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Effect of Hairiness on Fabric Colour Characteristics
Vpliv kosmatosti tkanine na njene barvne značilnosti

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Abstract
Designing the colour appearance of textiles requires taking into account their surface properties, hairiness among others. The villi protruding on the surface not only affect the quality of textile dyeing, but also largely determine its optical properties and the colour phenomenon. The analysis of studies of optical properties shows that the influence of hairiness on the phenomenon of colour is not well understood and that the amount of hairiness at which colour changes become significant for human perception remains indefinable. In this work, we studied the change in colour characteristics depending on the change in the hairiness of woollen fabrics, comparing "yarn – raw fabric", "yarn – raised fabric", "raw fabric – raised fabric". Hairiness was estimated by the hairiness index, which was obtained from the analysis of sample microphotographs of yarn and fabric using software. The value of colour characteristics (lightness, chroma and colour difference) was measured in the CIELAB colour space (1976) using a spectrophotometer. The obtained experimental results showed that the changes in lightness and saturation of textile materials from the index of its hairiness are directly proportional. However, the value of changes is different for raw and napped fabrics, undyed and dyed samples, the initial colour hue and raw material composition also making certain adjustments. This study analysed the colour difference and established the level of variation in hairiness at which the colour mismatch between woollen fabrics becomes visually noticeable. The results of the study can be used to predict the colour and design the optical properties of fabrics for weaving and finishing.
Keywords: woollen fabrics, colour, hairiness index, colour characteristics

Izvleček
Oblikovanje barvnega videza tekstilij zahteva upoštevanje njihovih površinskih lastnosti, med katerimi je tudi kosmatost. Resice, ki štrlijo s površine, ne vplivajo samo na kakovost barvanja tekstilije, temveč v veliki meri določajo tudi njene optične lastnosti in značilnosti barve. Analiza študij optičnih lastnosti kaže, da mehanizem vpliva kosmatosti na značilnosti barve ni dobro razumljen, obseg kosmatosti, pri katerem postanejo spremembe barve pomembne za človekovo zaznavanje, pa ni nedoločljiv. V tej raziskavi so bile proučevane spremembe barvnih lastnosti zaradi spremembe kosmatosti volnenih tkanin, in sicer s primerjavo „preja – surova tkanina", „preja – kosmatena tkanina" in „surova tkanina – kosmatena tkanina". Kosmatost je bila ocenjena z indeksom kosmatosti, ki smo ga dobili z računalniško analizo mikrofotografij vzorcev preje in tkanin. Vrednost barvnih lastnosti (svetlost, kroma in barvna razlika) smo izmerili v barvnem prostoru CIELAB (1976) s pomočjo spektrofotometra. Dobljeni eksperimentalni rezultati so pokazali, da so spremembe svetlosti in nasičenosti tekstilnega materiala neposredno sorazmerne z indeksom kosmatosti tekstilije. Vrednost sprememb je različna za surove in kosmatene tkanine, nebarvane in barvane vzorce, prav tako pa dodatno vplivata začetni barvni ton in surovinska sestava. V raziskavi je bila analizirana barvna razlika in določena stopnja

variacije kosmatosti, pri kateri postane barvna neskladnost med volnenimi tkaninami vizualno opazna. Rezultate te študije lahko uporabimo za napovedovanje barve in oblikovanje optičnih lastnosti tkanin pri tkanju in plemenitenju.
Ključne besede: volnene tkanine, barva, indeks kosmatosti, značilnosti barve

1 Introduction

The regular change of popular colours and their shades is relatively typical of the modern fashion industry; therefore, compliance with the trend colour is one of the key properties of products that ensure the commercial success of the textile production. Nevertheless, reproducing the desired colour in a textile product is a complex challenge, which includes not only choosing the optimal ratio of the dye formulation, but also predicting the appearance of colour in the texture of the finished material [1]. Texture features need to be taken into account since the nature of reflection or absorption of light rays depends on the material roughness, which affects perception and consequently distorts the colour phenomenon. Based on the requirements for the colour design and appearance of the fabric, attention needs to be paid to the structure when dyeing, hairiness being of particular importance. On the one hand, the layer of villi affects the adhesion of the dye, increasing the hydrophobicity of the textile [2–6]. Since this leads to an increase in the contact angle, to ensure the quality of dyeing, hairiness is undesirable [7]. On the other hand, the hairiness layer significantly affects the appearance of the finished product, as it is the main surface property [8]. Studies [9–13] show that reflection, gloss, lustre, dichroic, birefringence, as well as the lightness of the fabric surface largely depend on the density of villi and their orientation, i.e. hairiness affects the phenomenon of colour [13]. The influence of hairiness on dyeing textiles is much more studied than on the phenomenon of colour. Although studies [14–17] show that hairiness increases the lightness of the surface, these results are not sufficient to determine the colour of fabrics, since the amount of hairiness at which the changes in lightness become significant for human perception remains uncertain. Therefore, predicting the colour of textiles, especially for fuzzy fabrics such as fleece or flannel, continues to be difficult.

It is worth noting another difficulty in designing colours for textiles that are made from dyed yarn and are nap. The difficulty lies in choosing the appropriate colour of yarn, which should correspond to the established standard for the colour of fabric after all stages of its production and processing. The aim of this research was to study the effect of hairiness on colour indices in fabrics made from undyed and dyed yarn with a different amount of hairiness.

2 Experimental

2.1 Materials

Samples of yarn and fabric from the assortment of the Vladi textile enterprise (Kharkov, Ukraine) [18], made from woollen fibres, or from a mixture of woollen and chemical fibres (cf. Table 1), were selected as the subject of the study, since hairiness is especially

Table 1: Structural characteristics of textile samples

Textile set	Fabric composition	Weave pattern	Fabric weight (g/m^2)	Fabric density (threads/dm)
S1	100% acrylic	plain	280	160
S2	90% wool, 10% acrylic	plain	250	120
S3	100% wool	3/2 twill	270	160
S4	80% merino wool, 20% polyester	2/4 matting	250	170
S5	60% wool, 40% polyester	2/2 twill	270	110
S6	40% wool, 5% merino wool, 35% acrylic, 20% polyester	2/2 twill	275	120
S7	50% wool, 30% polyester, 20% acrylic	2/3 twill	245	180
S8	70% wool, 30% polyester	2/2 twill	250	160

a woollen characteristic and can easily be increased by the raising process. All samples were divided into 8 sets, each of which included yarn, a raw fabric made from this yarn and the same fabric after the raising process (cf. Table 1). Each set was prepared in two versions, i.e. undyed and dyed. Undyed samples had a natural white shade of wool. Colour samples of sets S1, S2, S4 and S8 were dyed in light colours (lightness $L^* > 60$), the rest in dark ($L^* < 50$). All studies were conducted in standard climatic conditions [19].
All fabrics were made of yarn of the same linear density, i.e. 100 tex. The sets differed among each other by the fibrous composition of yarn, type of weaving and fabric density. Each set was prepared in two versions, i.e. undyed and dyed. The undyed samples had a natural wool shade. The dyed samples of sets S1, S2, S4 and S8 were made in light shades (lightness $L^* = 60$), and the rest in dark shades ($L^* = 50$). Figure 1 shows an example of a set of textile materials selected for the study.
The dyeing of the fibrous mixture to obtain dyed yarn was carried out according to the technological regime developed by and operating at the Vladi enterprise [18]. At each stage of the processing of textile materials (spinning, weaving and finishing), samples were taken according to the method described in the standard GOST 20566-75. The undyed and dyed samples of yarn and fabric were made on the same equipment, which made it possible to obtain the same experimental conditions.
All experiments were performed under standard climatic conditions [19]. During the study, the structure of samples was not subjected to mechanical deformation and the villi were in the same orientation they acquired during the stabilisation.

2.2 Hairiness measurement

To measure the hairiness of yarn and fabrics, the optical method was used, the essence of which is to determine the amount of hair from sample micrographs [20]. However, the use of this method in the textile industry to assess the indicators of material hairiness has some peculiarities due to the difference in the structure of yarn and fabric. The index of yarn hairiness is thus determined by the total length of fibres protruding on both sides of the body of the yarn [21], and for the fabric, hairiness is determined by the total length of fibres protruding above the fold of one side of the fabric [16]. The indicators obtained in this way do not allow for a comparative analysis of the hairiness of textile materials, which is planned in this work. Therefore, in this study, changes were made to the experimental procedure in the stage of sample preparation. The yarn for the research was previously reeled up on plates of 5 cm × 5 cm in increments equal to the diameter of yarn to obtain a solid covering that simulates the surface of the fabric. The hairiness of both yarns and fabrics was determined at the fold, the contour of which was analysed using a software application [21]. When measuring hairiness, a layer of surface (tangled) pile was taken into account (cf. Figure 2), the boundaries of which were set by the operator based on the definition of

a)

b)

Figure 1: Example of set of samples for research (yarn, raw fabric and raised fabric) in two versions: a) undyed and b) dyed

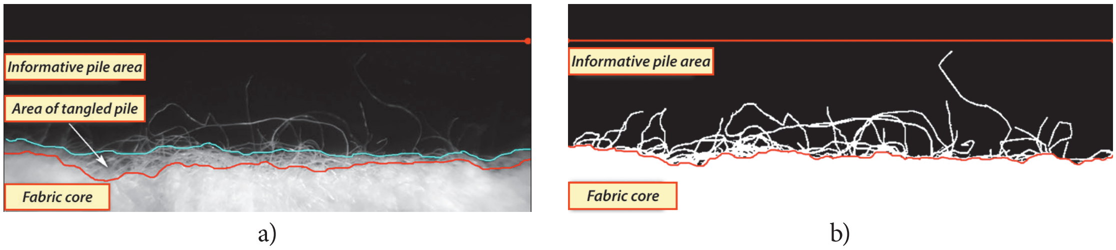


Figure 2: Image of fabric fold with processing zones: a) actual image of fold, b) image in binary format for analysis

the pile layer [8, 22]. The hairiness of the fabric was determined at the fold, which was formed along the warp and weft threads, and along the diagonal. This allowed us to level the influence of the weaving pattern and increase the objectivity of the research results. The amount of pile in the experiment was estimated by the hairiness index H_{tm} of the textile material, which shows the total length of fibres of the yarn (fabric) at the fold of a 1-cm long textile sample. When determining the hairiness of a fabric, the total number of experiments was calculated in a preliminary experiment with a 95% probability used for the textile industry [23]. Ten samples were made from one fabric. For each sample, three experiments were repeated. Taking into account that eight sets of textile materials were examined in two versions (undyed and dyed), the total number of experiments (separately for raw and raised fabrics) was 10 × 3 × 8 × 2 = 480. As a result, the reliability of the obtained results was ensured.

2.3 Colour measurement

The spectral characteristics of yarn and fabric samples were obtained using a system for measuring, evaluating and reproducing colour, consisting of a Spectra Scan 5100 spectrophotometer (Premier Colerscan) and applied programs, which allow solving problems in industrial coloristic applications [24]. The general principles for measuring fabric colour are in accordance with ISO 105-J01: 1997 - Textiles - Tests for colour fastness - Part J01: General principles for measurement of surface colour. This is a current standard version, which was last revised and confirmed in 2018.

The measurement of the colour characteristics of samples and their entry into the software database were conducted under the conditions that ensure the measurement reproducibility of chromaticity parameters. The colour parameters of samples were repeatedly measured using the maximum available viewing area of the spectrophotometer used, i.e. a large aperture (30 mm LAV aperture). The parameters of samples were measured on a backing material similar to a white standard calibration plate (titanium dioxide) used to calibrate the device. The backing material was the same for all samples during the measurement.

To obtain the required accuracy of colour characteristic measurements, each elementary spot sample was positioned on the measuring device, followed by rotation by 10° before carrying out the next measurement. After determining the required number of measurements (measurements with removing the sample from the device with an error not exceeding 0.15 units of chromaticity error ΔE), four control cycles of colour parameter measurements were performed in order to confirm that the averaged result for each of the four cycles was included in the permissible error ΔE = 0.15 units.

In this work, the spectral characteristics of samples were evaluated under standard illumination D65/10, the values of the colour coordinates for which are shown in Table 2.

Table 2: Values of colour coordinates under illumination D65/10

Light source	A	B	C	D_{65}
X_0	109.83	99.07	98.07	95.02
Y_0	100.00	100.00	100.00	100.00
Z_0	35.55	85.22	118.22	108.81

Colour differences were calculated using the CIE L* a* b* (1976) system. Since the essence of the study of colour characteristics was to determine their change depending on the change in the hairiness of textile samples in the process of technological processing, the colour indices of the textile material with the least hairiness were taken as a standard. The following indicators were used to analyse colour characteristics: lightness L*, saturation C* and colour difference dE*. The change in the colour characteristics of samples relative to the reference sample from the corresponding set was analysed by the difference in lightness DL*, difference in saturation DC*, differences in the coordinates Da*, Db*, and the colour difference dE*.

3 Results and discussion

3.1 Changes in colour characteristics of undyed textiles

The results of colour characteristics are demonstrated on the example of the set S2. Figure 3 shows micrographs of textile samples from this set, which were used to determine the hairiness index.

According to the results of the analysis of microphotographs, the hairiness of the yarn had the lowest values; therefore, yarn was chosen as a reference when comparing the colour characteristics of textile samples. The change in hairiness was reflected primarily in the lightness indicators of textile materials. Thus, the lightness of the raised fabric increased in comparison with the yarn, and the colour itself became more yellow. Figure 4 shows the average yarn-to-raised-fabric colour match results from the spectrophotometer analysis using standard test geometry.

Changes in hairiness ΔH_{tm} and colour characteristics of fabrics, presented as a percentage increase relative to yarn (yarn – raw fabric, yarn – raised fabric), and the differences between the corresponding characteristics of raw and raised fabrics are shown in Table 3. Based on the results shown in Table 3, the graphical dependencies of the difference in lightness and colour saturation of undyed textile samples on the changes in their hairiness index are presented in Figure 5.

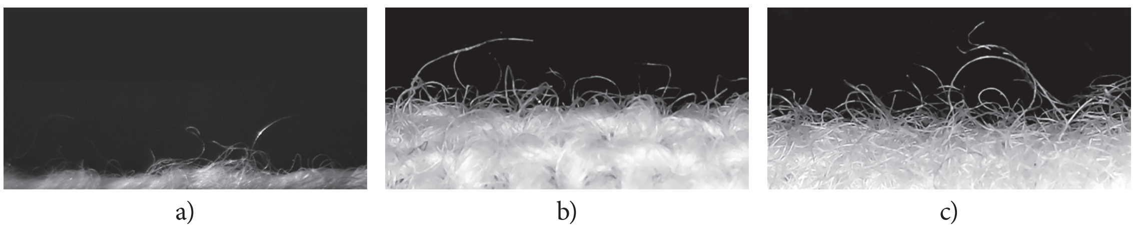


Figure 3: Layer of surface pile on: a) fold of yarn, b) raw fabric, and c) raised fabric

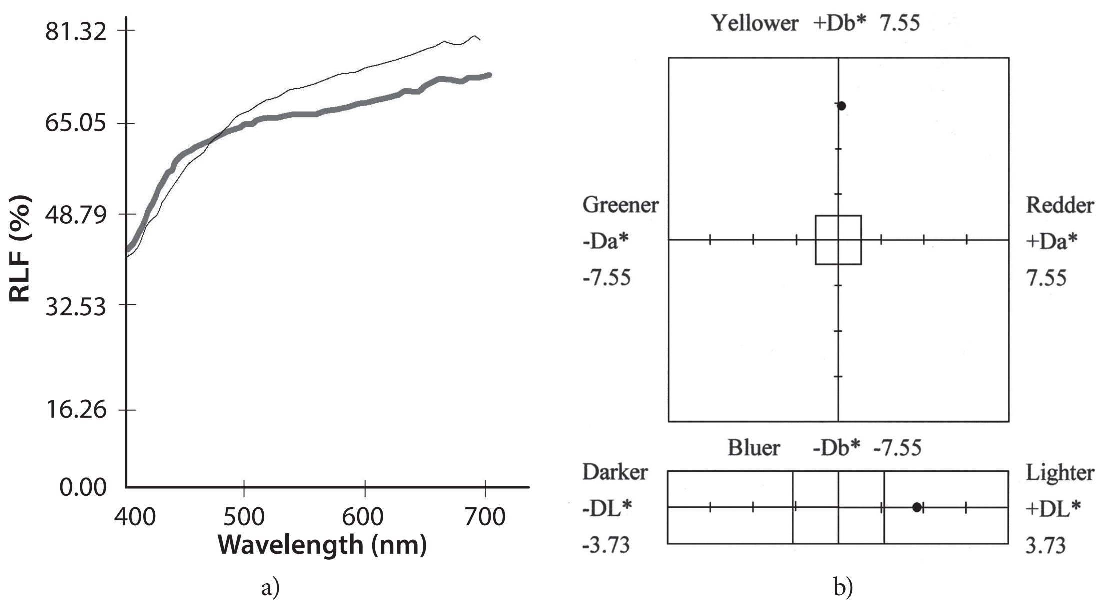
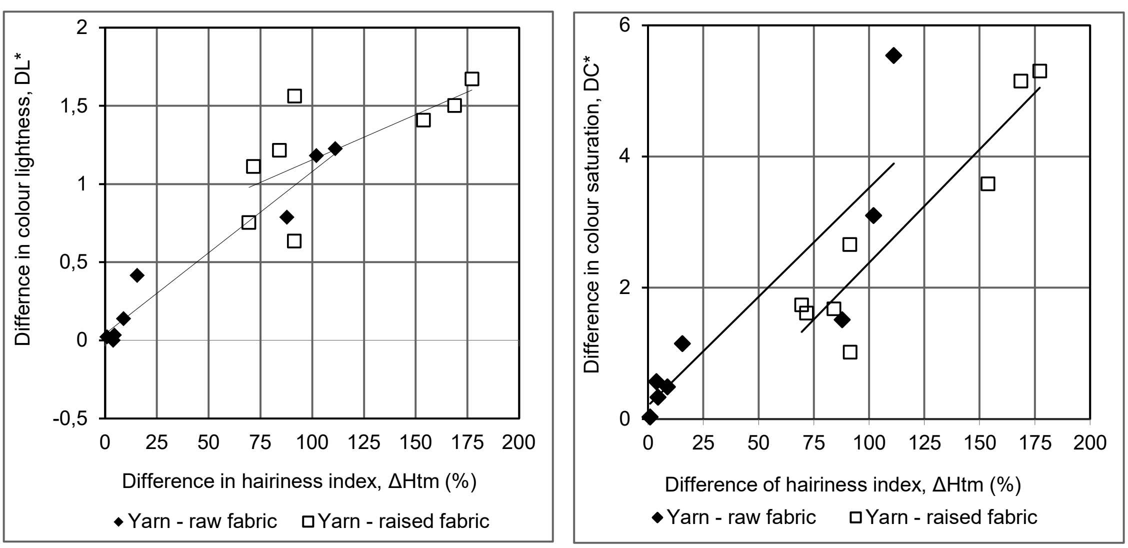


Figure 4: Colour matching of: a) undyed yarn and b) raised fabric from set S2

Table 3: Results of comparison of colour characteristics of undyed textile samples

Yarn – raw fabric								
Textile set	S1	S2	S3	S4	S5	S6	S7	S8
ΔH_{tm} (%)	15.53	102.06	87.82	111.22	4.47	0.91	8.82	3.85
DL*	0.42	1.18	0.79	1.23	0.03	0.02	0.14	0.00
Da*	−0.02	0.55	0.67	0.12	0.03	0.00	0.1	0.06
Db*	1.14	3.01	1.5	5.54	0.35	0.03	0.47	0.56
DC*	1.15	3.10	1.51	5.54	0.33	0.03	0.49	0.57
dE*	1.21	3.28	1.82	5.68	0.35	0.04	0.5	0.57
Yarn – raised fabric								
Textile set	S1	S2	S3	S4	S5	S6	S7	S8
ΔH_{tm} (%)	91.3	168.72	153.78	177.21	84.15	71.69	69.49	91.45
DL*	0.63	1.50	1.41	1.67	1.22	1.11	0.75	1.56
Da*	−0.22	−0.15	0.32	0.34	0.40	−0.25	−0.38	−0.13
Db*	2.62	5.14	3.41	5.3	1.64	1.43	1.99	1.53
DC*	2.66	5.15	3.59	5.31	1.68	1.61	1.74	1.02
dE*	2.71	5.36	3.71	5.57	2.08	1.83	2.16	2.19
Raw fabric – raised fabric								
Textile set	S1	S2	S3	S4	S5	S6	S7	S8
ΔH_{tm} (%)	65.59	89.01	84.87	83.04	70.7	71.09	65.74	75.56
DL*	0.42	1.18	1.67	1.52	1.21	1.36	1.00	0.84
Da*	−0.22	−0.13	−0.03	−0.12	−0.20	−0.08	−0.19	−0.13
Db*	1.17	3.12	2.99	2.85	1.66	1.35	1.22	1.91
DC*	1.15	3.10	2.95	2.75	1.44	1.14	1.46	1.91
dE*	1.26	3.34	3.42	3.23	2.06	1.91	1.59	2.09



a) b)

Figure 5: Change of colour characteristics for undyed samples

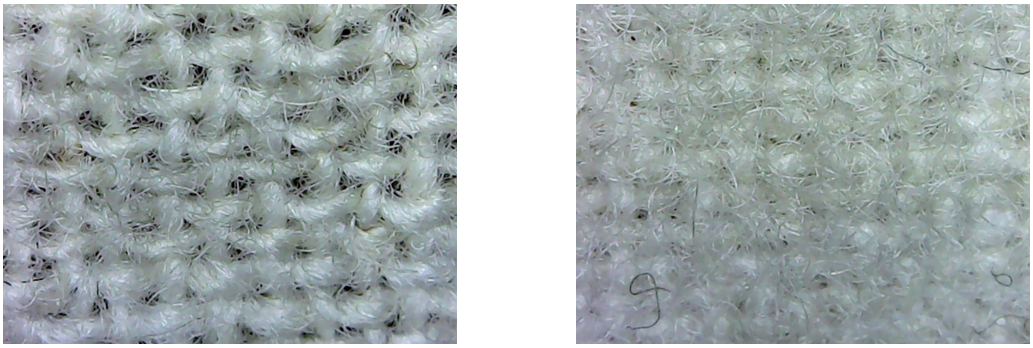
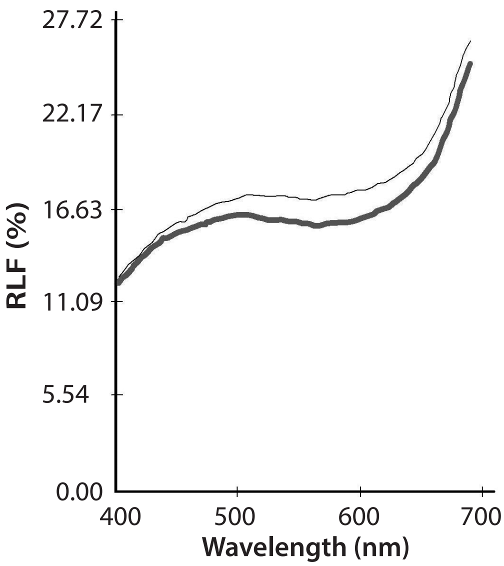


Figure 6: Surfaces of fabric samples from set S2: raw fabric and raised fabric

The analysis of graphic data showed that with an increase in the hairiness of textile materials, their colour characteristics (lightness and colour saturation) increased in direct proportion. The degree of this increase was manifested to a greater extent for the hairiness of the fabrics, since a thick layer of the surface pile covered uneven relief and pores formed by threads (cf. Figure 6). With a further increase in hairiness, the changes in the lightness of fuzzy fabrics reduced, which was confirmed by a decrease in the slope of the graph "yarn – raised fabric". Obviously, this moment came after the villi filled the space between the threads in the weave pattern and completely covered the body of the fabric (cf. Figure 6), forming a layer of solid thick pile, which is typical of fabrics after the raising [16].
The results presented in Table 3 show that hairiness increased the most for the fabric sample sets S2–S4 made from wool with a low proportion of chemical fibres. For these samples, the lightness of the L* colour also increased significantly. For the textiles made with the addition of acrylic fibres, the change in hairiness was less pronounced, and for these samples, the lightness DL* was correspondingly lower.
The analysis of the colour of undyed samples by the change in coordinates a* and b* (deviations towards green-purple or blue-yellow) showed that the colour of some raw fabrics and all raised fabrics with greater hairiness became less red (or greener) (negative Da*). As for the increase in Db*, according to the data obtained, with an increase in the hairiness index, their colour changed towards an increase in yellowness, i.e. the natural shade of woollen fibres from which the yarn was made. This suggests that with an increase in the hairiness of textiles, its natural subtone becomes more noticeable on the surface, which may be the subject of further scientific research.



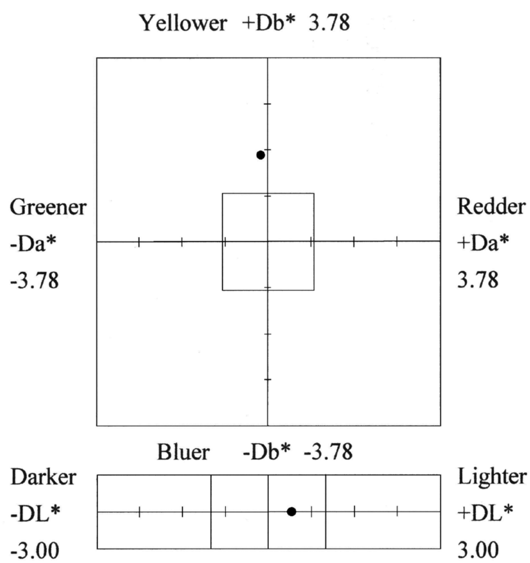


Figure 7: Colour matching of: a) dyed yarn and b) raised fabric from set S3

3.2 Changes in colour characteristics of dyed textiles

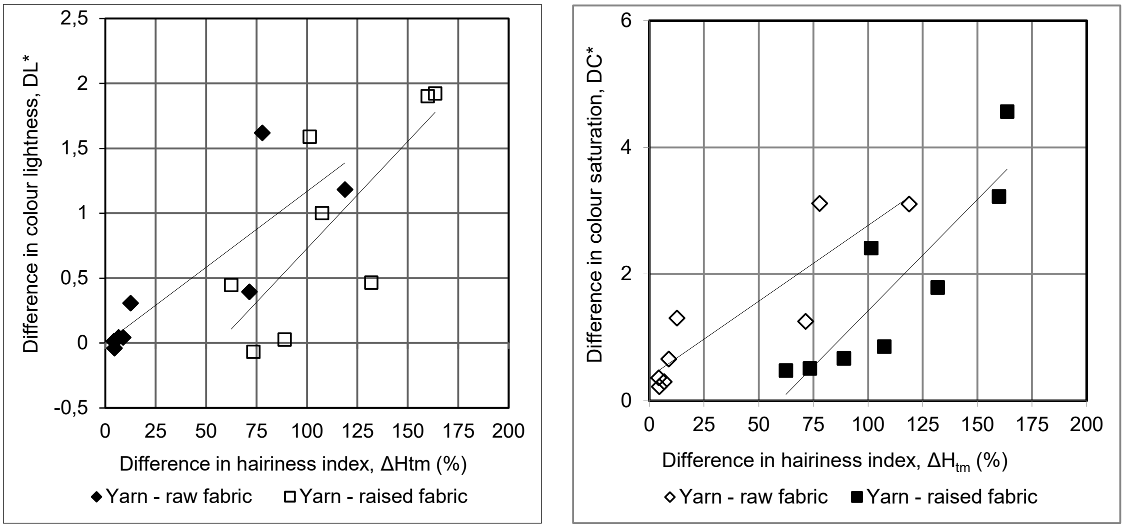
Figure 7 shows the average yarn – raised fabric colour match results from the dyed sample set S3, as measured by a spectrophotometer with standard test geometry.

The changes in hairiness ΔH_{tm} and colour characteristics for dyed textile samples are shown in Table 4. According to the results presented in Table 4, the graphical dependencies of the changes in lightness and colour saturation of dyed fabrics on the changes in their hairiness index were also plotted (cf. Figure 8).

The analysis of graphic data showed that the changes in the colour characteristics of undyed and dyed textile samples from their hairiness index had similar regularity: with an increase in the hairiness index, the values of colour characteristics increased proportionally. However, a certain correction in colour matching was made by the initial value of the lightness of samples, which differed significantly in initial conditions for dyed and undyed textile materials. Therefore, with almost the same increase in the hairiness index for undyed fabrics (cf. Figure 5), the level of change in colour characteristics increased with an increase in hairiness, and for dyed fabrics (cf. Figure 8), the level of lightness and saturation changes with an increase in hairiness did not practically change ("yarn – raised fabric" graphics). It should be assumed that the presence of dark tones in sets of fabrics, which are known to absorb light more than reflect, plays a significant role in the value of lightness of dyed fabrics. The increase in hairiness was reflected to a lesser extent in the level of their colour characteristics. Hence, a study of colour characteristics of dyed fabrics should be performed within groups assembled by colour tone.

Table 4: Results of comparison of colour characteristics of dyed textile samples

Yarn – raw fabric								
Textile set	S1	S2	S3	S4	S5	S6	S7	S8
ΔH_{tm} (%)	12.54	118.8	71.49	77.81	6.69	4.59	8.8	4.27
DL*	0.31	1.18	0.39	1.62	0.04	−0.04	0.04	0.01
Da*	−0.12	0.23	−0.25	0.21	0.39	0.34	0.73	0.60
Db*	1.30	3.1	0.35	3.10	0.3	0.22	0.65	0.35
DC*	1.30	3.10	1.25	3.11	0.3	0.22	0.65	0.36
dE*	1.34	3.32	0.58	3.51	0.49	0.40	0.98	0.7
Yarn – raised fabric								
Textile set	S1	S2	S3	S4	S5	S6	S7	S8
ΔH_{tm} (%)	101.35	159.83	131.82	163.58	62.47	73.39	107.39	88.89
DL*	1.59	1.90	0.47	1.92	0.45	−0.07	1.00	0.03
Da*	−0.1	−0.18	−0.03	−0.34	0.61	0.49	1.2	0.74
Db*	1.17	3.31	1.78	4.45	0.46	0.42	0.57	0.47
DC*	2.41	3.22	1.79	4.56	0.48	0.51	0.85	0.67
dE*	1.97	3.82	1.84	4.86	0.89	0.65	1.66	0.88
Raw fabric – raised fabric								
Textile set	S1	S2	S3	S4	S5	S6	S7	S8
ΔH_{tm} (%)	61.14	82.15	83.37	78.76	50.39	62.46	80.91	65.79
DL*	0.75	1.55	0.43	1.69	0.67	−0.05	0.1	1.34
Da*	0.08	−0.20	−0.14	0.02	0.83	−0.34	2.11	0.1
Db*	1.73	2.32	1.18	2.64	0.44	0.65	0.57	1.63
DC*	1.11	2.64	1.2	2.59	0.33	0.52	2.04	2.00
dE*	1.41	2.74	1.33	2.74	0.88	1.54	2.82	1.72



a) b)

Figure 8: Change of colour characteristics for dyed samples

For dyed textile samples, the difference Da* had both positive and negative values, which also indicates a redistribution of red and green colours, and that the level depends on the initial value of the colour tone. Positive values of Db* indicate that with an increase in the nap layer, the colour tone also deviates towards an increase in yellowness, i.e. a subtone of fibres appears.

3.3 Colour difference dE*

The difference in the colour characteristics for examined textile samples with different values of hairiness was most clearly demonstrated by the dE* value presented in Tables 3 and 4. For human perception, the dE* value between 0 and 1 indicates that there is no significant difference between the compared colours, and the observer sees the same colour. The slight difference within these limits can only be determined by instrumental methods. The difference between colours with dE* > 1 can be determined by an experienced colourist. To an ordinary observer, the differences between colours become noticeable at dE* ≥ 2. If dE* > 5, the observer sees two different colours [25]. With a hairiness increase of 70% or more, the colour difference between textile materials exceeds 1 and becomes visually noticeable. A particularly significant (more than 2) colour difference was manifested for undyed samples of sets S2, S4 and could be seen with the naked eye (cf. Figure 9). As it can be seen from Figure 9, a visual comparison of two samples of undyed raw and raised fabrics of set S2, for which dE* = 3.34, showed a significant difference in colour indicators, i.e. lightness and saturation of the raised fabric were greater. The same level of colour difference was observed for the dyed sets of textiles S1, S2, S4 (light colour). For the textile samples the lightness L* of which was below 40 (dark tones), an increase in ΔH_{tm} did not cause a colour difference between them. The colour difference of the dyed textile samples with an increase in hairiness was not so noticeable for an average observer, and the deviation from a given shade occurred more often under the influence of a subtone of villi. For example, for the sets of samples S3, S5 and S6, a significant increase in hairiness did not cause significant changes in colour characteristics, while for the undyed samples of the same sets, the colour difference reached 2 or more. For the textiles of dark shades, when the reflection of light rays from a dark fuzzy surface creates the effect of gloss rather than lightness, it is advisable to supplement the study with an analysis of gloss parameters [15].

Figure 9: Fabric from set S2 before rising (top) and after rising (bottom)

4 Conclusion

1. Numerous investigations show that hairiness is an important formative factor in the optical properties of textile materials, since it affects not only the technological processes of dyeing textiles, but also the visual perception of the surface of the material and the textile product as a whole.
2. As a result of our experiment, it was found that with an increase in the hairiness of woollen fabrics, their colour characteristics (lightness and colour saturation) increase in direct proportion. However, the degree of increase in lightness and chroma for undyed and dyed samples is different, and depends on the initial colour tone of the fabrics. With almost the same increase in the hairiness index for undyed fabrics, the level of change in colour characteristics increases, while for dyed fabrics, it does not practically change. The study of the colour characteristics of dyed fabrics must be conducted within groups assembled by colour tone.
3. The degree of increase in lightness and saturation is higher for raised fabrics, since a thick layer of surface pile closes relief irregularities and pores formed by threads. However, with a certain amount of hairiness, the increase in lightness decreases and subsequently remains unchanged.
4. The analysis of the colour of tissue samples by changing the coordinate Da^* indicates a certain redistribution of constituent colours in the structure of the colour tone, which is not visually determined. Positive values of the Db^* coordinate show that with an increase in the layer of hairiness, the colour of fabrics changes in the direction of increasing yellowness (natural shade of wool fibres the yarn is made of), i.e. the natural subtone of fibres becomes more noticeable on the surface of fabrics.
5. Moreover, it was established that the colour mismatch between woollen fabrics with different degrees of hairiness becomes visually noticeable with a total colour difference of $dE^* \geq 1$, which corresponds to an increase in hairiness of 70% or more.
6. The factor of the influence of hairiness on colour effects in textile materials should be taken into account when designing fabrics from dyed yarn, when developing the colour design of fabrics and when calculating technological dyeing modes to ensure the most accurate colour matching to a given sample.

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