directions for improving the anthropometric database and designing clothes taking into account the real three-dimensional geometry of the body.

A number of recent studies and publications are devoted to the implementation of three-dimensional technologies in the process of designing clothes.

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The value of three-dimensional technologies for the garment pattern making is considered in [1]. This work is an overview and needs further detailing.

The study [2] assessed the potential of three-dimensional dynamic fashion clothing together with three-dimensional virtual modelling systems. This research led to a discussion of the possible future of digital fashion design. The three-dimensional presentation of clothes is considered a real problem. Not enough attention is paid to the process of actually designing clothes to ensure the best optimal fitting conditions.

The paper [3] investigated the problem of combining 3D and 2D design methods based on the use of key modules of 3D digital modification of the morphological structure of the body and 2D generation of scans of jacket details. Recommendations are developed for a limited range.

The problems of improving the selection of clothes without manual measurement are given in the study [4]. The developed methods involve sizing garments based on a shape model using large-scale 3D scanned measurements as input. Determination of design features for an individual consumer is not provided.

Alternative methods of determining real forms of clothing without the use of expensive 3D scanners are proposed in the article [5]. Such systems require significant preparation in the form of multi-colored painting. In some cases [6], the use of 3D scanners can be replaced by cheap kinect devices.

The article [7] presents the results of anthropometric studies of the human body using 3D scanning. The relationships between the main dimensional features were revealed. Traditional signs although 3D technologies were used in the study, allow to determine any signs (positions in space of the main levels of the figure, perimeters of contours, on the right and left parts of the body separately) and introduce new ones.

Studies [8, 9] are devoted to the development of real pattern making methods based on the development of a 3D garment model. The developed algorithms allow pattern making after two-dimensional parameterization. The work does not provide methods for building structures of individual parts of the human body that are complex in shape.

The problems of creating real structures based on three-dimensional measurements are also considered in [10, 11]. The study added methods of virtual dressing and fitting.

A three-dimensional prototype of clothing was developed in the study [12] to ensure a better fit and balance of clothing in the process of dynamic anthropometry. Allowances for loose fit were researched. The task of practical creation of structures taking into account the complex shape of individual parts of the human body has not been proven.

It was proved in work [13], that the morphological parameters of the zones of the female torso affect the methods and parameters of the formation of typical articulations of corset products. Methods of three-dimensional visualization were applied.

3D scanning methods make it possible to advance significantly research in the direction of anthropometric standardization. Supplementing the database with new measurements for use within existing or newly created clothing design methods is not excluded. This direction requires careful approaches for different parts of the body. The most famous studies were conducted on the shape of female breasts [14]. Deeper segmentation of parts of the human body, as well as the importance of studying their shape, is proven in [15]. Features of the formation of a typological series of dimensional features for the construction of waist products are given in the work [16]. The importance of continuing anthropometric studies using three-dimensional technologies is also noted in [17].

As a result of the analysis of the state of the issue, it is possible to draw conclusions about the relevance of further anthropometric studies of parts of the human body that have a complex spatial shape for further standardization, as well as the creation of designs for the individual consumer that best match the body structure. For research, the shoulder zone and the breast gland zone, the geometry of which is insufficiently covered in existing standards and scientific publications, were selected.

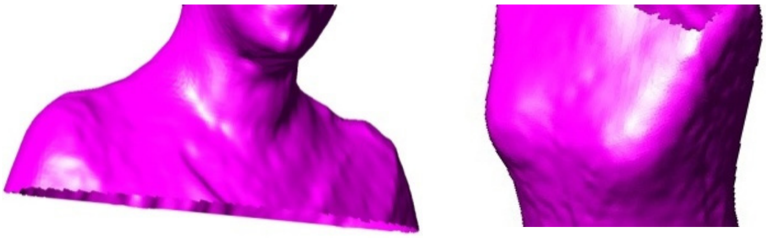
The aim of this study is to substantiate additional anthropometric data followed by pattern making of complex geometric shapes of the human body based on 3D scanning.

MATERIALS AND METHODS

The support surface for shoulder clothing is limited by the lines of articulation of the neck and arm with the torso and the protruding points of the chest and shoulder blades.

Real three-dimensional anthropometric studies determine the expediency of using modern means of three-dimensional scanning, which, accordingly, determines the fulfilment of certain requirements for software and material support of this process.

Modern gadgets in the form of Kinect systems have a budget cost and are quite capable of being used as means of three-dimensional determination of dimensions. The use of KScan3D software compatible with Meshlab in the process of scanning the human body gives the ability to form a network of points in the form of a DXF file, which determines the coordinates of all points in the triangulation network that forms the surface. Such a network allows to obtain the surface of any part of the human body



(a) (b)

Figure 1. The surface of a part of the human body, obtained with the help of a kinect device: (a) the area of articulation of the neck and arms with the trunk; (b) the area of protruding points of the chest.

(Fig. 1), as well as to determine any dimensions in an arbitrary projection.

Coordinates of surface points obtained as a result of 3D scanning allow creating approximation models in the form of polynomials. Such models are capable of solving the task of creating a structure by scanning the resulting analytical surface onto a plane.

RESULTS

To achieve the goal, the shoulder and breast areas of 57 women aged 18 to 29 from different regions of Ukraine were examined. The resulting surfaces have a rather diverse shape, which is shown in Fig, 2 on the example of the shoulder area.

Modern three-dimensional software tools allow to compare the general spatial form, as well as to analyse the appearance in different projections and sections. The frontal projection can be the most informative. The frontal view of the shoulder area for different respondents is shown in Fig. 3.

In the process of statistical analysis, a hypothesis was made about the normal distribution of the obtained results. For this sample of 57 people, confidence probability parameters within 95% were determined, and a confidence interval of 4.51% was determined for the five proposed parameters.

For further analysis of the obtained data, the projection curves of the shoulder zones were tied to a rectangular coordinate system. The graphs obtained in the specified coordinates together with noticeable discrepancies have common features.

The general appearance of the graph is a smooth, rising curve. That is, such dependence can be described by a continuous increasing function. Measurements can determine the total length of the section equal to the width of the shoulder, as well as the height of the shoulder near the neck above the zero value.

All graphs at a certain distance have an inflection point. Up to this point, the convexity of the graph is directed upwards and determines the gradual decrease in the intensity of the growth of the function, which is mathematically determined by the negative values of the derivative function. The intensity of growth increases after this point, the derivative of the function has a positive sign. At the inflection point, the derivative changes sign. In the conditions of traditional anthropometric measurements, it is difficult to determine the exact location of this point.

In the conditions of three-dimensional modelling and saving information in DXF format, access to the coordinates of all points of the surface is provided, in particular, the points defining the outline of the shoulder. After placing the points in ascending order, a simpler algorithm determines the height difference between the next point and the previous one. The first section of the function is characterized by a gradual decrease of this difference. The inflection point determines the beginning of the increase in the difference between the coordinates of the next and previous points:

$$y_{k+1} - y_k > y_k - y_{k-1} \, . \qquad (1)$$

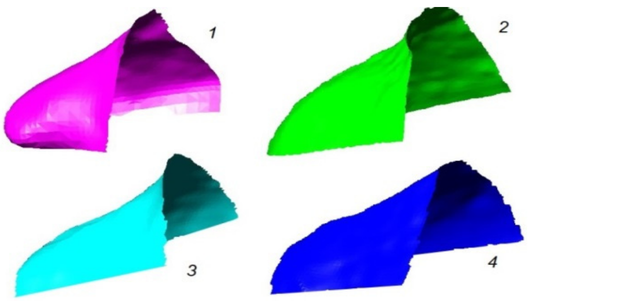


Figure 2. Spatial shapes of shoulder zones obtained by 3D scanning methods.

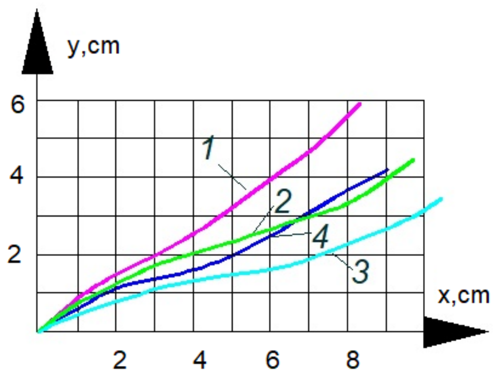


Figure 3. Front projections of shoulder zones.

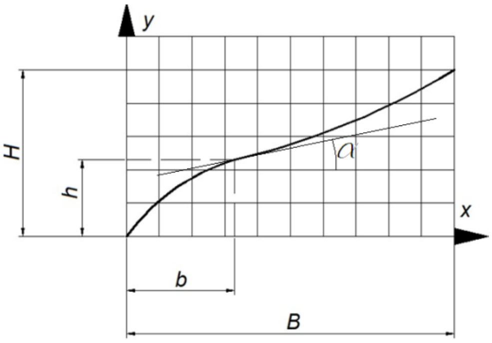


Figure 4. Graphic dependence of the shoulder line.

In such conditions, it is quite simple to determine for each adjacent pair of points the derivative, which is equal to the tangent of the angle of inclination of the tangent to the graph.

$$tg\alpha = \frac{y_{k+1} - y_{k-1}}{x_{k+1} - x_{k-1}} . \quad (2)$$

Then, for the characteristics of the frontal projection of the shoulder zone, it is advisable to highlight the following indicators, which are determined on the basis of three-dimensional scanning algorithms and subsequent computer processing of the results (Fig. 4).

Height of the shoulder above the base point is $H = \sum_{i=1}^{n} y_i$. Shoulder width is $B = \sum_{i=1}^{n} x_i$ (n is the total number of points). The height of the inflection point is $h = \sum_{i=1}^{k} y_i$. Distance to the point of intersection is $b = \sum_{i=1}^{k} x_i$. Angle of inclination of the tangent at the inflection point is *α*.

The function describing this curve can be represented in the form of two branches of square parabolas:

$$y = \begin{cases} a01 + a11 \cdot x - a21 \cdot x^2, x \le b \\ a02 + a12 \cdot x + a22 \cdot x^2, x \ge b \end{cases} . \quad (3)$$

The condition *y*=0 at *x*=0 gives the value *a*01=0.

At the point *x*=*b* for both functions *y*=*h*, and the derivatives of both functions are the same and equal to the tangent of the angle of inclination of the tangent to the shoulder line and the given point *t*=tan(*α*).

At the point *x*=*B*, the value of the function *y*=*H*.

The derivative of a function can be defined as:

$$\frac{dy}{dx} = \begin{cases} a11 - 2 \cdot a21 \cdot x, x \le b \\ a12 + 2 \cdot a22 \cdot x, x \ge b \end{cases} . \quad (4)$$

The above-mentioned conditions create a system of equations:

$$\begin{cases} a11 \cdot b - a21 \cdot b^2 = h \\ a02 + a12 \cdot b + a22 \cdot b^2 = h \\ a02 + a12 \cdot B + a22 \cdot B^2 = H \\ a11 - 2 \cdot a21 \cdot b = t \\ a12 + 2 \cdot a22 \cdot b = t \end{cases} . \quad (5)$$

The solution of the system can be presented in the form of:

$$a21 = \frac{h}{b^2} - \frac{t}{b}, \; a22 = \frac{H-h}{(B-b)^2} - \frac{t}{B-b},$$
$$a11 = \frac{2h}{b} - t, \; a12 = \frac{t \cdot (B+b)}{B-b} - \frac{2 \cdot (H-h) \cdot b}{(B-b)^2}, \quad (6)$$
$$a02 = h - \frac{t \cdot B \cdot b}{B-b} + \frac{(H-h) \cdot b^2}{(B-b)^2} .$$

Examination of horizontal cross-sections of the back surface of the shoulder demonstrates the proximity of them and the general vertical projection to an ellipse with semi-axes B and A (Fig. 5).

Under these conditions, the cross-section function can be written in the form:

$$z = A \cdot \sqrt{1 - \left(\frac{x}{B}\right)^2} . \quad (7)$$

The described functions make it possible to synthesize the general equation of the surface.

The obtained data make it possible to determine the lengths of arbitrary areas on the surface and to construct a surface sweep with any accuracy (Fig. 6).

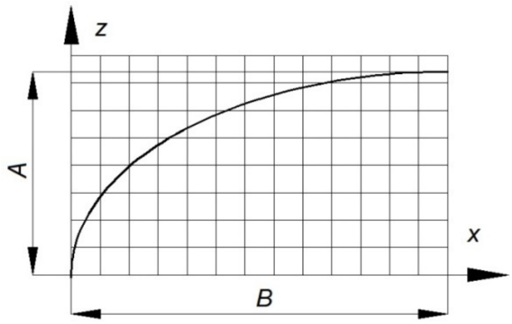


Figure 5. Vertical projection of the back surface of the shoulder.

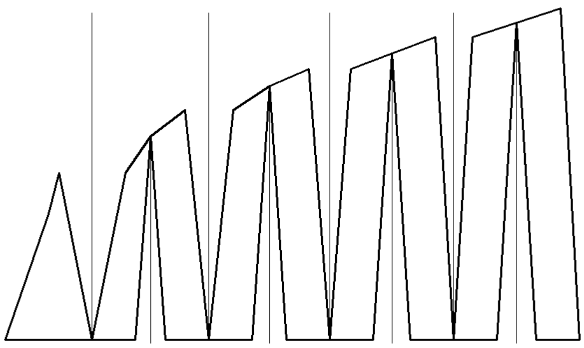


Figure 6. Sweeping of the back surface of the shoulder.

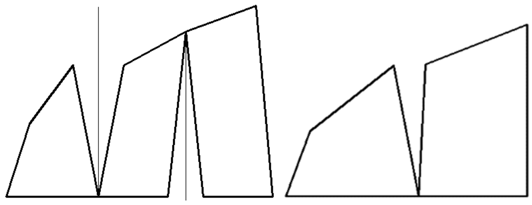
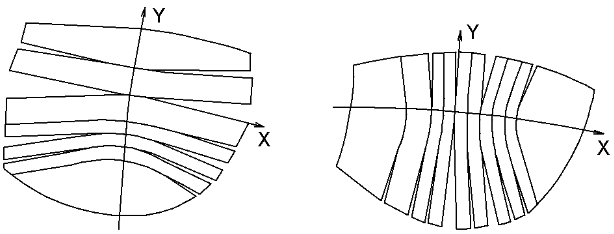
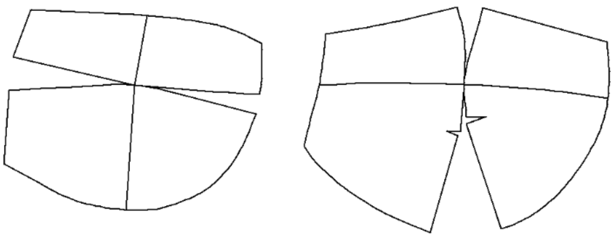


Figure 7. Sweeping of the back surface of the shoulder.



(a) (b)

Figure 8. Breast expansion: (a) initial expansion axis Y; (b) the output axis of deployment X.



(a) (b)

Figure 9. Design of the cup: (a) with horizontal division; (b) with vertical membership.

The actual design of the shoulder area of clothing can be created as a reduced sweep with two or one darts (Fig. 7).

According to a similar algorithm, the construction of the sweep of the mammary glands was performed, taking both the vertical and the horizontal as the starting axis of the sweep (Fig. 8).

The real design of the cup can be created with both horizontal and vertical articulation (Fig. 9).

Designs built on the basis of three-dimensional scanning provide a high quality fit for the individual consumer of both typical and atypical figures.

DISCUSSION

In contrast to previous studies, this article provides a thorough analysis of the most complex surfaces of the human body, which are surfaces of double curvature. In reality, such surfaces can be examined exclusively with the help of 3D measuring devices. At the same time, in the process of real pattern making, it is desirable to use a limited amount of information, reduced to certain dimensional features. 3D scanning allows to determine known dimensional features, as well as discover new ones. The dependencies obtained in the previous section allow us to formulate the basic requirements for dimensional features that define surfaces with double curvature, which include shoulder and chest areas. Thus, five dimensional characteristics are required to provide a description of the shoulder area. Two well-known parameters determine the width and height of the shoulder. The 3D scanning procedure allows to determine additional parameters. Direct measurement of the scanned surface determines the coordinates of the inflection point of the shoulder line, as well as the angle of inclination.

Comparison with previous studies gives the following advantages of the proposed method:

Possibility of using cheap Kinect devices instead of expensive ones for 3D scanning purposes is proved, whereas in previous studies [1,2,9] expensive 3D scanning methods are used.

Additional dimensional characteristics, which can be determined using 3D scanning, allow to achieve a greater level of proportionality of clothing in places of complex geometry. In previous studies, conventional dimensional characteristics were used [3,4]. Other studies used mathematical approaches [8,12], which are difficult to reduce to known methods. In previous studies, conventional dimensional characteristics were used [3,4]. Other studies used mathematical approaches [8,12], which are difficult to lead to or compare with known methods.

Assembling patterns with different number of cuts allows to adjust accuracy and proportionality;

Conducted research can clarify existing dimensional standards, taking into account that previous studies mainly discussed the general issues of improving anthropometric standards [17], the studies did not foresee additional dimensional characteristics that can be provided by 3D scanning methods [7].

The scanned surface in the form of a DXF file defines an array of point coordinates that can be calculated in distances using triangulation methods. The resulting parameters allow creating pattern with any accuracy, which is determined by the number of individual elements. At the same time, real pattern making determines the limitations of the structural elements. The overall size of the clothes for the specified body parts is determined by the number of individual elements of the sweep. Co-dimensionality parameters depending on the type of construction require additional research.

CONCLUSIONS

As a result of the analysis of three-dimensional scanning of the human body, the possibility of approximating the frontal projection with two branches of the parabola has been proven. New anthropometric points and dimensional features are defined, which are determined on the basis of three-dimensional scanning with the use of computer modelling. Such features include the height and width of the shoulder from the base point, the height and coordinate of the inflection point, the angle of inclination of the frontal projection curve at the inflection point. The analytical model of the surface of the human body in the area of the shoulders and chest allows you to build a surface scan with arbitrary accuracy, as well as the construction of the shoulder area of clothing with a given number of folds, which ensures a high quality of fit.

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INVESTIGATION OF THE RESISTANCE OF DIFFERENT TEXTILE PRINTS TO WASHING AND ABRASION

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ABSTRACT

The article presents the next stage of experimental studies applying images to textile materials. The method of calculating the cost of manufacturing thermal transfer according to the proposed technologies, which were obtained as a result of the practical activity of the authors of the article in production conditions, was tested. The operational, and functional properties of thermal transfers have been studied. Durability of printed fabrics to rubbing and washing has been established. The images were applied to synthetic and natural fabrics. The methods of printing were as follows: DTF printing, offset and screen printing. The application of the results of this study will allow to carry out a qualitative and effective assessment of methods of printing images on textile materials depending on the production conditions for each type of product. A practical test of the proposed method of printing images on the products of the author's collection of women's clothing was carried out.

KEYWORDS

Images; Textile materials; Innovative technologies; Decoration; Printing methods; Screen printing; Digital printing; sublimation printing; Thermal transfer printing; Printing cost; Print; Author's collection.

INTRODUCTION

Fashion is one of the most profitable areas of business that is constantly developing a high level of competition in the fashion industry market becomes an impetus for designers to search for more and more effective methods of designing clothes and apply innovative approaches to solving a number of artistic and deseveral [1,2,3]. Therefore, innovative technologies are actively introduced into the fashion industry, influencing the formation of fashion trends [4,5].

This market is currently one of the most dynamic, which means it is one of the most promising. Thus, one of the main tasks facing fashion industry specialists is the application of the achievements of science, technology, and art in creating ordinary, aesthetically, and ergonomically perfect clothes and the decoration itself provides an opportunity to increase competitiveness and expand the range of sewing products. Therefore, the search for the concept of future collections, it's rethinking, and the use of means of artistic expressiveness and novelty in the form of innovative decoration become the key to the success of an author's clothing collection among a wide range of consumers.

For the garment industry, the possibility of decorating the models of the collection by applying a print to the clothes is familiar [6, 7]. Products decorated with a pattern look impressive and can give exclusivity to even the simplest models. The main types of image application on textiles are known, in particular, transfer printing; silk screen printing; sublimation; author's artistic painting of textile products, etc. [3,7]. Over the past few years, brands have been created worldwide that work exclusively with their own designed print.

That is why the direction of design is a priority given to designing sewing products with the optimal and high-quality method of printing author's prints.

In previous studies, the authors proved that textile printing is an increasingly important area of the contemporary graphic industry, and screen printing represents a dominant technique in this field [6]. The quality of the print depends on many parameters, such as the type of substrate material or the type of printing ink. The usual way to evaluate print quality consists of an objective assessment of the color and tone of the printed image. Quality parameters, such as contrast, sharpness, and macro non-uniformity, are not associated with color reproduction but certainly, affect print quality. These parameters are

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directly related to the quality of the lines and raster dots, which is an integral part of any image.

In particular, the research of the authors [9, 11] is aimed at the development by artists of new color palettes for inkjet printing and the study of the appearance of a color image from the point of view of the psychophysical perception of images. The psychophysical relationship between image quality and its component attributes was investigated. The authors found a high correlation between four points that form image quality: between sharpness and contrast and between naturalness and visual information.

In the study [10], the effect of whiteness, roughness, and paper gloss on the optical density of color digital printing is substantiated.

In studies [11,12], the methodology of color printing in digital inkjet textile printing was developed, and an algorithm for the application of knowledge about color in the methods of creating a project and new color palettes for inkjet printing was proposed.

The analysis of literary sources [13-15] made it possible to establish that the main studied characteristic affecting the quality parameters of t-screen printing is the structure of the fabric and the type of printing ink.

Also, researchers [2,3,5,16] develop prints using modern computer methods of clothing modeling and 3D virtual clothing prototyping. The author [16] offers examples of the development of smart textile prints with an interactive capability.

The desire for innovation becomes an impetus for designers to choose a great, complex source of inspiration and search for new ideas for its rethinking and interpretation in the material, form-forming elements of the collection, and rhythmic organization of the composition series [2-5, 16-18].

All of the above studies form a powerful direction of innovative author's decoration of clothing models.

At the same time, this direction is relevant from an economic point of view because today, in Ukraine, there are no approaches to the mass design and production of sewing products with high-quality author's prints obtained by the screen printing technique.

This paper aims to continue experimental research on applying images to textile materials. To achieve the goal, the following tasks were solved:

1) The method of calculating the cost of manufacturing thermal transfer according to the proposed technologies, which was obtained as a result of the practical activity of the authors of the article in production conditions, was tested.

2) The degree of resistance of images printed by DTF print, Screen printing, and Offset printing to friction and during washing has been established using two different transferring techniques (hot press, iron) and two different textile substrates (polyester, cotton). .

3) A practical test of the proposed method of printing images on the author's collection of women's clothing products was carried out.

Therefore, when evaluating print quality, it is necessary to analyze these elements [7,8].

METHODOLOGY

One of the critical factors influencing the choice of the method of applying the image to textile materials is the cost of making the print.

To determine the total cost, it is necessary to consider the cost of each stage of the technological sequence, the cost of electricity, and the cost of preparing the print.

To determine the cost of one print calculation was made for a batch of 100 units. Execution of a set of 100 units made it possible to decide on the ink cost for different printing methods.

The above method of calculating the cost of a batch of products is simplified and corresponds to each way of applying the image to textiles. However, each of the preprinting method's technical operations affects the final result of the cost calculation.

Data for calculating the costs of manufacturing images on textile materials by different printing methods were obtained as a result of the practical activities of the authors of the article in terms of production in enterprises FOP Zozulyuk and Dprint Studio, Khmelnytskyi, Ukraine.

The results of calculations according to the above method are presented in Table 1. When an operation is absent in the technological sequence, the sign «–» is put into Table 1.

The calculation is given for the national currency of Ukraine; at the time of analysis, the exchange rate of UAH to the EURO was 36: 1 at the rate of the National Bank of Ukraine. The calculation for European countries will differ in absolute value, but in relative terms, i.e., in percentage terms, it will be fair. This will give a general idea of the economic feasibility of using a particular method of printing images.

Based on the cost calculation results summarized in Table 1, it is possible to draw conclusions about the economic feasibility of each method under consideration.

For a batch of 1000 units, the cost of printing for all three methods differs for both light and dark fabrics. It is more expensive to make one sample than to make one unit in a batch of 1000 units. Since prepress is expensive and is done both for a single sample and for a batch of 1000 units. For example, for light fabrics, the difference between sublimation and screen printing is 60%, while for dark fabrics, the difference between direct printing using DTF technology and screen printing is 300%.

Table 1. The cost of applying the image to textile materials.

№	Cost item	The method of making a transfer of A4 format (210x297 mm)		
		DTF (digital CMYK/ CMYK+White)	**screen printing** for white/colored fabrics	**Offset + substrate (base) by screen printing**
1	C_D Image design preparation for batches of 1000 units of products, UAH	100	100	100
2	The cost of technological tools C_E for batches of 1000 units of products, UAH	-	300/350	1500
3	The cost of ink C_p, UAH	4.5	2.5/3	1.5
4	The cost of the intermediate carrier, C_I, UAH	7	3	3
5	Worker's labor costs C_w, UAH:			
	– applying the image to the intermediate medium;	10	6	6
	– applying an adhesive layer;	-	1	1
	– transfer the image to the product	5	5	5
6	Electricity costs C_{El} for, UAH:			
	– applying the image to the intermediate medium;	0.55	- (in the case of non-automated printing)	- (included in the price of offset printing)
	– transfer from the intermediate carrier to the product;	0.2	0.2	0.2
	– intermediate drying operation;	-	0.33/0.42	-
	– finishing drying operation or glue drying	-	0.16	0.16
∑	The cost of making C , UAH: batches of 1000 units of products;	27.25	18.59/19.23	18.46
	product units	127.25	418.19/468.78	1616.86

CMYK – subtractive color model (Cyan, Magenta, Yellow, Key/BlacK)

If we consider the manufacture of a single sample, the cost of the product increases significantly in contrast to mass production. This is because the cost of technological tools is fully transferred to the product's price. In this case, the cost of printing on light fabrics for the first two methods is almost equal, and for screen printing is 240% higher.

Therefore, in the case of a single production, screen printing is considered inexpedient in terms of economic effect; however, for serial production, it is the cheapest way to apply the image, and given the results in Table 1, it is the moseffectiveve and versatile in terms of raw material composition and fabric color.

RESULTS AND DISCUSSION

To assess the performance of the applied image

DTF printing. First, the image is printed on a special transfer film, in our production this happens in a roll. Then, in automatic mode, a special thermal transfer glue is applied to the still raw image, and it is immediately baked in the oven. Next, the image is cut out and transferred from the film to the product using a heat press. At the same time, the product does not need to be pre-processed, and the image should be cut out with a contour. Any fabric, cotton, synthetic, etc., is suitable for carrying. To the touch, the application is similar to silk screen printing, elastic and resistant to washing, and also does not burn out, does not crack, and does not wear out.

Screen printing. The essence of this method of printing is to push by a special tool (squeegee) ink through the open holes of the flexible mesh stencil on the printing surface. Printing can be done on paper, tin, glass, fabric, polyethylene, plastic, leather and other sheet or roll materials and products from them.

The technological process of applying the image to the transfer surface by screen printing contains some differences from the direct screen printing method:

- design preparation - mirror image;
- drying transfer (used for paper media, to remove excess moisture and prevent further deposition, the film, unlike paper, is non-hygroscopic, so it does not require this operation);
- applying colors of multicolor images in the opposite direction;
- application of a layer of paint - an adhesive base that covers the entire image to create a unique adhesive surface (usually performed with white paint or anti-migration paint, which then acts as a barrier when applied to colored and black fabrics).

(a)

(b)

Figure 1. Equipment for transferring a picture to fabric: (a) Thermal printing press Weijie WJ-38, the size of the compression plate: 380×380 mm, power: 3200 W, temperature range: 50-300 °C, timer: 60 s; (b) Steam iron Silter STB-200, weight: 2 kg, power: 800 W.

Offset printing. Printing technology, in which the ink is transferred from the printing form to the receptive surface (the material to be printed) not directly, but with the help of an intermediate transfer and, in fact, through an intermediate, offset cylinder. Accordingly, unlike other printing methods, the image on the printing form is not a mirror, but a direct one.

The image are made by three printing methods and applied to a transparent transfer base. The next step was to transfer the picture on the fabric. The transfer of the picture is done with an iron and a press to show the possibility of decorating clothes at home. The consumer can buy a picture and apply it to clothes with an iron.

Transfer temperature modes depend on the type of media, paint, and material on which the drawing is applied, and range from 170 to 190 °C, exposure from 10 to 15 s, under pressure in the range from 35 to 40 psi (from 0.24 to 0.31 N / mm^2). Specific modes of temperature 180 °C, exposure 15 s, pressure were selected for the experiment 0.31 N/mm^2. The appearance and characteristics of the press and iron is shown in Fig. 1.

Research was conducted on two types of material, detailed information about which is shown in Table 2.

By analogy with the previous study [7], the performance indicators of images printed using DTF print, Screen printing, and Offset printing were evaluated for resistance to friction and washing. The first stage of experimental research was the evaluation of the preservation of image quality on textile materials in the friction process according to GOST 9733.27–83, DSTU ISO 12947-2:2005, Table 3.

Sample 1-4 made by DTF (direct to films) technology. Cotton and polyester fabrics were chosen for the research.

After 50 cycles, there are no saws, and color loss is insignificant in samples 1 and 2. There is a more significant loss of color in samples 3 and 4, due to the transfer of the image with iron, creating uneven pressure during transfer. After 100 cycles: visible to the naked eye, discoloration and mechanical damage to the tissue. The trend was maintained for samples 3 and 4.

Sample 1-4 made by screen printing similar to the previous technology, more wear occurs when transferring the image with an iron. Screen printing is more resistant to friction than DTF. At 50 and 100 cycles, the loss of color along the abrasion trajectory is barely noticeable. More significant color loss is observed at 150 cycles of abrasion in the samples obtained by transferring the image with an iron.

Offset printing is the least durable. In all samples already at 50 cycles of processing, loss of color of the image is observed. After 100 cycles of processes, there is a significant loss of color along the abrasion trajectory, the fabric structure is broken. The study of this sample is stopped.

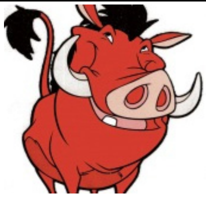
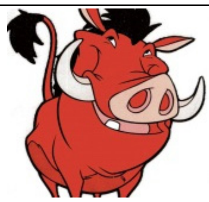
So, according to the results of the research, screen printing is the best way to make a picture. The best result is achieved when the image is transferred to fabric 1 using a press.

Table 2. Characteristics of materials.

Material	Color	Thickness [mm]	Weave	Yarn linear density [tex]	Density [treads/10cm]	Weigh (GSM), [g/m^2]
Fabric 1 (80% cotton; 20% polyester)	White	0.36	Plain	warp:24.1 weft: 22.5	warp:329 weft: 248	206
Fabric 2 (100% polyester)	White	0.42	Plain	warp:34.8 weft: 34.4	warp:256 weft: 188	254

Table 3. The results of the study of image stability during friction.

Sample №	Type of material	Photographs of the sample after friction			
		Reference images	50 cycles	100 cycles	150 cycles
DTF print					
Sample 1 press	Fabric 1				-
Sample 2 press	Fabric 2				-
Sample 3 iron	Fabric 1				-
Sample 4 iron	Fabric 2				-
Screen printing					
Sample 1 press	Fabric 1				
Sample 2 press	Fabric 2				
Sample 3 iron	Fabric 1				

Sample 4 iron	Fabric 2				
Offset printing					
Sample 1 press	Fabric 1				-
Sample 2 press	Fabric 2				-
Sample 3 iron	Fabric 1				-
Sample 4 iron	Fabric 2				-

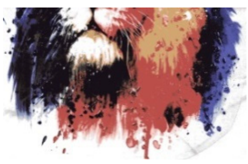
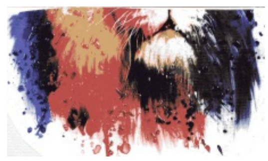
The next step in studying the performance characteristics of images on textiles was to determine the stability of the image during washing according to DSTU ISO 105-C06:2009 on a household washing machine using detergents, in accordance with the composition of the textile. The temperature mode is 40 °C; washing time 30 minutes; spin 800 min-1. Drying took place in a vertical position until completely dry, after which the ironing of the sample was performed at a temperature of 100-110 °C. [7]. The results of studies on the loss of image quality on textiles during washing are presented in Table 4.

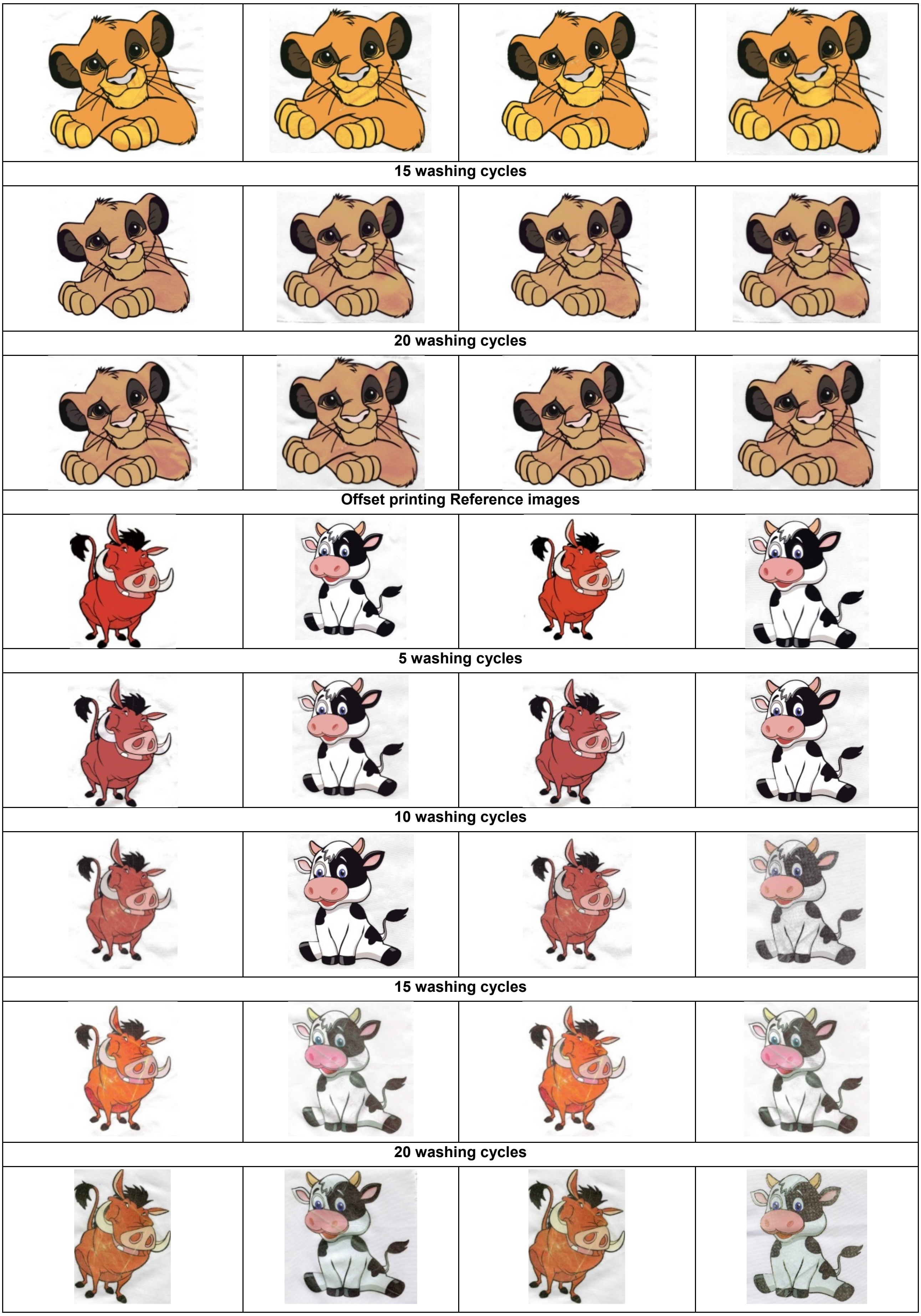
As a result of organoleptic evaluation of images on textiles made by different printing methods, a gradual loss of color in the samples was established. The most resistant to washing were the samples of pictures created by screen printing 20 cycles of washing and DTF 20 cycles of washing. The image obtained by offset printing of only 15 wash cycles turned out to be less stable.

In table 3, the patterns have changed color because the washing cycles have passed. And after the 15th washing cycle, a change in color is observed in all types of printing. A visual comparison of the images shows that the most resistant to washing without a significant loss of color were the samples created by DTF after 15 washing cycles and the samples created by screen printing after 10 washing cycles. The loss of color during a longer cycle of washing and drying significantly disrupts the aesthetic appearance of the product and this would be unacceptable to the consumer.

Analyzing the effect of washing, we can conclude that the composition of the fabric did not affect the durability of the picture. Because the washing and ironing regimes according to the fabric were maintained.

Table 4. The results of research on the loss of image quality on textiles during washing.

Printing method			
Cotton, press	**Polyester, press**	**Cotton, iron**	**Polyester, iron**
DTF, Reference images			
			
5 washing cycles			
			
10 washing cycles			
			
15 washing cycles			
			
20 washing cycles			
			
Screen printing, Reference images			
			
5 washing cycles			
			
10 washing cycles			


15 washing cycles
20 washing cycles
Offset printing Reference images
5 washing cycles
10 washing cycles
15 washing cycles
20 washing cycles

Analyzing the effect of washing, we can conclude that the composition of the fabric did not affect the durability of the picture. Because the washing and ironing regimes according to the fabric were maintained.

So, the study of the effect of washing and resistance to friction of three methods of applying the picture showed the following: All three techniques were in combination with iron and press. There are no significant differences in the quality of the picture when using an iron and a press to transfer the picture. Therefore, it is possible to decorate clothes at home in this way. The best result will be achieved using pictures made by the screen printing and DTF method, as they are the most resistant to washing and wiping.

Designing an author's collection of women's clothing using screen printing

Thus, it can be concluded that screen printing on textile materials is one of the most popular, economically expedient, and sustainable operations among the types of decoration of light industry products today. It has been proven that the decoration of products with different designs, which are oriented towards a specific brand, different age categories, gender, and youth movements, significantly improves the appearance of products [1-3, 16].

It is known that the style of clothing, the basis of which is the author's prints, is the style of Arty Fashion and its variety of Pop art [3, 17]. This sophisticated fashion style draws attention with bold, bright colors and prints. Features of these styles are that they do not depend on fashion trends and modern style. They are chosen by creative, self-confident individuals - experimenters. Among the most famous brands that presented their collections in the Pop Art style, fashion houses Maison Margiela, Marni, Prada, Burberry, and Alexander McQueen are worth noting.

At the preliminary stage of research [18], the authors defined and thought out the main images, forms, and constituent elements of the developed products of the author's collection sets. The collection was created open in the Pop Art style format using fashion trends. The products in the collection are made of different materials, which, when combined into sets, give the image of unusualness and sophistication.

When creating clothing models, special attention was paid to the originality and multifunctionality of the collection's products and their parts, Figure 2.

When designing an author's clothing collection using their prints, the drawings are female portraits. It is planned to place the picture on each product of the group differently, but in general, these will be large portraits placed on the central parts of the products.

To achieve the research goal, thermal transfer or flux printing of authority prints in the style of Pop Art was chosen to create a harmonious image for the consumer.

The design and development of an author's print and ready-made thermal transfer films with the author's prints are presented in a previous study.

In the first stage, the print is developed in color in the Gimp 2.10 bitmap graphic editor. In the second stage, its vector step-by-step development was performed in the Xara Designer Pro X 19 Free Trial vector graphics editor. The CMYK color scheme was chosen as the image's color scheme, as it is the most widespread in the printing industry and in full-color direct screen printing [8, 18]. Examples of prints for decorating clothing models of the author's collection are shown in Figure 3.

Figure 2. The author's collection women's clothing in the style of Pop art.

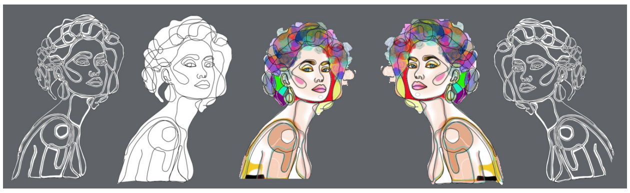


Figure 3. Examples of author's print options in the Xara PRO X 19 graphic editor.

Technological progress, market oversaturation with goods, and the speed of changes in society force manufacturers to reconsider their development strategy, in which they should develop.

The essence and content of automated design systems, such as Marvelous designer, CLO 3D, and other approaches involving digital technologies, today partially raise and resolve the issue of overproduction and excessive consumption of objects in the fashion industry.

Modern technologies of 3D design of clothes at the stage of artistic development of models provide for the following functions: 1) visualization of the appearance of clothing models before the creation of patterns and sewing of the product itself; 2) the possibility of selecting materials, color solutions and simulating the physical properties of a large number of materials for the future model; 3) forming a presentation of sketches of a complete collection of models.

The practical implementation of the described approach is presented by the study's authors in the form of visual transformations of images of sketch forms of project images of digital products of the author's collection using the computer graphics program PaintTool SAI [19]. PaintTool SAI is a lightweight raster graphics editor, and painting software for Microsoft Windows developed and published by Systemax Software. The Digital - presentation of the clothing collection is shown in Figure 4.

Visualization allows you to work out options for the color solution of clothing models and to offer the optimal placement of prints. As a result of the completed work, the models of the author's collection were approved and manufactured, Figure 5.

CONCLUSION

According to the simplified calculation method, the cost of a 100-unit batch of products is determined for each image printing method. The influence of the features of each printing method's individual technological operations on the calculation's final result is taken into account.

The obtained results make it possible to perform an economic assessment of each method and decide on the appropriateness of their use in each case.

The following result of this study is the evaluation of the performance of the image on textile materials applied by different printing methods. In the course of experimental research, the degree of resistance of the images made by various ways of printing to friction and in the course of washing was established.

It was found that the most resistant to abrasion and washing were samples of images applied by screen printing and DTF printing.

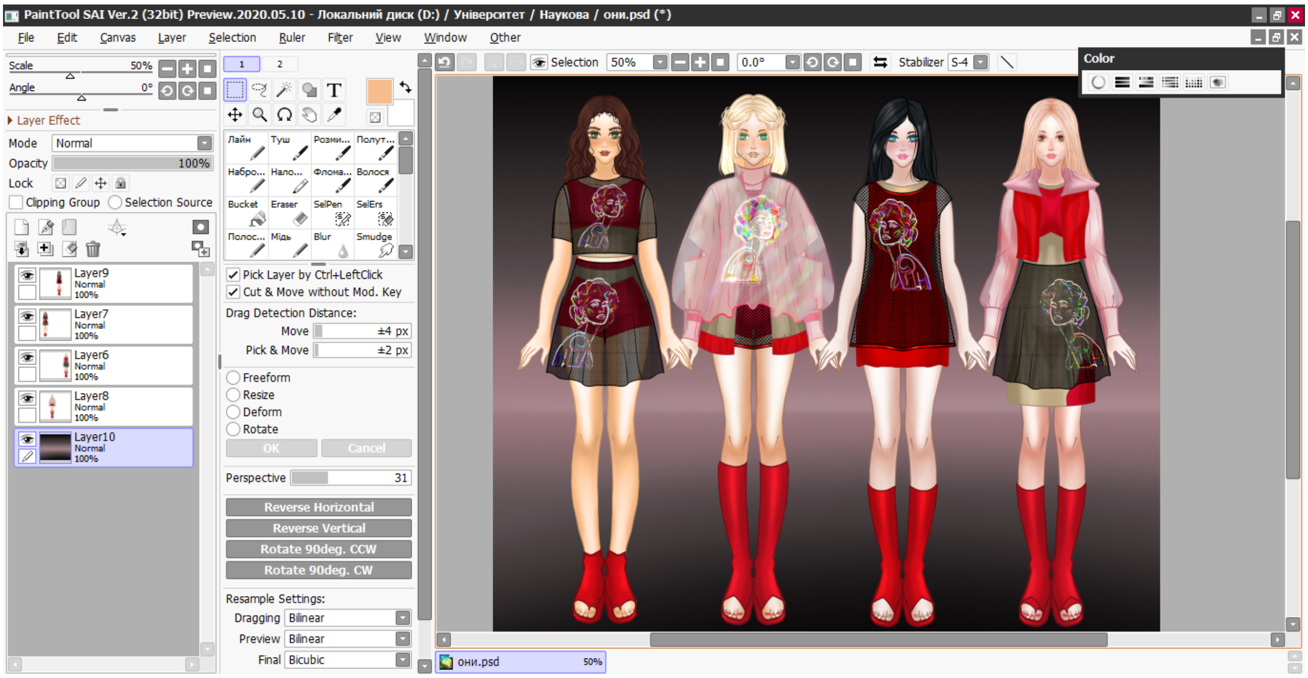


Figure 4. Sketches of the author's collection of women's clothing in Paint Tool SAI.

Figure 5. The author's collection women's clothing in the style of Pop art decorated with the author's prints.

So, the study of the effect of washing and resistance to friction of three methods of applying the picture showed the following: All three techniques were in combination with iron and press. There are no significant differences in the quality of the picture when using an iron and a press to transfer the picture. Therefore, it is possible to decorate clothes at home in this way. The best result will be achieved using pictures made by the screen printing and DTF method, as they are the most resistant to washing and wiping.

The scientific novelty of the study consists of the analysis and systematization of creative and innovative decoration technologies with the aim of further integration into the fashion design of clothing.

The practical significance lies in the experimental study of the functional properties of thermal transfers as elements of clothing decoration. It has been proven that screen printing on textile materials, currently among the types of decoration of light industry products, is economically expedient and sustainable in the operation process. This is confirmed by calcalculatinge the cost of transfer production methods for various types of printing.

The presented Digital technology - presentation of the clothing collection gives space for implementing engineering and design ideas. It can also be an effective tool for product promotion on the market. In particular, the obtained images of the product on figures in different projections can become the basis for creating an electronic catalog of products available for viewing in online stores and the simulation of a mannequin walking on a catwalk - for various video advertisements.

As part of this study, we obtained results reflecting the psychophysiological reactions of consumers, as well as their dynamics for choosing a prototype of a projected image of a clothing model and author's prints for the development of a new clothing model that meets the wishes of the consumer [20]. The image evaluation results on textile products can be used as a data set to populate the database with knowledge of pre-developed expert systems to support designing clothes that correspond to predetermined consumer impressions [21, 22].

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RESEARCH ON LIGHT RESISTANCE OF THE CHENILLE COTTON FABRICS' COLORING

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ABSTRACT

Colour fastness is one of the important characteristics, which depends on the further effective and rational use of the potential fabric resource, durability, wear resistance, and the level of competitiveness in the market. Therefore, evaluating the light fastness of colours of cotton fabrics, in the wear of which sunlight plays a major role, is an urgent scientific task. Chenille cotton fabric, which is currently in demand by textile decorators and modern interior decoration, was chosen for the research. The research was carried out using methods of visual and instrumental colorimetry. The conducted research is valuable for providing information to the market and for further analysis and implementation of the process of developing a system technology for designing chenille cotton fabrics.

KEYWORDS

Colour fastness; Chenille cotton fabrics; Consumer characteristics; Colorimetry.

INTRODUCTION

As is well known, the light fastness of the colour of interior cotton fabrics is one of the main characteristics of their quality. It is the light fastness of the colour that depends on the provision of aesthetic properties in the process of wear of products made of these fabrics used in modern interiors, the effective and rational use of the potential resource of their fibrous base, the provision of the necessary durability of the finished products, as well as the level of their environmental safety and, in general, the level competitiveness in the market. The light fastness of colouring is determined by many factors, in particular, the lightfastness of dyes, fibres, and finishes, the appropriate selection of individual parameters of fabric characteristics, and the methods of their final and special decoration [1,2]. The light fastness of the colour of chenille cotton fabrics provides functional and technological properties, affects the quality indicators of textile products, and plays a significant role in the formation of modern interior design [3].

The high level of quality of the modern residential and public interior, and the comfort of its internal environment, is an indicator of the successful development of the state. There is a significant amount of research on the properties of fabrics and their use in modern interiors.

In the 21st century, the inner filling of the modern interior acquires a new meaning, new properties, and features, new requirements are placed on fabrics and textiles that participate in the formation of the interior space. On the one hand, the filling of the modern interior continues to preserve the connection with the traditions of folk art of the past, taking into account history, archaeology, and ethnography, which is reflected in publications [4]. This is evidenced by the use of artistic and decorative textiles in the interiors of public buildings, as well as the use of applied arts, which vividly reflect Ukrainian folk traditions. Decorative fabrics in a modern interior can act as an active artistic accent, allowing to achieve an individual solution, both for large halls, various institutions, and individual rooms. In this regard, various studies were conducted on the artistic properties of textile products in the formation of the interior design of household service establishments and the identification of the peculiarities of their use [5].

On the other hand, the filling of a modern interior puts forward new requirements for the quality characteristics of fabrics and textiles, which are associated with new materials and technologies, the emergence of new styles, and directions of fashion trends. The analysis of modern trends in determining the colour fastness of natural dyes on cotton fabrics by instrumental methods using a spectrophotometer is reflected in the publication [6]. The publication [7] is dedicated to the study of air permeability, vapor

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permeability, and individual structural parameters of the fabric. The physical properties of cotton fabric after five washing-drying cycles were studied, as well as the effect of drying on the smoothness and shrinkage of the fabric [8]. Tests related to the process of fixing the natural colours of natural dyes on cotton and silk fabrics using the bone ash test are presented in the scientific paper [9]. Research is aimed at studying the effect of styrene-acrylic and urethane-polymer films filled with titanium dioxide nanoparticles on the change in thermophysical properties of the surface of cotton fabric [10]. Experimental studies of the effect of washing and moisture on changes in the breathability of cotton fabrics and the effect of different types of seams on breathability were conducted, and the results of these studies are presented in the scientific paper [11]. The scientific paper is devoted to the study of the behaviour of woollen fabrics during friction (experimental research), to the study of their frictional characteristics. The possibility of increasing the dyeability of viscose fabric by modifying the surface with silk fibroin is considered in the scientific paper [12].

Therefore, various aspects of the study of the properties of textile fabrics for the interior design of civil buildings and structures are considered in the works of many authors, however, the internal environment of the modern interior has its specifics of their use and requires additional research. This concerns the use of chenille cotton fabrics, and their properties for choosing the area of their application as curtains, pillowcases, tablecloths, upholstered furniture, etc. In fact, it is not possible to cover the work of all the studies that were conducted, there were a lot of them, however, after analysing this issue, we found that there are currently no studies related to the use of chenille cotton fabrics in modern interiors. These fabrics won the favour of the consumer, thanks to their attractive appearance and pleasant tactile sensations. It is the chenille thread that gives the fabric additional velvetiness, uniqueness, and special softness. Chenille cotton fabric with the content of natural components - cotton - is especially popular among consumers. As a rule, it has in its composition, in addition to natural cotton fibres, synthetic components: acrylic, polyester, polyester, viscose, etc. The combination of natural and synthetic fibres in the fabric provides, in turn, high characteristics of environmental friendliness, wear resistance, and practicality.

There are known studies that show that chenille fabric is most often used for upholstering upholstered furniture. As a rule, for the upholstery of seating furniture made in a classic style, in particular, this applies to chairs and armchairs, chenille cotton fabric in a stripe or with a small pattern is chosen. Furniture made in the Art Nouveau style prefers monophonic chenille cotton fabrics for upholstery. A type of chenille cotton fabric is jacquard chenille, which is a type of jacquard fabric with a complex weaving pattern and an exquisite appearance. Chenille, which belongs to the group of jacquard fabrics, has several chenille threads in its structure. The fluffiness of the chenille thread gives the fabric additional volume, unique texture, and special softness. In terms of environmental characteristics, such chenille is close to tapestry, as it contains natural components; however, such chenille is cheaper in price than tapestry, as it uses a smaller range of threads [13].

Manufacturers of chenille cotton fabrics began to impregnate them with various chemical means in order to extend the term of their use and increase strength, wear resistance, and practicality; such additional interventions in the fabric base make fabrics more resistant to scratches, moisture absorption, abrasion, peeling, high-temperature effects, etc.

In turn, expanding the range of chenille cotton fabrics requires research into their quality characteristics. The need for different production methods, hygienic, aesthetic, practical chenille cotton fabrics, significant expansion and optimization of the assortment, poses the task of providing consumers with information. In particular, it is necessary to investigate the consumer characteristics of chenille cotton fabrics for the further process of developing a system technology for their design. This, first of all, concerns light resistance - one of the main factors of their wear and deterioration of the aesthetic appearance. At the same time, in our opinion, insufficient attention is paid to the issue of evaluating the light fastness of chenille cotton fabrics in domestic periodicals and monographic publications. Therefore, evaluating the light fastness of the colours of chenille cotton fabrics, in the wear of which sunlight and artificial light play a major role, is an actual scientific task.

The purpose of the work is to study the light fastness of chenille cotton fabrics for interior use depending on the duration of artificial lighting with the aim of developing recommendations for the scope of their application.

MATERIALS AND METHODS

The study of the light resistance of chenille cotton fabrics depending on the duration of artificial lighting was carried out visually and instrumentally.

The object of research in this work was chenille cotton fabric of Turkish production Divotex, the characteristics of which are given in Table 1.

Laboratory studies were conducted in accordance with the methodology of the international standard EN 20105 – B02:1996 [16]. An air-cooled laboratory unit was used. Six samples of chenille cotton fabric were prepared for the study, the size of the samples was 100*70 mm. Fabric samples had the same raw material composition and physical and mechanical properties (Table 1) but were decorated in different shades of the same color scheme (from light to dark).

Table 1. Characteristics of the investigated fabric.

Fabric	Fibre composition	Fabric dye	Thickness, [mm]	Weigh (GSM), [g/m^2]	Density [threads/cm]	Type of decoration	Weave
Chenille decor volvo duz	acrylic 46%, polyester 34%, cotton 20%	Reactive Red H8B	0.92	260	warp: 33 weft: 25	dyed in one color	plain

The tissue samples prepared by us, together with the reference samples, were placed in a laboratory installation, which contained:

1) Light source – xenon arc lamp with a corresponding color temperature from 5500 to 6500 K;

2) A light filter was placed between the light source, samples, and standards in such a way that the ultraviolet spectrum was constantly reduced. According to the methodology [16], the transmittance of the glass used should be 90% between 380 and 750nm, decreasing to 0% between 310 and 320nm;

3) Thermal filter, the spectrum of the xenon arc contains a significant amount of infrared radiation, which must be minimised by thermal filters. At the same time, the light source is in a well-ventilated exposure chamber.

In the laboratory setup, indicators of lighting, temperature, and humidity were maintained according to the methodology. According to the method, a special opaque cover was placed on one-third of the fabric sample and reference samples. The fabric sample, together with the standards, was secured with sample holders on the sample rack of the laboratory setup so that the holders were supported both above and below and in the proper vertical center. All remaining spaces in the sample rack were completely filled with white cardboard holders. In the laboratory setup, all six tissue samples were located at the same distance from the light source – a xenon arc lamp. Six fabric samples and six reference samples were simultaneously exposed. After every 24 hours of insolation, 6 samples of chenille cotton fabric were removed to evaluate the light fastness of the color. The total duration of exposure was 288 hours. At the same time, changes in the light fastness of dyed samples of chenille cotton fabrics were assessed visually and instrumentally.

Visual studies of tissue samples were performed according to the scale of blue standards.

Light fastness was evaluated by indicators of the color difference *ΔE* between dyed tissue samples after 24 and 288 hours of irradiation, respectively. In turn, the color difference *ΔE* was determined using the spectrophotometer "Datacolor-9600" according to the calculation formulas of the system CIELAB MKO [4,14].

This system also determined the purity of shade *L*, color saturation *S*, and color tone *T*. The determined color characteristics calculated in the CIELAB MKO system are presented in Table 2. The results of the studies, which were obtained when compared with known methods, are presented in Table 3. About the change the lightfastness of the color of the studied samples of chenille cotton fabrics after the corresponding periods of their insolation was judged by the indicators of color difference *ΔE*, the results of the studies are presented in Table 4 and Figure 1.

RESULTS AND THEIR DISCUSSION

The main characteristics of colour fastness are purity of shade *L* (lightness), colour saturation S, colour tone *T*, and indicators of general color difference ΔE [4,14]. The purity of the shade *L* % is a value that characterizes the brightness of the light stream reflected or transmitted by the colour body in relation to the incident light stream:

$$L = \frac{\int_{380}^{780} \phi(\lambda)\rho(\lambda)d(\lambda)}{\int_{380}^{780} \phi(\lambda)\varphi(\lambda)d(\lambda)}, \qquad (1)$$

where: (λ) - the intensity of monochromatic radiation of the incident light stream; $\rho(\lambda)$ - reflection coefficient of monochromatic rays; $\phi(\lambda)$ - function of the spectral sensitivity of the eye.

Colour saturation *S* - determines the degree of manifestation of the colour tone. Colour saturation is defined as the ratio of the brightness of monochromatic radiation to the total brightness of the colour:

$$C = \frac{B_\lambda}{B_\lambda + B_\varpi} 100 \qquad (2)$$

where: B_λ - brightness of monochromatic radiation; B_ϖ - the brightness of white colour.

The colour tone *T* of a chromatic colour is the wavelength of such a monochromatic colour, the mixing of which in a certain proportion with white when projecting on an achromatic screen ensures that a given chromatic colour is obtained.

The Δ*E* value characterizes the color difference (both in terms of chrominance and lightness) of two compared samples and is proportional to the visually reproduced color difference for these samples. The International Organization for Standardization, responsible for measuring colour in the textile industry, recommends the following formula for calculating color difference in the CIELAB MKO system:

Table 2. Colorimetric characteristics of researched chenille cotton fabrics

Fabric samples that have been investigated	PANTONE Color system (American system)	The visual appearance of fabrics that were investigated	Colour differences in the CIELAB MKO system		
			Colour tone *T*	Colour saturation *S*	Purity of shade *L*
Fabric 1	15 -5217	The darkest (saturated) color	86.4	26.6	43.2
Fabric 2	15 - 5219	The brightest (juiciest) color	84.4	25.2	43.3
Fabric 3	15 - 5220	Bright color	83.8	24.7	43.8
Fabric 4	15 - 5223	Muted colour	82.6	23.7	45.4
Fabric 5	15 - 5225	The most muted	81.5	22.7	47.8
Fabric 6	15 - 5227	The lightest colour	81.32	15.2	51.53

$$\Delta E = [(\Delta a)^2 + (\Delta B)^2 + (\Delta L)^2]^{1/2}, \qquad (3)$$

where: Δ*E* – colour difference the two test samples;

L – purity of shade;

a,B – colour coefficients.

The color characteristics of the samples were evaluated according to the PANTONE Colour system [4], the SIELAB system of the MKO, and the scale of blue standards [4, 14] are presented in Table 2. The main characteristics of light resistance were defined and presented in Table 2.

It can be seen from Table 2 that the greatest saturation of color *S* and colour tone *T* is observed in the darkest and brightest fabric samples, and the purity indicators of shade L in these samples are the lowest. As a result of research, it was found that artificial lighting has the greatest effect on the purity of the shade, at the same time, it was found that with the maximum decrease in color saturation, the color tone decreases.

The overall color difference Δ*E* was determined according to the method, it is the most important indicator of the light fastness of the colour.

The next stage of the study was a comparison of the results of the overall color difference ΔE of the tissue samples, which were determined by the instrumental method using the spectrophotometer «Datacolor-9600» with the results of the study, which were determined by the visual method according to the methods of ISO 105 BO1: 2014 [4,14] and AATCC 16.3 [15]. The results of the study are presented in Table 3.

Table 3 presents indicators of the total color difference Δ*E* of the studied samples of chenille cotton fabrics for the entire period of their insolation. The results show that the highest indicator is observed in fabric samples that have the darkest and most striking colour. According to the international standard ISO 105- B02: 2014 (E) the smallest number of points is observed in fabric 6, which is the most striking. According to the methodology of the american standard AATCC 16.3 of fabric 2, according to the scale of blue standards, corresponds to the indicator L8, which is the highest.

According to the data in Table 3, it can be concluded that the results of the study of the resistance of the fabric to artificial light by the instrumental method do not differ significantly in comparison with the results of the study by visual methods, namely by the methodology of the international standard ISO 105-B02: 2014 (E) and the methodology of the American standard AA TCC 16.3.

The light fastness of the color of fabric samples was determined by the visual method according to standard EN 20105 – B02:1996 [16]. This standard is based on the assessment of the degree of change in the original color of the examined fabric sample, which is established visually by comparison with special standards. The scale of "blue standards" is used to determine the degree of change of the primary color of the fabric due to artificial light.

Table 3. The results of the study of the general color difference ΔE.

Fabric samples that have been investigated	Color difference in tissue samples, Δ*E* (instrumental method)		International standard ISO 105- B02: 2014 (E) (visual method)		American standard AA TCC 16.3 (visual method)
	In 24 hours	In 288 hours	According to the classification	By rating, in points	On a scale of blue standards, from L2 to L9
Fabric 1	8,2	12,0 (3.8)	High light fastness	8	L7
Fabric 2	7,2	11,8 (4.6)	The highest light fastness	8	L8
Fabric 3	6,4	10,1 (3.7)	High light fastness	7	L5
Fabric 4	6,2	9,8 (3,6)	Good light fastness	6	L4
Fabric 5	2,0	5,4 (3,4)	Good light fastness	5	L3
Fabric 6	3,8	5,7 (1,9)	Satisfactory light fastness	4	L2

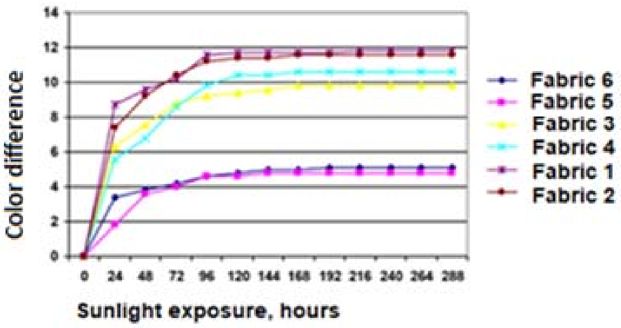


Figure 1. Influence of insulation on the light resistance of the chenille cotton fabrics' color.

The light fastness of the color of fabric samples is estimated from 2 to 9 points according to this scale. A score of 5 and above is considered high. Below 3 points are low-quality fabrics.

The results of the study of the change in the value of the total color difference Δ*E* of six investigated samples of chenille cotton fabrics depending on the duration of insolation, which according to the method was 288 hours, are illustrated in Fig. 1.

It can be seen from the graph that during the first 24 hours of the study, a sharp change in the color difference Δ*E* is observed in all six samples. During the next three days of the study, when the total duration of insolation was 96 hours, in samples 1, 2, 3 and 4, a sharp change in the color difference ΔE is observed, after which the stabilization of the change in Δ*E* occurs until the end of insolation. Fabric samples 5 and 6 undergo sharp changes in color difference only in the first 24 hours, and more gradual changes are observed during other periods of insolation.

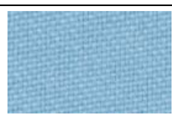
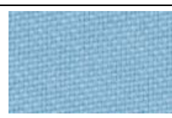
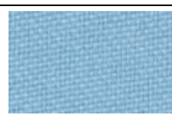
The visual method of research is best seen in the macro photos in Table 4. Throughout the research, macro photography of the samples was carried out. For macro shots, we chose sample 2 and sample 6. It is these samples that most convincingly demonstrate changes in the color difference (Table 3), starting from the highest light resistance to the lowest. The colour change (Table 4) is followed after 24, 96, 192, and 288 hours of insolation according to the conducted research.

Therefore, the lightfastness of the color of samples of cotton chenille fabrics depends not only on the structural characteristics of the fabric (Table 1), but also to a large extent on the saturation of color S, color tone *T*, purity of shade *L*, color difference Δ*E*, as well as on the duration of insolation. It was found that as a result of insolation of fabric samples, higher light fastness of colors is observed in samples of the darkest saturated and brightest colors. Studies have shown that the highest color difference Δ*E* is observed in sample 2. The color difference Δ*E* for fabric 1 and fabric 2, which have the darkest and brightest colors, are insignificant.

This indicates that such samples have good resistance to artificial light and do not lose their color under the influence of prolonged insolation. Therefore, you can sew curtains and curtains from such fabrics, they will keep their color for a long time and look good. This indicates that such samples have good resistance to artificial light and do not lose their color under the influence of prolonged insolation. Therefore, you can sew curtains and curtains from such fabrics, they will keep their color for a long time and look good.

At the same time, when comparing the data of the research results, it should be borne in mind that the color difference Δ*E* for fabric 1 and fabric 2, established by the spectrophotometric method, which occurs as a result of color fading under prolonged exposure to artificial light, corresponds to the contrast, which is evaluated by 8 points, according to the scale blue standards. This indicator is considered the limit of light aging of the color of samples of cotton fabrics and is widely used in the practice of materials science and commodity research as an objective criterion for evaluating the stability of the color of samples of cotton fabrics during their operation. Therefore, using this criterion to evaluate the change in light fastness of colour on the examined samples of chenille cotton fabrics, all six samples we took can be considered lightfast to artificial light. This makes it possible to recommend samples of chenille cotton fabrics of certain characteristics for use in textile design, and in furnishing a modern interior on the consumer market.

Table 4. The results of the study of image stability during insulation.

Fabric №	Reference images	Photographs of the sample after insulation			
		24 hours	96 hours	192 hours	288 hours
Fabric 1					
Fabric 6					

CONCLUSION

So, it was established that the color indicators of samples of chenille cotton fabrics of different shades of the same colour scheme, which are calculated in the CIELAB MKO system, which corresponds to the color codes according to the PANTONE Colors catalogue, have acceptable indicators for use.

The comparison of the methods for determining the light fastness of chenille cotton fabrics made it possible to verify the minor deviations in the results, which in turn indicates the feasibility of using these methods for research in practice.

The change in the overall color difference ΔE in tissue samples during 288 hours of insolation in laboratory conditions was studied. This opens up the further possibility of fabric design, in which by appropriate selection of color saturation S, color tone T, and purity of shade L, it will be possible to purposefully form the given light resistance of the color of chenille cotton fabrics, depending on the specific conditions of their use. The conducted research made it possible to make sure that such chenille cotton fabrics, which will have light and calm shades, will have the greatest use in the consumer market.

The conducted research is valuable, first of all, for a person who uses chenille cotton fabrics for furnishing a modern interior. Using the colour code from the PANTONE Colour, a person must understand which fabrics can be used for sewing curtains, and which for sewing pillows, tablecloths, furniture upholstery, etc. Research of this kind should bring practical benefit to a person, and bring them moral and aesthetic satisfaction from the use of such a fabric in the interior. Research of this kind should also be carried out for the further implementation of the process of developing a system technology for the design of new chenille cotton fabrics, taking into account the peculiarities of the raw material composition, the type of dye, the technologies of the final treatment of the fabric, etc.

The prospect for further research is the search for more perfect and ecologically safe ways of light stabilization of dyeing since the dominant factor in the wear of chenille cotton fabrics in operating conditions is the long-term effect of light weather on them.

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AN ECO-FRIENDLY DYE FOR BATIK CLOTHES: A NATURAL DYE SOLUTION MADE OF MANGO SEEDS EXTRACT (*Mangifera indica L.*)

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ABSTRACT

Waste pollution resulting from the production process of synthetic batik dyes is against the Sustainable Development Goals (SDGs) in the aspects of waste management systems and clean water. One effort to cut down the amount of pollution is the use of natural dyes for coloring batik clothes. This undertaking is not only healthy but also expected to bring in some added value economically, community empowerment, and intergenerational inheritance. This experimental research was carried out collaboratively between the Textile and Batik Craft Studio at the Indonesian University of Education, the Umymay Batik Studio, and the Yogyakarta Batik and Craft Center. A batik cloth was dyed 5 times with a mango seed extract solution as the dependent variable, then fixed with lime solution ($Ca(OH)_2$) and Ferrous Sulfate solution ($FeSO_4.7H_2O$) as the independent variables. The dyed fabrics were tested for their colorfastness against washing and sun exposure. The results of the study: 1) The process of dyeing the batik cloth was performed through several stages, that is, by cutting the cloth with a canting stamp, dyeing the cloth, and fixing it with $Ca(OH)_2$ and $FeSO_4.7H_2O$, the batik cloth fixed with $Ca(OH)_2$ tended to be brown in color while the other one fixed with $FeSO_4.7H_2O$ resulted in black; 2) The results of the Color Fastness Test against Washing at 40℃ on the batik cloth that has been dyed with mango seed extract fixed with $Ca(OH)_2$ and $FeSO_4.7H_2O$ were considered a good category with respective values of 4 on a scale of 5. Likewise, the results of the Color Resistance to Light: Day Light Ray Resistant Test Value with the fixation of $Ca(OH)_2$ and $FeSO_4.7H_2O$ was in the moderate category with a value of 3 each on a scale of 5. There should be a governmental policy to promote a green industry. As for batik artisans, they can utilize an eco-friendly alternative dye for batik clothes.

KEYWORDS

Mangifera indica L.; Batik; Eco-friendly; Natural Dyes; SDGs.

INTRODUCTION

Humans have created textile products with various techniques to meet their needs, improve lives, and adorn the surface of fabrics [1]. Historically speaking, since ancient times, natural dyes have been frequently used to color textiles [2]. However, along with the increasing public demand for textile and batik materials and products, a new problem arises, namely environmental pollution polluted by waste/wastewater produced by the process and production of textile and batik companies [3], [4]. The use of fabric dyes with synthetic materials that have no guidelines has been confirmed as a major cause of pollution that harms human health and the environment [5]. The problem of environmental pollution as a result of the use of synthetic colors in the production of batik is currently under the spotlight of various parties. Handayani, et al reported that pollution caused by synthetic dyes and the problem of excessive water use by the home-based batik industry has raised water scarcity problems [6]. The need for efforts to conserve natural resources, such as water, soil, air, and others, is one of the goals of the SDGs. Lack of environmental education, an open mindset, socio-cultural practices in making batik, and the consideration of production costs appear to have affected the awareness of environmental sustainability among batik entrepreneurs, batik industry waste is not well processed yet rather disposed into waterways resulting in water pollution [7]. For this reason, genuine efforts are needed by the government, batik artisan communities, and the community to build citizen awareness through environment-based education, understanding the

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dangers of synthetic waste and how to overcome it and finding alternative solutions through the use of environmentally friendly natural dyes in batik production. The shared view of protecting the environment implies that meeting the needs of our present and future generations needs to be identified and pursued by cutting back on the production of waste and the use of toxic materials, to prevent soil, water, and air pollution and to conserve and reuse resources wisely [8].

One of the efforts to reduce such environmental pollution is through the production concept of naturally dyed batik emphasizing the crucial role of sustainable production. According to Pedro, et al, replacing chemicals with natural materials is not only healthy and safe but also in practice there lie the so-called aspects of empowerment and passing on skills to the next generation [9]. This goes hand in hand with public demand for the textile industry to utilize natural dyes that are more functionally advanced, without harmful effects on the environment and aquatic ecosystems [10]. In particular, the attitude and satisfaction factors of producers have a significantly positive effect on the intention to produce naturally dyed batik products. In addition, producer attitudes and satisfaction are also significantly influenced by social values, quality values, and green industry values 11.

Mango (*Mangifera indica L.*) is a type of tropical fruit notable worldwide for its production, distribution, marketing, and use for human health. Even mango waste (such as the seeds and skin) has high functional and nutritional potentia [12]. More than 38 million tons of this type of fruit are produced and traded in the world every year, currently, mango seeds are being re-evaluated as a potential food source of functional ingredients because of their composition in proteins, antioxidant compounds, and lipids [13]. Mango seed kernel flour (MSKF) has the potential to be a good source of nutrients for humans and antioxidants, and its composition consists of carbohydrates (36.2-39.3%), crude protein (5.2-6.6%), total lipids (5.9-7.2%), natural fiber (2.2-2.5%), and ash content (2.9-5.5%) [14]. The results of other studies report that the composition of mango seeds kernels (MSK), which contains carbohydrate sources (58-80%), protein (6-13%) and fat (6-16%), can be used for poultry food [15]. Mango fruit as a member of the Anacardiaceae family is widely grown and produced in countries such as India, China, Thailand, Indonesia, Pakistan, Mexico, Brazil, Bangladesh, Nigeria, and the Philippines [16].

Mango by-products, especially the seeds, and the peels, are considered valuable sources of food and medicinal and inexpensive nutraceutical ingredients for the food, pharmaceutical, nutraceutical, and cosmetic industries, with antioxidant, anti-inflammatory, immunomodulatory, antibacterial, antidiabetic, antiobesity, anti-inflammatory effects, and anticancer was highlighted [17],[18]. In particular, studies related to mango seeds have been carried out by many experts in their fields. In food studies, Mango seed kernel (MS) has total phenolic compounds, total lipids, non-saponifiable material, and crude protein, all of which are significant, but the quality of the protein is good because it is abundant in all important amino acids [19]. Mango seeds which represent between 20-60% of the fruit also have limited food or industrial use in most producing countries and are therefore wasted. The kernel contained in the seeds (mango seed kernel: MSK) is a good source of carbohydrates (58-80%), contains moderate amounts of protein (6-13%), and has a fat content (6-16%) [15]. Meanwhile, a study of mango seeds in the area of medicine found that mango seeds are a by-product that is usually discarded even though they are identified as a natural source of phenolic compounds with health-promoting activities as well as multifunctional bioactive ingredients for nutraceutical and cosmeceutical applications [20],[21],[22]. The effect of the ethanolic extract contained in mango seeds can restore tissue damage in acutely injured hind limb ischemia in diabetic rats [23].

The waste of the mango fruit production (with special regard to the seeds and skin) can be used for the sake of environmental preservation and renewable energy. Mango waste products are used in bioremediation studies of chromium contamination as a potential sorbent for removing Cr(VI) from aqueous solutions [24]. Mango Peel Waste (MPW) which has a high content of pectin and cellulose, offers potential use as an effective adsorbent to remove toxic metal ions such as Cd2+ and Pb2+, dyes, and other organic matter from water solutions in industrial waste [25]. Mango seeds are a viable source of bioactive compounds which can be recovered by a water-ethanol binary solvent system [26]. The activated carbon was made from the shells of mango seeds and is used as a CO2 adsorbent [27]. Mango seed extract can be used successfully in water purification processes [28]. In particular, mango seed husks as a by-product of the mango industry can also be explored and have some potential in the production of bioethanol, the use of this waste material allows added value because it can serve as an alternative and affordable source of raw materials in energy production [29].

The aforementioned studies delineate that many experts from various disciplines have discussed the benefits and uses of mango seeds for humans. Mango seeds can be developed as food and pharmaceutical ingredients, in the domain of environmental protection as a potential sorbent material with the ability to absorb some pollutants from the environment, such as heavy metals and dyes, bioethanol material which functions as an alternative raw material source in the energy sector. However, there seems to be no research discussing the benefits of mango seeds as natural dyes for batik

Fig 1. Mango Seed Materials (*Magnifera indica L.*).

cloth that are environmentally or eco-friendly and have not been widely explored. For this vacancy, the author intends to study and explain the benefits of mango seed as a by-product of mango fruit to be used as a natural dye for batik cloth that can be developed by batik artisans and entrepreneurs in Indonesia and other countries.

Mango seeds are in the protection of the skin and the mango fruit that covers them. Furthermore, mango seeds are also located inside a hard seed coat (endocarp) with various sizes (see Figure 1). From these seeds grow fibers that can sometimes penetrate into the flesh of the fruit resulting a fibrous flesh. According to Mukherjee & Litz, mango seeds are solitary, large and flat, oval-ovate, and surrounded by a fibrous endocarp at maturity [30]. If we peel off the hard skin of the mango seed (endocarp), we will find two fleshy pieces, namely mono-embryonic seeds and polyembryonic seeds [31].

MATERIALS AND METHODS

Materials and tools

In this experimental study, the researchers utilized raw materials from mango seeds (*Mangifera indica L.).* the mango seeds originally intact were then processed by chopping the seeds into small pieces so that the resulting color was optimal. Other materials used for the reinforcing, locking, and color-guiding process were made from a solution of lime ($Ca(OH)_2$) and a solution of ferrous sulfate ($FeSO_4.7H_2O$). Apart from the main ingredients, there were also other supplementary ingredients such as alum ($Al_2(SO_4)_3.K_2SO_4.24H_2O$), Turkey Red Oil (TRO), Natrium Carbonate (Na_2CO_3), and starch. Alum and TRO were used to soak the cloth so that the color absorption process got to be optimal, while the Soda ash was used in the process of removing batik wax from the cloth which is known in the context of batik in Java as "lorodan".

In addition to the natural dye from mango seeds used, in this experiment, researchers also used the medium of "mori prima" type fabric, one type of fabric commonly used for making batik. "Mori prima" is the second subtle mori group after "mori primissima". Prima can be used for the process of making *batik tulis* (writing techniques with canthing tools) and can also be used for *batik cap* (using the stamp technique). Prima fabric is traded in pieces (roll-shaped). This type of fabric comes from Holland and Japan. Prima fabric from Holland with a size per piece is 40 inches wide and 17.5 yards (± 15.5 m) long, while prima fabric from Japan has a size, which is 4.2 inches (± 106 cm) wide and 17.5 yards (± 15.5 m) long. The average fabric arrangement or construction has a total thread per inch for warp 85 – 105 and for feed 70 – 90, while the thread in the English system number Ne_1 for warp is between 36 – 46 and for feed between 38 – 48. Prima fabric contains light starch (under 10%). The prima fabric can be stamped immediately for batik rather rough, while for *batik tulis* (with writing techniques) the *kanji* (cassava flour) in the mori is removed [32]. Mori fabric is a cotton woven fabric with plain woven and yarn density, bleached and without or given starch refinement, used for batik materials, while mori prima fabric is fine mori fabric, made from yarn number Tex 12.3 – Tex 15.5 with weight without starch per square meter 85 grams – 100 grams. The importance of the fabric is highly dependent on the thickness of the fabric and is closely related to the amount of diameter of the warp thread and weft. The tensile strength of the fabric is the strength of the fabric in withstanding the maximum load; an example of a fabric test until the fabric breaks, Tensile Strength Test (kg) of mori fabric warp direction: 19.4, a tensile strength of mori fabric feed direction: 13.3. To determine the resistance of fabric to tearing, mori fabric based on the Tear Strength Test (g) is at least known the warp direction: 680 and the tear strength (g) is at least the feed direction: 680. In detail, the mori fabric material used in this experiment is presented in Table 1.

Tabel 1. Mori fabric test results.

No.	Test Type	Test Method	Test Results
1.	Fabric thickness [mm]	SNI ISO 5084:2010	0.24
2.	Fabric weight [g/m^2]	SNI ISO 3801:2010	111.70
3.	Construction: – Warp density [1/cm] – Weft density [1/cm] – Warp thread number [tex] – Weft thread number [tex] – Face Webbing	 SNI ISO 7211-2:2010 SNI ISO 7211-5:2010 SNI ISO 7211-1:2010	 42.52 30.91 14.37 13.75 Plain
4.	Fabric composition (%)	SNI 08-0265-89	Cotton 80.23% Rayon 19.77%

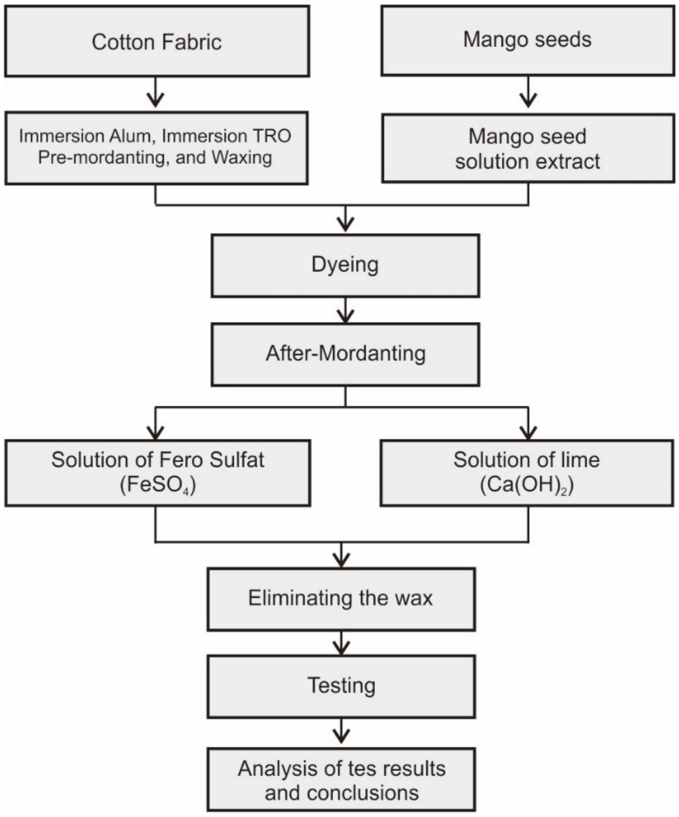

Fig 2. The dyeing process of a batik cloth with a solution of natural dye extract from mango seeds (Mangifera indica L.) [33].

Table 1 describes technical data information on mori fabric material used in experiments with mango seed extract. Mori cloth is a cotton woven fabric with plain woven and tight density, bleached and without or given kanji refinement, used for batik materials.

Mori prima contains light starch (under 10%). The mori can be stamped immediately for batik rather rough, while for *batik tulis* (with writing techniques) the *kanji* (cassava flour) in the mori is removed. The tools used in the process of exploring and developing the dyes were made of mango seed extract which included the tjanting (a pen-like tool) and/or tjanting stamp, pans, electric or gas stoves, scales, measuring cups, dip tubs, pans for extracting natural dyes, “lorodan” tubs, and a tool for testing the color durability through washing and solar exposure.

Research methodology

This study employed an experimental method to explore the natural color of mango seed extraction. Furthermore, the stages of the process and the length of time needed to process mango seed extract are presented in part two in part Preparatory stage. Through this research, it is expected that the existence of mango fruit seeds which were formerly solely a by-product and even as waste got to be utilized as a natural dye for coloring batik clothes. In addition to testing the suitability of mango seeds as a natural dye for batik cloth, this implementation was also carried out as an effort to develop a Teaching Factory-based Batik and Textile Craft Studio.

The process of this natural dye began by selecting the mango seeds, processing the mango seed material, boiling the mango seeds to make their extract, dyeing the fabric/cloth with a solution of mango seed extract, and finalizing it with the fixation process. The material exploration stage was carried out at the Textile and Batik Craft Studio, Visual Arts Education Study Program, Faculty of Art and Design Education, Indonesian University of Education. The findings were then applied to color a batik cloth with the Ubi Cilembu patterns by the researchers teaming up with several batik artisans as well as the owner of the Umy May Batik Studio in Tanjungsari, Sumedang Regency. Furthermore, the result of dyeing the cloth with the Ubi Cilembu patterns with a mango seed extract solution is finally verified. The Seed material of the mango seed extract solution was the dependent variable while the fixator was in the form of lime solution ($Ca(OH)_2$) and Ferrous Sulfate solution ($FeSO_4.7H_2O$) as the independent variables. The cloth that has been dyed and verified was then tested for its Color durability or fastness to washing at 40℃ and Color Fastness to Light: Daylight at the Yogyakarta Center for Crafts and Batik.

Work procedures

The steps taken by the researchers in this study included: a) the processing of the cotton cloth (soaking the cloth with alum or TRO solution); b) the processing of the natural ingredients from mango seeds to obtain the extract solution; c) the process of dyeing the cloth with a mango seed solution extract up to 5 times; d) the color fixation process with a lime solution ($Ca(OH)_2$) as well as a Ferrous Sulfate solution ($FeSO_4.7H_2O$); e) the process of releasing batik wax (pelorodan); e) laboratory testing process; f) the analysis of test results and conclusions. Schematically, the research steps are visualized on the following flowchart in Figure 2.

Preparation stage

In this preparatory stage, there are two main activities comprising the fabric processing and the processing of natural dyes: The first activity, the cloth to be used is firstly soaked using an alum or TRO in order that the absorption of the cloth into the natural dyes from mango seed extract shall be better. The use of alum mordant can be done using two techniques, that is, firstly the so-called 'hot technique' performed by boiling the cloth in an alum mordant solution (alum dose: 50 – 70 g/liter) at 85-90 ºC for 45 minutes, and/or secondly through the cold temperature performed by soaking the cloth for around 10-12 hours.

The second activity is to prepare natural dyes from the mango seeds. At this stage, the researcher prepared the mango seed material in which the mango seeds have to be chopped into smaller pieces. The chopped seeds were then boiled in a ratio: 1:10 (1 kg of ingredients with 10 liters of water). The boiling process for making a solution of mango seed coloring extract is done until the 10 liters of water were reduced to 5 liters only. The process of boiling (solution extraction) of dyes can be done by immersing the material in cold water for 24 hours and heating it up to its boiling state (98°C-100°C). For dyes that are sensitive to heat (eg dyes from flowers), the boiling process can be done around a temperature of 70-80°C [34]. The extract from the mango seeds would next be used for the cloth dyeing process.

Dyeing process

Before the cotton is processed for batik, that is, by writing or applying some hot wax with a writing tjanting or canting stamp, the cotton cloth is preliminarily mordanted with alum solution (6 g/L) by a cold soaking technique for 24 hours. After that, the cotton cloth gets to be rinsed and dried. The cloth that has become a batik is dipped in some water with enough TRO added for a faster and more even wetting process, the cloth is drained until there are no more water droplets, yet the cloth is not supposed to be dried out.

The batik cloth having been prepared is dipped or immersed into the color extract solution from the mango seeds that were brought off in the previous stage. The dyeing process was carried out manually, gradually, and repeatedly as much as needed, with the following stages: a) immerse the batik cloth for 2-4 minutes (as needed), remove the cloth from the dyeing solution and drain the cloth until it is almost dry. The stages of the dyeing process are repeated like those stages. The immersion process in this study was performed up to 5 times with a predetermined duration of immersion (about 2-4 minutes).

Fixation process

The fixation process used in this stage is final mordant fixation. This activity serves to determine the direction as well as to brace the color into the batik cloth so it will not fade out swiftly. In this study, the materials used were a lime fixation solution ($Ca(OH)_2$) with a lime composition of 50 g/L water and a solution of Ferrous Sulfate ($FeSO_4\ 7H_2O$) with a composition of 30 g/L water. This clear fixation solution was obtained after having been deposited for 24 hours. The fixation process in principle is to condition the dye that has been absorbed for a certain time so that an expected reaction will take place between the material being colored with the dye and the material used for fixation. The use of color fixation will affect color fastness or durability. The fixation process aside from strengthening the color and changing the natural dye according to the type of metal that binds it; also gets to brace the dye that has got into the fiber. Materials commonly used for fixation include alum [$K_2SO_4\ Al_2(SO_4)_3\ 24H_2O$], lime ($CaCO_3$), and ferrous sulfate ($FeSO_4$) [35].

Removing wax process

Removing the wax from batik cloth is one important step in the making of batik. The cloth having been written with batik wax and colored with natural dyes is boiled in boiling hot water on a stove at a temperature of 100 ℃. The process of boiling batik cloth uses Natrium Carbonate (Na_2CO_3) (5 g/L) and starch (10 g/L). This auxiliary substance serves to facilitate the removal of wax from batik clothes. After the batik cloth is dyed, it has to be washed using clean water and dried out.

Testing

To find out the accomplishment of the process of coloring a batik cloth with a mango seed extract, some monitoring of the process and results was carried out at the Textile and Batik Craft Studio, Faculty of Art and Design Education, Indonesian University of Education, and at the Umymay Batik Studio. Meanwhile, to determine the color fastness to washing and sunlight, a test was carried out at the Yogyakarta Institute of Batik and Handicraft, Yogyakarta.

Testing results and conclusions

At this stage, the author analyzed and interpreted data elicited from the results of color testing conducted in the laboratory. The type of test employed on this mango seed-dyed batik is related to the dyed batik's color fastness to washing at 40°C and color fastness to sunlight using fixation of lime and ferrous sulfate. The results of the analysis and interpretation were ultimately drawn conclusions upon.

Fig 3. A batik cloth crafted with Ubi Cilembu Patterns.

Fig 4. A natural dye of mango seeds batik patterns with lime fixation.

Fig 5. The results of mango seed-dyed batik with a ferro sulfate fixation.

RESULTS AND DISCUSSION

The results of dyeing Ubi Cilembu – patterned batik with mango seed extract

The process of dyeing the batik cloth with natural dyes of mango seed extract was carried out after the process of writing the cotton cloth with hot wax using a tjanting stamp and or writing canting. The results of the process of stamping or writing batik cloth with hot wax in this study used a tjanting stamp (see Figure 3).

The next process was dyeing the batik cloth with a solution made of mango seed extract. Based on the results of the dyeing, it is known that the color results that appear on the batik cloth with the Cilembu Sweet Potato pattern seemed to result in a different hue. Thus, the same natural dyes, but using a different fixation, will produce different colors (see Figure 4 and Figure 5).

Figure 4 above visualizes the results of dyeing a batik cloth with mango seed extract with a lime fixation solution ($Ca(OH)_2$) prone to produce a cream color towards brown. Meanwhile, Figure 5 visualizes the results of dyeing a batik cloth using a solution of mango seed extract with a solution of ferrous sulfate ($FeSO_4.7H_2O$) fixing agent which brought about a darker color, that is black (Figure 5).

The application of the natural color of the mango seed extract that has been tested is employed in the batik process by batik artisans at the Umymay Studio, Tanjung Sari Sumedang. Figure 6 from left to right shows the activities: the process of stamping batik cloth with a tjanting stamp, dyeing cloth with TRO, the process of dyeing batik cloth, the process of coloring batik cloth, and the pelorodan process. Based on this series of activities, masterworks of batik clothes got to be created (Figure 7).

Figure 7 above is a batik fabric product that uses natural dyes from mango seed extract. The background color of this deep black batik cloth is produced after the batik cloth is dipped five times into the extract of the solution from mango seeds, then dified with ferrous sulfate solution. The color of the Cilembu sweet potato batik motif with red flowers and green leaves uses the synthetic color Remasol with the *colet* technique using kwas. For the next process, this batik fabric can be designed into clothing patterns for both men and women, then sewn into clothes according to the needs of batik lovers consumers.

Fig 6. The immersion process of the batik cloth with the mango seed extract.

Fig 7. A batik cloth dyed with a mango seed extract solution.

Fastness test results to washing and light: daylight

The results of tests performed at the Yogyakarta Arts and Batik Center on a cloth dyed with a mango seed extract solution, the results are presented in Table 2.

The data presented in Table 2 presents a description of the results of the natural color test with mango seed dyes. The batik cloth is made by a means of a stamped batik technique using a tjanting stamp with an Ubi Cilembu pattern. Based on the results of previous studies, the immersion technique of mango seed extract was carried out using a cold technique up to five times. After the batik cloth was dyed, the next step was to fix the batik cloth with a solution of lime ($Ca(OH)_2$) and/or a solution of Ferrous Sulfate ($FeSO_4.7H_2O$).

Batik fabrics fixed with a lime solution and Ferrous Sulfate solution are tested using multifiber upholstery fabric medium: Acetate, Cotton, Polyamide, Polyester, Acrylate, and Wool. This type of test aims to see the stain on each fibre using the Indonesian National Standard (SNI ISO 105-C06:2010). Comparison of color change values (ISO 105-A02) through a type of color fastness test against 40º C washing of fabrics fixed with lime solution ($Ca(OH)_2$) and / or solution of Ferrous Sulfate ($FeSO_4.7H_2O$) It is known the comparison of the results of each with a good category (value 4 on a scale of 5). Next, a comparison of color stain values (ISO 105-A03) against fabrics using lime solution ($Ca(OH)_2$) and / or solution of Ferrous Sulfate ($FeSO_4.7H_2O$) was tested using multifiber coating fabrics known to the results of color stain levels in Acetate, Polyester, Acrylate, and Wool good and very good categories (values 4-5), while the use of cotton upholstery on fabrics fixed with lime solution shows good categories (value 4) and on fabrics fixed with solutions of Ferrous Sulfate categorized as sufficient and very sufficient (values 3-4). Based on these data, information was obtained that the color stain value in acetate, polyamide, polyester, acrylate and wool mediums was better (the natural color of mango seed extract did not move to stain the multifiber coating fabric) than the cotton fibre coating cloth medium with good and very good categories.

In the table above, we also know the information on color fastness to bright sunlight. Based on the type of color fastness test against bright sunlight, it is known that the same ratio in fabrics with fixation of lime solution and Ferrous Sulfate solution with sufficient category values (value 3 on a scale of 5). Batik cloth, so that it is durable and not dull in color, should avoid sunlight.

Fastness test results against washing at 40 °C

This testing process usually makes use of an AATTC WOB soap, which is an optical bleach-free soap used as a standard washing soap in laboratory work on the fastness test of fabric color to washing [36].

The results of the testing respective to the color fastness to washing at 40℃ as presented in Table 1 above were performed using the following testing technique: SNI ISO 105 - C06:2010 (Textile - Test method for color fastness - Part C06: Colorfastness to household and commercial washing); SNI ISO 105-A02:2010 (Textile - Test method for color fastness - Part A02: Grayscale for assessment of discoloration); and SNI ISO 105-A03:2010 (Textile - Test method for color fastness - Part A03: Grayscale for tarnishing assessment). These results shed light that natural dyes from mango seed extract with lime fixation ($Ca(OH)_2$) and/or Ferrous Sulfate solution ($FeSO_4.7H_2O$) are each in a good category (score 4

Table 2 Color Testing Results of Mango Seed Extract.

No.	Test Type	Test Results (Fixator Type)		Test Method
		$Ca(OH)_2$	$FeSO_4.7H_2O$	
1.	Washing Resistance 40 ℃ Color Change Value Color Blemishes Value - Acetate - Cotton - Polyamide - Polyester - Acrylate - Wool	 4 4 - 5 4 4 - 5 4 - 5 4 - 5 4 - 5	 4 4 - 5 3 - 4 4 - 5 4 - 5 4 - 5 4 - 5	SNI ISO 105-C06:2010 SNI ISO 105-A02:2010 SNI ISO 105-A03:2010
2.	Color Resistance to Light: Day Light Ray - Resistant Value	 3	 3	SNI ISO 105-B01:2010 SNI ISO 105-B02:2010

Description: 1 = bad, 1-2 = bad, 2 = poor, 2-3 = not good, 3 = enough, good enough, 4 = good, 4-5 = good, 5 = very good

on a scale of 5). It means that the color of the clothes made from mango seeds does not dehydrate the color pigment due to dyeing, so the color remains or does not change and does not fade either.

Thus, it is concluded that mango seed extract can be utilized, by the batik artisans, as an alternative dye that is eco-friendly. Based on these data, the use of fixation determines as well as strengthens the colors in the batik cloth. This is in accordance with the opinion that the function of accompaniments apart from increasing the color intensity is also to strengthen the bonds between fibers and colors so as to prevent the dehydration of color pigments [35]. These findings are also advocated by a research report showing that the more/higher the concentration of fixation (mordant) affects the intensity of the resulting color, the higher the concentration of the fixator, the stronger the color will be produced, the function of the fixator is not only to result in forming a color but also to strengthen the bonds between fibers and color so as to prevent dehydration of color pigments [37]. Mordant, meaning "to bite," is a distinct chemical that reacts with dyes in such a way as to bond the dyestuff to the fiber by increasing affinity and/or strengthening the interaction, in certain cases through durable chemical connections, making the color impervious to light and to the washing process [38]. Resting on the author's empirical experience in exploring and experimenting with techniques, natural materials, and fixation materials, and the duration of time in the dyeing process, such activities could affect the results of color intensity on a batik cloth. The color intensity of the batik cloth dyed with natural colors can be adjusted as much as needed. For that being the case, there are several ways that can be done, including a) adjusting the ratio of the number of natural dyes and the boiling water used (the composition is 1 kg of natural ingredients: 10 L of water), the more natural the materials are, the darker/stronger the color intensity will turn up, the smaller the proportion of materials are, the lighter/brighter the intensity will become; b) adjusting the amount of dyeing, the more the amount of dyeing of the batik cloth we use, the darker/stronger the color intensity will appear, while the less the amount of dyeing we use, the lighter/brighter the color intensity will result in; c) immersion time, the longer the dipping duration takes place, the darker/stronger the color intensity will form, while the shorter the dipping time is, the weaker/brighter the color intensity will emerge.

In particular, the color staining value on cotton clothes is closely related to the characteristics of cotton fiber which can bind more dyes than mango seed extract with the fiber to form a bond or have great absorption power after the final mordant processing is completed. The use of organic textile products made from cotton has a higher price but is a form of public awareness about health and the environment [39]. The test results show that there was a slight difference, that is, the batik cloth using fixation lime ($Ca(OH)_2$) was considered in a good category (value 4 on a scale of 5) compared to that using a solution of Ferrous Sulfate ($FeSO_4.7H_2O$) which was in the good enough category (value 3-4 on a scale of 5).

Fastness test results against light: daylight

Color fastness test to light: daylight was performed using testing techniques with SNI ISO 105-B01:2010 (Textiles - Method of color fastness test - Part B01: Colorfastness to light: Daylight) and SNI ISO 105-B02:2010 (Textiles - Test method for color fastness - Part B02: Color fastness to artificial light: Xenon lamp). The results of the color fastness test to light: light, indicate that the results of the dyeing with mango seed extract fixed with lime ($Ca(OH)_2$) and/or Ferrous Sulfate solution ($FeSO_4.7H_2O$) were found to be in the sufficient category (value 3 on the scale 5). In this case, despite employing a different fixation, no significant difference was found. Based on these findings, it is concluded that the use of mango seed extract has a moderate light resistance value, so it is recommended that fabric products that use colors made from mango seed extract should not come into direct contact with sunlight. This is very logical and believed empirically that one that threatens the quality of color is direct sunlight on the batik clothes, the same thing also applies to batik clothes with synthetic dyes.

Built on the results of the data description and analysis above, it is concluded that the natural waste material of mango seeds can be used as an alternative material for good quality natural dyes that are environmentally or eco-friendly. The report by Martuti supports this, et al that clean textile production can protect the environment by applying organic materials as natural dyes. Compared to synthetic variants, this pigment material is considered more biodegradable, relatively safe, and easy to obtain without liquid waste [40]. The discovery of new sources of materials for the textile dyeing process, especially in the batik industry, is also seen as an effort to preserve the textile heritage in Indonesia [41].

The utilization of mango seed waste, formerly a food industry waste that later became an extract for batik dyes, has the value of local wisdom to get to know the biodiversity of the Indonesian nation. This condition is highly expected to improve our attitude in seeing what might appear, at face value, useless as matter of fact, can get to be very useful for the people's prosperity, in this regard, through the discovery of natural organic dye materials. Efforts made to increase the production of natural-colored batik towards sustainable production are significantly influenced by the attitudes and satisfaction of producers, social values, quality values, and green environmental values that produce natural-dyed batik products [11]. Furthermore, to support the use of natural dyes in the Indonesian batik industry, it is necessary to develop instruments containing indicators to assess the sustainability of current batik production with indicators from environmental, economic, and social dimensions [42]. In addition, to address issues related to the environment, there are key factors at the level of goals and objectives which include: a) the role of new ideas about the importance of the environment and an integrated approach to sustainable development promoted by the scientific and research community; b) a group of entrepreneurs promoting these ideas; and c) the institutional structure and working modalities of the Open Working Group (to develop the text of the SDGs) that facilitate the final agreement [43].

The global demand for sustainable, eco-friendly fabrics is challenging to preserve batik as Indonesia's cultural identity [44]**.** For this reason, using natural colors requires understanding and awareness from various stakeholders. Using natural colors to color batik clothes is the right action in reducing environmental pollution today.

CONCLUSION

The utilization of natural materials as a source of developing natural dyes aside from increasing the awareness of environmental sustainability, will also have economically added value in developing a sustainable batik industrial process. Using natural dyes from mango seed extract is an appropriate alternative to reducing environmental pollution problems. For this reason, selecting materials and using the right fixation will produce good colors and be eco-friendly. Based on the testing results related to its fastness to washing and light: daylight, on a batik cloth dyed with mango seed extract showed satisfactory results, thus, natural dyes from mango seeds can be used to develop the current batik industry. Therefore, this study accentuates the need to use natural dyes such as those from the extracted mango seeds. The use of such an eco-friendly material comes as an effort to preserve the value of local wisdom and provide added value to batik artisans.

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EVALUATION OF THE QUALITY OF CELLULOSE SEMI-FINISHED PRODUCTS FROM TECHNICAL HEMP AND THE POSSIBILITY OF THEIR FURTHER USE

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ABSTRACT

The article discusses the issues of processing industrial hemp into goods for various functional purposes. Particular attention is paid to the processing of hemp trusts into cellulose-containing semi-finished products, as well as to the analysis of the properties of cellulose-containing fibrous materials obtained from industrial hemp. Based on the results of the study of physical, mechanical and organoleptic characteristics of the obtained cellulose-containing semi-finished products, their suitability for the pulp and paper industry and other sectors of the national economy has been established. The presented research is relevant for the purpose of creating an own raw material base for pulp and paper enterprises and light industry enterprises.

KEYWORDS

Technical hemp; Shale trust; Trust obtained by soaking; Husk layer; Fibrous semi-finished product; Hemp cellulose; organoleptic indicators.

INTRODUCTION

Technical hemp remains potentially the most profitable of the technical crops grown in Ukraine. Like no other agricultural crop, technical hemp has advanced technologies for in-depth processing into a large number of final products. Hemp stalks are a universal raw material in the textile industry, furniture production, in construction and composite materials, and it is also possible to obtain biofuel, cellulose and many other products from it [1-4]. Valuable medicinal, perfume and cosmetic preparations are obtained from hemp seeds, they are very useful as additives in many food products, and high-quality technical oils and paints are made from them.

The economic use of hemp has undergone a number of significant changes, reflecting the demand for fiber products depending on the level of technological progress and the changing needs of society. Due to the high exceptional properties of elementary fibers, fiber semi-finished products, cellulose and hemp fabrics are able to scatter and absorb sound waves and light rays. Chinese researchers claim that hemp clothing absorbs 95 % of UV rays, while others absorb 30 – 90 %. When heated to 370 °C, the color of the fabric does not change, and at a temperature of 1000 °C, when it becomes charred, its ignition does not occur [3, 4].

According to Lithuanian researchers, the hemp fibrous semi-finished product has the ability to resist the waves of mobile communication [5, 6]. In addition, it can be used for sewing military uniforms, including body armor. Considering the antistatic properties of hemp fiber and considering ancient medical research, linen and medical dressing materials made of hemp have a beneficial effect on the human body, prevent the development and reproduction of anaerobic bacteria.

Now, more than ever, the ecological danger to the environment from the use of synthetic materials, such as synthetic textile materials, packaging, chemical plastic, synthetic cellulose, is an urgent problem. Recently, the world has seen an increase in demand for pulp materials used to produce various types of paper and composite materials for various functional

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purposes. The growing shortage of wood raw materials and the high cost of imported pulp procurement make it possible to use industrial hemp to produce pulp-containing materials. In addition, given the properties of hemp to accumulate a huge biological mass and the ability to clean up contaminated areas, which is currently very important for the restoration of post-war Ukraine, the research presented here is relevant for the creation of a domestic raw material base for pulp and paper and light industry enterprises.

The aim of the presented studies is to evaluate the physical, mechanical and organoleptic properties of cellulose-containing semi-finished products obtained by the sodium method and neutral sulfite methods in order to determine the possibilities of their further use.

LITERATURE REVIEW

Recently, a number of publications have appeared in the literature on the processing of hemp stalks into cellulose-containing semi-finished products. Technical hemp is a very promising raw material. Due to its chemical composition and unique combination of properties such as hygiene, high strength, natural bactericidal properties, technical hemp has long been used for textile, paper, construction, fuel, cosmetology and other industries. Hemp fibers are used in the production of ropes, cables and twine. Hemp products are strong and durable. In addition, the cultivation of hemp does not require any chemical fertilizers, thanks to which such raw material is 100% environmentally friendly [7-9]. On the basis of cellulose from hemp pulp, a biopolymer can be made that decomposes in the environment, is recyclable and safely disposed of, and has high strength and flexibility. Such a polymer finds multifaceted application: from packaging for food products and industrial products to interior equipment of cars [10-12].

Cellulose is a valuable component because it gives fibers and fabrics made from them tensile strength, flexibility and elasticity, wearability, hygroscopicity, softness and shine. The content of cellulose in hemp fibers is 70 - 77 %, pectin substances - up to 3.3 %, lignin - 3.7 - 8 %, water - up to 10 %. Lignin adds stiffness and other negative properties to the fiber, so it is an undesirable component from a technological point of view [13-15].

The process of obtaining cellulose consists in releasing it from other accompanying substances of plant tissue - lignin, hemicellulose, fats, etc. - by the method of chemical treatment. Since the main substance that must be removed as a result of processing is lignin, the process of obtaining cellulose is called delignification of the corresponding plant material. The product of delignification is called cellulose [16].

The quality of cellulose-containing semi-finished products is determined by a complex of physical-chemical and mechanical-strength properties. A large number of different indicators are used to characterize the physicochemical properties of fibrous materials: lignin content, yield, ash content, moisture and clogging. Mechanical strength indicators are breaking length, resistance to breaking, bending, tearing and crushing.

Depending on the conditions of processing cellulose-containing raw materials with various chemical reagents at elevated temperatures and pressure, as a result of cooking, technical cellulose is obtained with different quantitative yields. According to the amount of output from the mass of raw materials, technical pulps are divided into three main categories: semi-cellulose, high-yield cellulose and normal-yield cellulose. Production of semi-cellulose consists of two stages of processing - chemical and mechanical. In the process of chemical processing, lignin and hemicelluloses are released from non-wood raw materials, and during mechanical processing, it is separated into fibers under the action of hot grinding [17].

The possibilities of using hemp stems for the production of cellulose-containing semi-finished products have been investigated by the laboratory of the University of Toronto (Canada). The semi-finished product obtained by the sodium cooking method with a yield of 55% and a residual lignin content of 3% is suitable for the production of printing types of paper [16, 17]. The industrial use of hemp in the production of fibrous semi-finished products was studied by the Olympia College laboratory (Washington, USA). To obtain the semi-finished product, sulfate and sodium methods, cooking with organic solvents were used. As a result, a chemical-thermomechanical mass was obtained with a yield of cellulose-containing semi-finished products of more than 60% and satisfactory quality indicators [17].

In the literature, there was a report on the creation of a new method of environmentally friendly technology for obtaining cellulose from annual plants (straw, hemp, perennial plants, agricultural waste, etc.) called Natural Pulping. Formic acid and hydrogen peroxide are used as reagents for cooking and bleaching. The technology makes it possible to reduce the amount of harmful toxic emissions while improving the quality of the obtained semi-finished product in comparison with the sulfate method [18, 19].

RESEARCH METHODOLOGY

When processing non-woody types of plant raw materials, the choice of the processing method and regime should be related to the peculiarities of the morphological and anatomical structure, chemical composition, physical and mechanical properties of the raw material, as well as requirements for the quality of the semi-finished product and the main technical and economic indicators of production.

Table 1. Chemical composition and fiber length of hemp raw materials.

Chemical composition and fiber length	Stem		Fiber	
	fibrous part or lob	wooden part or bonfire	received from the trust obtained by soaking	obtained from the shale trust
Cellulose [%]	66.0 - 70.4	37.1 - 39.4	65.8 - 67.4	66.5 - 68.9
Lignin [%]	3.7 - 6.0	21.0 - 32.9	5.0 - 7.5	4.1 - 6.2
Hemicellulose [%]	7.0 - 7.4	18.9 - 21.2	3.5 - 4.5	4.1 - 6.8
Other components (pectin, tannins, nitrogenous substances) [%]	23.3 – 16.2	23.0 – 6.5	25.7 – 20.6	25.3 – 18.1
Length [mm]	5.0 - 55.0	0.60 - 0.75	5.0 - 55.0	5.0 - 55.0

A characteristic feature of the anatomical structure of technical hemp is the presence of bast fibrous and woody layers. The first layer is 30 – 40 % of the entire stem, and the second is 60 – 70 %, respectively. The most valuable cellulose fibers are located in the husk layer their content is 60 - 70%.

The chemical composition of hemp raw materials, potentially considered as raw materials for obtaining cellulose-containing semi-finished products, is given in Table. 1 [26].

The difference in the chemical composition of the fibers and their length makes it necessary to separate these two fractions before starting the cooking of hemp raw materials, as well as their separate use for the manufacture of cellulose semi-finished products for different purposes [23-25].

It is believed that the most acceptable alkaline methods for chemical processing of industrial hemp stems are sodium, sulfate, and neutral-sulfite. The sodium method of cellulose production allows processing any wood species and annual plants into cellulose and semi-cellulose. In the sodium method, a solution of caustic soda is used as a reagent.

In the sulphate method, the reagent is a mixture of caustic soda (NaOH) and sodium sulphide (Na_2S). Sulphite pulping is carried out using an aqueous solution of Na_2SO_3 and Na_2CO_3. Sulphate pulp is superior to sulphite pulp in terms of mechanical strength. In neutral-sulfite pulping, a mixture of caustic soda (NaOH) and sodium sulfite (Na_2SO_3) is used as a reagent [16,17,24].

To conduct production tests, we used hemp trust, obtained by the methods of cold-water impregnation (trust obtained by soaking) and dew impregnation with the use of chemical composite preparations (slaked trust).

Biological and chemical methods such as cold-water soaking, dew impregnation and steaming of stems are used to produce hemp trusses. Cold-water soaking and steaming are carried out in accordance with regulated technological regimes developed by the Scientific Research Institute of Institute of bast crops (Hlukhiv, Ukraine).

The production of hemp trusses by cold-water soaking and dew soaking with the use of chemical compositions was carried out in the laboratory at the Kherson National Technical University (Kherson, Ukraine). To obtain hemp trusses by cold-water soaking, stems are loaded into the chamber in bales with horizontal laying. The loading density is 80-100 kg/m^3. The initial water module (the ratio of dry matter to water) is from 1:10 to 1:12. The water level in the chamber should be 10-15 cm higher than the surface of the loaded straw. The first change of liquid is carried out 12-15 hours after the start of urination, draining 25 % of its previous volume and adding fresh water instead. Subsequent fluid changes are made depending on the acidity of the fluid. If more than 2.0 ml of 0.01 normal sodium hydroxide solution (molar concentration of NaOH in the solution, in this case, is 0.008 [mol/l] is used to titrate the urine fluid, 25 % of the fluid volume is changed in the chamber with the addition of fresh water. If the acidity of the liquid is lower, it is not changed until the end of the process. The final water module is in the range of 1:30 to 1:35.

Dew impregnation was carried out in the laboratory on a specially prepared artificial plot as follows: first, the stems were treated with chemical compositions based on surfactants, and then sprayed with water to maintain the level of humidity necessary for the development of pectin-degrading microflora. The duration of dew soaking was 20 days [15,20,21,26].

The difference between the samples in terms of color was visually observed. The sample that had a white-golden color was labeled as sample No. 1 (shale trust), and the sample that had a dark golden color with a greenish tint, respectively, as sample No. 2 (trust obtained by soaking).

The raw material – hemp pulp – was sorted on a laboratory sorter in order to remove rejected elements (small particles, mineral impurities), which must be removed at the preparation stage because their presence during the production of cellulose-containing semi-finished products will lead to disruption of the technological process. The crushed and sorted raw materials were placed in a desiccator for moisture averaging. After that, the moisture content of raw material samples was determined according to the standard method. According to the calculations, the average moisture content of sample No. 1 was 8.94%, and that of sample No. 2 was 9.08%.

The moisture content of the raw material significantly affects the process of its impregnation with the cooking solution, the concentration of active reagents

Table 2. Production of cellulose-containing semi-finished products by the sodium method.

Parameters of thermochemical treatment	Indexes	
	Sample №1	Sample №2
1. Weigth [g]	80	80
2. Consumption of NaOH [%]	15	15
3. Hydro module	1:4	1:4
4. Temperature [°C]	170	170
5. Duration [min.]	180	180
6. Coefficient of dryness	0.38	0.39
7. Yield after washing [%]	64.8	64.2
8. Degree of delignification [units. Kappa]	7.23	7.44

Table 3. Production of cellulose-containing semi-finished products by the neutral-sulfite method.

Parameters of thermochemical treatment	Indexes	
	Sample №1	Sample №2
1. Weigth [g]	80	80
2. Consumption of NaOH [%]	3	3
3. Consumption of Na_2SO_3 [%]	23	23
4. Hydro module	1:3	1:3
5. Temperature [°C]	170	170
6. Duration [min.]	180	180
7. Coefficient of dryness	0.33	0.41
8. Yield after washing [%]	66.4	71.89
9. Degree of delignification [units. Kappa]	11.6	14.98

Table 4. Quality indicators of the cellulose-containing semi-finished product obtained by the sodium method.

Physico-mechanical indicators of cellulose	Size	
	Sample №1	Sample №2
1. Density [g/cm^3]	0.67	0.63
2. Breaking length [m]	5070	5012
3. Absolute compression resistance [kPa]	250	248
4. Absolute tear resistance [mN]	1067	1003
5. Fracture [number of double inflections]	914	1048
6. Linen [%]	42.0	-

in the delignification process, and therefore the uniformity of cooking, the yield of cellulose and its quality. Therefore, the raw materials used for the production of cellulose-containing semi-finished products should have a uniform fractional composition and uniform moisture content, the fluctuations of these indicators should be insignificant.

After determining the moisture content, accurately weighed samples of crushed hemp pulp were loaded into laboratory reactors for thermochemical treatment. Cellulose was boiled by sodium and neutral sulfite methods in a laboratory autoclave at a temperature of 170 °C [17, 23, 25]. The process parameters are listed in Table 2 - 3.

After thermochemical treatment, the resulting semi-finished product was crushed and loosened in a laboratory disintegrator, and then washed on a sieve. After washing, the mass was squeezed, the total yield of cellulose and the degree of its delignification were determined.

The preparation of the cellulose-containing semi-finished product for physical and mechanical tests consisted of grinding and making paper-like samples based on it. The following physical and mechanical parameters were evaluated experimentally: density, breaking length, absolute compression resistance, absolute tear resistance and fracture. The values of the resulting pulp-containing semi-finished product were determined using standard methods in accordance with the current international and national standards for wood pulp-based paper: STATE STANDARD 27015-86 "Paper and cardboard. Methods for determination of thickness, density and specific volume", STATE STANDARD 13525.1-79 "Fibre semi-finished products, paper and cardboard. Methods for determination of tensile strength and elongation at tension", STATE STANDARD 13525.8-86 "Semi-finished fibre products, paper and cardboard.

Table 5. Quality indicators of the cellulose-containing semi-finished product obtained by the neutral-sulfite method.

Physico-mechanical indicators of cellulose	Size	
	Sample №1	Sample №2
1. Density [g/cm^3]	0.7	0.82
2. Breaking length [m]	6230	6294
3. Absolute compression resistance [kPa]	349	393
4. Absolute tear resistance [mN]	2293	1280
5. Fracture [number of double inflections]	4000	4076
6. Linen [%]	55.7	53.0

Table 6. Organoleptic quality indicators of the cellulose-containing semi-finished product obtained from technical hemp.

Indicator	Cellulose-containing semi-finished product from technical hemp	
	received from the trust obtained by soaking	derived from a shale trust
Appearance and structure	fine fibrous loose mass	fine fibrous loose mass
Color	white with a grayish tint	light yellow
The presence of foreign impurities	contains impurities of single fibers from dark yellow to brown	does not contain non-cellulosic impurities

Method for determining the resistance to pressing", DSTU 3368-96 "Semi-finished fibre products and paper. Method for determination of tear resistance", DSTU 3476-96 (ISO 5626-97) (ISO 5626:1993) "Paper. Determination of fracture strength at multiple bends". The values of the quality indicators of the obtained samples are given in the Table 4 - 5.

It should be noted that the cellulose-containing semi-finished product obtained by both the sodium and neutral-sulfite methods, after dissolution in a disintegrator and washing, was well divided into bundles and individual fibers. A semi-finished product with a cellulose yield of 60% has a sufficiently low degree of delignification, which should not complicate the bleaching process in the future.

The obtained material has high quality indicators. Analyzing the physical and mechanical parameters of the obtained samples, it should be noted that the cellulose-containing semi-finished product obtained by the neutral-sulfite method with indicators of yield 70 %, whiteness 54-56 %, degree of delignification 12 - 10 units. Kappa, fracture resistance 4000 - 5000 number of double inflections and tear resistance of 1200-1500 mN, its quality exceeds cellulose obtained from wood.

Given the high strength indicators, the obtained cellulose-containing semi-finished product can be used in the composition for the production of high-strength, durable and special types of paper, non-woven materials, as well as for the production of technical textiles of various functional purposes.

The next stage of the research was the organoleptic evaluation of the samples of the cellulose-containing semi-finished product. The following indicators were chosen for evaluation and comparison: appearance and structure, color, presence of foreign impurities. The results of the research are presented in Table 6.

After analyzing the organoleptic evaluation of the studied samples, it was established that the samples of the hemp cellulose-containing semi-finished product have a loose, fine-fiber structure. The color of the semi-finished product obtained from slaked hemp trust is light yellow (Figure 1).

The color of the semi-finished product obtained from the received from the trust obtained by soaking is white with a grayish tint (Figure 2).

The difference in the color of the studied samples is explained by the conditions and regimes of primary processing of technical hemp with the aim of obtaining high-quality fibrous mass.

Having investigated the presence of foreign impurities, it was established that the cellulose semi-finished product obtained from shale trust does not contain foreign impurities in the form of trust, sand, pieces of rubber, metal inclusions and other impurities of a non-cellulosic nature.

Figure 1. A sample of cellulose-containing semi-finished product obtained from the trust obtained by soaking.

Figure 2. A sample of a cellulose-containing semi-finished product obtained from a shale trust.

Table 7. Physicochemical properties of cellulose-containing semi-finished products of various origins.

Indicator	Cellulose-containing semi-finished product					
	Cotton	from coniferous wood	viscose	linen	hemp from trust obtained by soaking	hemp from shale trust
Moisture [%]	8 – 10	8 - 12	6 – 10	7.5	6.22	5,6
Degree of swelling [%]	450 - 550	450 - 550	450 - 550	-	400	250
α-cellulose [%]	96 – 99	82-88	90 - 92.5	87 - 88	86.66	83.33
Lignin [%]	0.3 - 0.5	0.1 - 0.5	-	0.5	10	15
Ash content [%]	0.1 - 0.3	0.3 - 0.5	0.08 - 0.12	1.0 - 1.1	1.07	1.06

The semi-finished product obtained from the trust obtained by soaking contains impurities of single fibers from dark yellow to brown in color, but they are of cellulosic origin.

The results of research on the physical and chemical properties of cellulose-containing semi-finished products of various origins are given in Table. 7

Analyzing the given indicators, it should be noted that according to the humidity indicator, the tested samples of semi-finished products from hemp contain slightly less moisture than those from cotton and coniferous wood. Thus, the cellulose-containing semi-finished product from hemp contains 5.6 - 6.22 % moisture, cotton: 8 - 10%, and from coniferous wood: 8 - 12%.

The degree of swelling of the pulp was determined by the Schwalbe weight method, the essence of which is to determine the increase in pulp weight during its soaking in sodium hydroxide solutions. The degree of swelling (C_{sw}) was determined as a percentage by the formula:

$$C_{SW} = \frac{m_1}{m_2} 100 \,, \qquad (1)$$

where m_1 is the mass of the test sample before swelling [g], m_2 is the mass of the test sample after swelling [g].

According to the degree of swelling, samples obtained from technical hemp have slightly lower values compared to other types. Thus, the semi-finished product obtained from shale trust - has a degree of swelling of 250 %, and obtained from urea trust - has a degree of swelling of 400 %. The difference in these indicators is due to the regimes and conditions of primary processing of industrial hemp with the aim of obtaining fiber, which subsequently affects the structure of hemp cellulose.

According to the content of α-cellulose, it should be noted that the largest amount of it is contained in the cotton cellulose-containing semi-finished product: 96 - 99%, slightly less in viscose: 90 - 92.5 % and linen: 87 - 88 %. It should be noted that the smallest amount of α-cellulose is contained in semi-finished softwood 82 - 88%. The examined samples of hemp semi-finished products contain 86.66 % and 83.33 % of α-cellulose, respectively.

Analyzing the lignin content, it was found that the studied samples of cellulose-containing semi-finished products from industrial hemp contain more lignin (10 - 15 %) compared to others (0.1 - 0.5 %). Lignin, namely its high content, is an undesirable component of the fibrous semi-finished product, which makes it impossible to obtain high-quality textile and cellulosic materials. Therefore, to obtain fibrous and cellulosic semi-finished products of better quality, it is necessary to use additional processing aimed at removing lignin.

Based on the results of research, it can be stated that the replacement of synthetic and traditional cellulose with cellulose from technical hemp will not lead to a decrease in the quality of products, because its physical and chemical indicators, including moisture content, ash content, α-cellulose content, are on a par with other types cellulose The main attention should be paid to the content of lignin, which is slightly overestimated in hemp cellulose, which is explained by the biological and morphological structure. At the same time, the lignin content can be corrected by additional processing of hemp pulp. Replacing flax and wood cellulose with hemp can improve the quality of fibrous materials, which is confirmed by the high content of α-cellulose as a valuable component for the production of fibrous semi-finished products, composite materials based on hemp cellulose, as well as packaging materials.

RESULTS

Thus, the conducted studies confirm the possibility of obtaining a fibrous semi-finished product from drug-free hemp. Based on the obtained results, it can be concluded that cellulose and fibrous semi-finished products obtained from drug-free hemp are characterized by a high level of physical and mechanical indicators, which are not inferior to the indicators of cellulose and fibrous semi-finished products obtained from other types of raw materials (cotton, wood, flax, synthetic fibers), and in some parameters even exceed them.

Given the unique properties of industrial hemp, namely the accumulation of a huge biological mass and the ability to clean up contaminated areas, hemp can be a unique alternative to replace imported raw materials and create its own raw material base for pulp and paper and light industry enterprises. Considering the unique properties of technical hemp and the results of the conducted research, it is possible to assert the possibility of using hemp products in various sectors of the economy: this includes the textile industry, pulp and paper industry, and the production of various types of composite materials. In addition, high physical and mechanical indicators (density, resistance to crushing and tearing) and sanitary and hygienic properties of hemp fibers confirm the possibility of using hemp raw materials not only for sewing clothes and underwear, but also for the manufacture of military clothing and protective body armor.

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AIMS AND SCOPES

“Vlakna a Textil” is a peer-reviewed scientific journal serving the fields of fibers, textile structures and fiber-based products including research, production, processing, and applications.

The birth of this journal is connected with three institutions, Research Institute for Man-Made Fibers, Svit (VÚCHV), Research Institute of Chemistry of Textiles (VÚTCH) in Žilina and Department of Fibers and Textiles at the Faculty of Chemical Technology, Slovak Technical University in Bratislava, having a joint intention to provide, utilize and deposit results obtained through the research, development and production activities dealing with the aforementioned scopes. „Vlákna a Textil“ journal has been launched as a consequence of a joing of existing magazines „Chemické vládkna“ (VÚCHV) and „Textil a chémia“ (VÚTCH). Their tradition should provide a good framework for the new journal with the main aim to create a closer link between the basic element of the product - fibre and its fabric - textile.

Since its founding in 1994, the journal introduces new concepts, innovative technologies and better understanding of textile materials (physics and chemistry of fiber forming polymers), processes (technological, chemical and finishing), garment technology and its evaluation (analysis, testing and quality control) including non-traditional applications, such as technical textiles, composites, smart textiles or garment, and nano applications among others. The journal publishes original research papers and reviews. Original papers should present a significant advance in the understanding or application of materials and/or textile structures made of them.

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