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USE OF ARDUINO-COMPATIBLE SYSTEMS IN DEVICES FOR DETERMINATION OF COLOR INDICATORS OF FLAX FIBER

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ABSTRACT

The paper substantiates the use for Hue, Saturation, Value color model to determine the color coordinates of flax fiber, based on it proposed a new device for determining the color indicators of flax fiber using of arduino-compatible systems, outlines the principle of its operation and design features, and tests of the developed device using reference samples of flax fiber.

KEYWORDS

Flax fiber; Algorithm; Color group; Arduino; Device.

INTRODUCTION

To determine the parameters of scutched flax fiber in Ukraine use the methods set out in State Standard 4015-2001 [1], which determines the fiber number by the sum of the scores of such indicators as handful length, tensile load, flexibility and color group. To determine the color group of flax, each of the 30 handfuls previously prepared according to the method defined by the standard should be assigned the number of the group to which it is closest in color. There are 4 color groups in total. The first group of colors corresponds to a brown, green, bast-like color of a handful of flax; the second group - yellow, yellow with shades, gray and dark gray with shades; the third is gray and dark gray; the fourth is light gray.

During the visual examination, the main analyzers are the organs of vision, ie the eyes, whose light receptors are excited by waves of light rays in the visible region of the spectrum. However, the unequal perception of the color components by the eye leads to the fact that the brightness of different parts of the visible spectrum is perceived differently. This can distort the results during the visual assessment. The perception of color depends on subjective factors: the physiological characteristics of the expert, his age, qualifications, color vision disorders, the purpose of the study. All methods developed so far to determine the color of the fiber are based on organoleptic evaluation, so they do not provide the necessary accuracy of analysis, which directly depends on the spectral sensitivity of the visual organs and the accuracy of their determination. In addition, based on the obtained values of the intensity of light reflected from the surface of the test sample, it is possible to determine both the degree of retting of the stems, and the rate of separation of the fiber.

To determine the color indicators of an object, raw material or material, its image must be somehow recorded for further analysis or analyzed immediately in real time. Existing devices use either computer technology with a webcam, scanner, camcorder, digital camera connected to it, or electronic signal processing circuits to which photosensors are connected. In the second case, the measurement results depend on the characteristics of the photosensor and lighting. If the level of illumination of the sample is insufficient, the base colors are shifted to the corresponding dark shades, if on the contrary - the base colors are shifted to light shades, and then to white. The use of photosensors, such as photodiodes, phototransistors, color and light sensors, allows them to be used in relatively small devices, which provides autonomy and mobility of the measuring system.

Thus, the actual and expedient task is to develop instrumental methods for assessing color as one of the indicators of the quality of flax fiber. The use of these methods in practice will increase the objectivity of quality assessment and reduce the time for research.

Unlike cotton, flax fibers do not have objective standards for testing or classification. Flax fibers are

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evaluated and graded within countries or individual companies, but only one test method (ISO 2370 for flax fiber fineness) is recognized on an international level. Marketing of flax fiber is generally based on subjective methods of evaluation, but strong interest has existed for developing objective standards such as those that exist for cotton [2].

To study the properties of flax fiber, gas–liquid chromatographic methods, 13C CPMAS NMR spectrometry, histochemistry, electron microscopy and UV absorption microspectrophotometry are used to assist in determining the structure and composition of these cell walls in relation to quality and utilization [3]. But Saeideh G. [4] was shown that the spectrophotometer geometry influences the color coordinates of the samples.

Color is an important factor in the evaluation of functionality of many products, but especially of textile industry ones. Color evaluation can be done visually or using specialized test instruments such as colorimeters or spectrometers, therefore a high accuracy of measurements must be achieved. Standards describe different procedures and testing techniques depending on the product type and the quality level required by the customer [5].

Color is one quality parameter that is very dependent upon retting methods, and new procedures such as enzyme-retting greatly expand the color choices. To determine color values, use the well accepted CIElab method [6]. It is generally known that scientific analysis and interpretation of natural dyeing processes is essential to demonstrate the economic feasibility of dyeing flax and other natural fibers with environmentally benign natural colorants [7].

Color measurements are made of various kinds of flax retted by dew, water or enzymes. Two sets of samples are analyzed under different conditions using different spectrophotometers and by reflectance in the visible and near infrared spectral regions. Sample set one consists of 55 samples of various flax types retted by traditional dew and water methods and various experimental enzyme retted samples. Means and standard deviations of CIELAB color values for each of the classes are displayed as spheroid plots. The enzyme retted fiber flax class forms a separate group that is substantially lighter and slightly yellower than dew retted flax [8].

Weisnerova D. and Weisner I. [9] applied computer image analysis to group together flax cultivars (Linum usitatissimum L.) according to their similarity in commercially important dry seed traits. Both the seed shape and seed-colour traits were tested on 53 cultivars from world germplasm collections. Four shape traits (Area, Perimeter, MeanChord, and MinFeret) and three color traits (L*, a*, b* calculated from original RGB color channels as CIE color space coordinates) were computer extracted from digital images of 62349 seeds with 1200 seeds per cultivar in average. Cultivar clustering was generated by two independent methods of multivariate analysis.

Epps H.H., Akin D.E., Foulk, J.A., Dodd R.B. [10] use twenty-seven samples representing variations of retted flax fibers are analyzed using a color spectrophotometer and CIELAB models. Variables included enzyme or dew retting, fiber or seed flax, enzyme and chelator concentrations, and sequential cleaning steps. In addition to differences in color with enzyme or dew retting, the variables involved in enzyme retting also contribute to differences in the lightness, redness-greenness, and yellowness-blueness of the resulting fibers. Results indicate that objective color measurements and color standards can define important fiber properties in order to tailor raw materials for specific industrial applications.

Jablonský M. et al. [11] use a method of objective fiber identification using color vectors of a microscan from stained fiber digital photography. The objective micro-colorimetric method, using RGB (red, green, blue) vectors with discriminatory analysis, reduced the number of stains to 1; requires no morphological information; and the discriminatory power (dp,) of this approach is up to 95 to 100% of correctly identified unknown samples with one color vector R or B.

Using optical arrays based on chemoresponsive colorants (dyes and nanoporous pigments) probe the chemical reactivity of analytes, rather than their physical properties. Colorimetric sensor arrays have demonstrated excellent potential for complex systems analysis in real-world applications and provide a novel method for discrimination among closely similar complex mixtures (Askim J. R. et al. [12]).

Bergfjord C. and Holst B. [13] presents a simple procedure for identifying the textile bast fibers. The procedure is based on measuring the fibrillar orientation with polarised light microscopy and detecting the presence of calcium oxalate crystals (CaC_2O_4) in association with the fibers. To demonstrate the procedure, a series of fibre samples of flax, nettle, ramie, hemp and jute were investigated. An advantage of the procedure is that only a small amount of fiber material is needed.

Hinsch E. and Robinson S. [14] use a method of testing for colorfastness to light was developed. Additionally, the colorfastness to light testing method developed using the L-2 Blue Wool Standard and QUV Accelerated Weathering Machine is a viable alternative to current standard colorfastness to light testing methods.

It should be noted that digital image colorimetry (DIC) on smartphone is regarded as a powerful, fast and low-cost analysis method to measure target analyte with color changes of digital image obtained by the built-in camera [15].

To process the results of the study, we used the methodology of comparing means using statistical analysis is illustrated with solid examples in the textile field in the work of K. F. Choi [16].

METHODS

To describe the characteristics of color in practice use different color models, which include RGB, HSL, CIELAB, HSV and others. These models represent color indicators in the form of corresponding coordinates. The RGB model has been adopted as a standard by the International Commission on Lighting. Based on it, the color coordinates of any radiation given by its spectral composition can be calculated, and the coordinates of any color in another color system, the reference colors of which are set in the RGB system, can be calculated.

The master model for almost all color models used in technical fields is CIEXYZ. The XYZ color is set as follows:

$$\begin{aligned} X &= \int_{380}^{780} I(\lambda)\bar{x}(\lambda)d\lambda \\ Y &= \int_{380}^{780} I(\lambda)\bar{y}(\lambda)d\lambda \\ Z &= \int_{380}^{780} I(\lambda)\bar{z}(\lambda)d\lambda \end{aligned} \tag{1}$$

where $I(\lambda)$ is the spectral density of any energy photometric quantity, such as radiation flux, energy brightness, etc., in absolute or relative terms.

Like the CIEXYZ space it derives from, CIELAB colorspace is a device-independent, "standard observer" model. The colors it defines are not relative to any particular device such as a computer monitor or a printer, but instead relate to the CIE standard observer which is an averaging of the results of color matching experiments under laboratory conditions. The three coordinates of CIELAB represent the lightness of the color (L^* = 0 yields black and L^* = 100 indicates diffuse white; specular white may be higher), its position between red and green (a^*, where negative values indicate green and positive values indicate red) and its position between yellow and blue (b^*, where negative values indicate blue and positive values indicate yellow).

CIECAM02 is the color appearance model. The two major parts of the model are its chromatic adaptation transform, CIECAT02, and its equations for calculating mathematical correlates for the six technically defined dimensions of color appearance: brightness (luminance), lightness, colorfulness, chroma, saturation, and hue.

To describe the color coordinates of the flax fiber, the HSB model was chosen compatible with the standards of organoleptic evaluation of fiber quality. HSB (hue, saturation, brightness) are alternative representations of the RGB color model, designed in the 1970s by computer graphics.

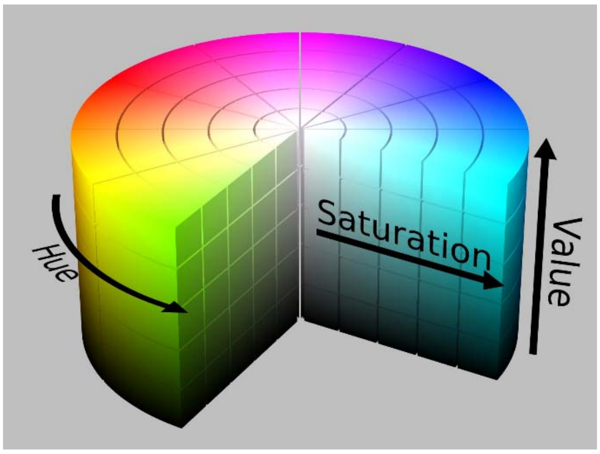

Figure 1. Color distribution scheme in the HSV model (for Hue, Saturation, Value; also known as HSB, for Hue, Saturation, Brightness).

This color model is the easiest to understand. In addition, it is equally used for both additive and subtractive colors. It agrees well with human perception, because the color tone is equivalent to the wavelength of light, the saturation is the intensity of the wave, and the brightness is the amount of light. The HSB model diagram is shown in fig. 1. It can be used for both additive and substrate colors. This model is named after the first letters of English words: Hue - color tone, Saturation - saturation, Brightness - brightness. It agrees well with human perception, because the color tone is equivalent to the wavelength of light, Saturation - the intensity of the wave, and Brightness - the amount of light.

The value of the Hue is expressed in the angle of rotation of the radius vector *N*. Red corresponds to 0°, yellow - 60°, green - 120°, blue - 180°, blue - 240°, purple - 300°. The Saturation value is described as the length of the radius vector. The less saturated the color, the closer to the center of the circle is the coordinate. The center of the circle corresponds to black. Saturation is measured as a percentage: the minimum Saturation is 0, the maximum is 100.

The HSB system is abstract. There is no direct procedure for measuring Hue and Saturation. According to any method, the red, blue and green components are first measured, which are then converted into HSB coordinates. The equation is used to convert from RGB to HSV

$$\begin{gathered} V = \max(R, G, B);\; v = \min(R, G, B); \\ S = \begin{cases} 0;\, if\ V = 0 \\ (V - v)/V \end{cases}; \\ C_r = \frac{(V - R)}{(V - v)};\; C_g = \frac{(V - G)}{(V - v)};\; C_b = \frac{(V - B)}{(V - v)}; \\ H = \frac{\pi}{3} \cdot \begin{cases} C_b - C_g;\, if\ R = V \\ 2 + C_r - C_b;\, if\ G = V \\ 4 + C_g - C_r;\, if\ B = V \end{cases} \end{gathered} \tag{2}$$

where $C = (c_1, c_2, c_3)$ – the sensation of radiation given by the vector of its coordinates in the physiological color system. Signals of photoreceptors c1, c2, c3 represent radiation coordinates in the physiological color system. If we denote the spectral sensitivities of the photoreceptors of the eye with maxima in the zone of long, medium and short wavelengths of the visible range by l(λ), m(λ) and s(λ), then the radiation with the spectral composition c(λ) that excites the corresponding photoreceptors and determines the color of radiation, described by the formula

$$\begin{aligned} c_1 &= \int c(\lambda)\cdot l(\lambda)d\lambda \\ c_2 &= \int c(\lambda)\cdot m(\lambda)d\lambda \\ c_3 &= \int c(\lambda)\cdot s(\lambda)d\lambda \end{aligned} \quad (3)$$

Based on the analysis of standard methods for determining the color properties of flax fibers and device designs to determine these properties, a digital stand-alone device was created to determine the color of the test specimen, calculate color coordinates in RGB and HSB formats, and determine color uniformity and whiteness of the test material. To determine the color of flax fiber, a device DDCIFF-1 was developed (Fig. 2). The principle of operation of the developed device is based on measuring with the help of a photo sensor the intensity of the basic components of light reflected from the surface of the test material in the RGB system.

The device consists of a plastic housing 1, inside which are the electronic circuit, digital display 4, optical unit and light source. On the reverse side is the control panel 5. On top under the protective cover 3 is the measuring chamber 2.

To determine the color index, it is necessary to tightly fill the measuring chamber 2 with a uniform layer of fiber weighing 20 g and a length of at least 85 mm, following the parallel arrangement of the fibers (Fig. 3).

The normalized mass, the length of the fiber sample and the number of repeats of measurements were determined by research results. To obtain objective measurement results, it is necessary to prepare 3 fiber samples and analyze each sample on both sides and in three zones: apical, middle, basal. The final measurement result is the average value for each color coordinate. The measuring chamber with the enclosed sample is covered with a protective cover 3. Then you need to turn on the device and using the buttons on the control panel 5, select the desired mode and perform measurements. The digital display will show the color coordinates in HSB format, and if necessary, using the control panel, you can display the digital color coordinates in RGB format (Fig. 4). The scheme of the device DDCIFF-1 for measurement of indicators of color of flax fiber (DDCIFF-1) is presented in Fig. 5.

The device is implemented on arduino-compatible systems (Arduino/Genuino Nano) (Fig. 6). The device uses special RGB LEDs with fixed spectral characteristics to illuminate the surface of the test sample.

The Arduino Nano is Arduino's classic breadboard friendly designed board with the smallest dimensions. The Arduino Nano comes with pin headers that allow for an easy attachment onto a breadboard and features a Mini-B USB connector. The ATMega328 CPU runs with 16 MHz and features 32 KB of Flash Memory (of which 2 KB used by bootloader). With a length of 45 mm and a width of 18 mm the Nano is Arduino's smallest board and weighs only 7 grams. The Nano is made for breadboard use and features soldered headers for all pins, allowing to attach the board easily on any breadboard. Built-in LED Pin - 13. Digital I/O Pins - 14. Analog input pins - 8. PWM pins - 6. I/O Voltage 5V. Input voltage (nominal) 7-12V. DC Current per I/O Pin 20 mA.

Character display LCD0802A has 2 lines of 8 characters; it is possible to display a total of 16 letters, numbers or symbols. Dimensions 58mm x 32mm x 13mm. Weight: 25g. Based on SPLC78D controller with 14 pins.

The device uses 5050 RGB BIN1 LEDs. For red diode LZ-5054BIN1Red TOP LED (5050) absolute Maximum Ratings (T_a=25 °C). Power Dissipation *PD* = 80 mW. Forward Current (DC) I_F =30 mA. Peak Forward Current I_{FP} =100 mA. Operation Temperature T_{opr} = -40~ +95 °C. Storage Temperature T_{stg} = -40 ~ +100 °C. The electrical and thermal characteristics of the green and blue diodes are similar. Some optical characteristics are shown in Figure 7.

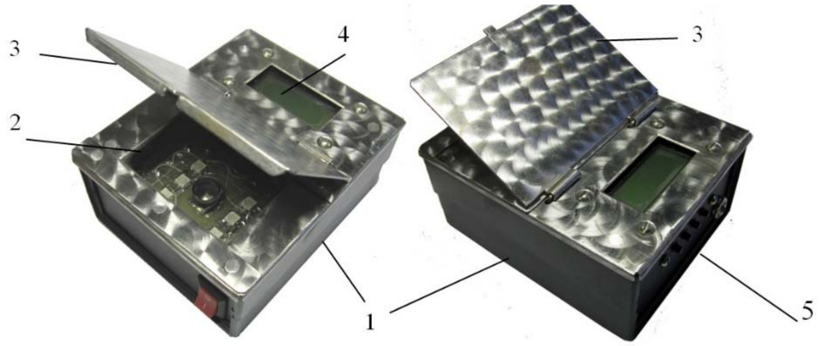

Figure 2. The device DDCIFF-1: 1 - the case; 2 - measuring chamber; 3 - protective cover; 4 - digital display; 5 - control panel.

Figure 3. Placement of the sample in the measuring chamber of the device DDCIFF-1.

Figure 4. The digital display will show the color coordinates in HSB format, and if necessary, using the control panel, you can display the digital color coordinates in RGB format.

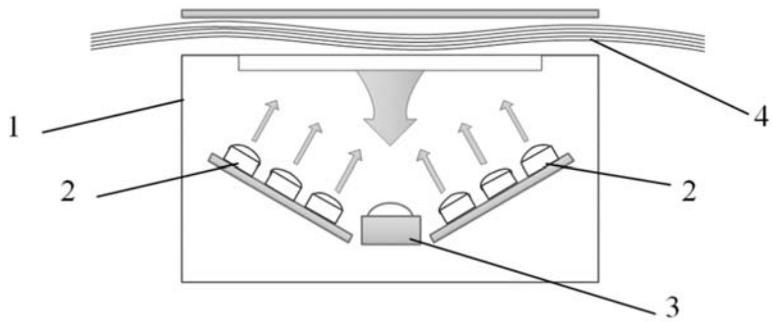

Figure 5. Scheme of the device DDCIFF-1: 1 - the case; 2 - RGB LEDs; 3 - photo sensor (photoresistor); 4 - research material.

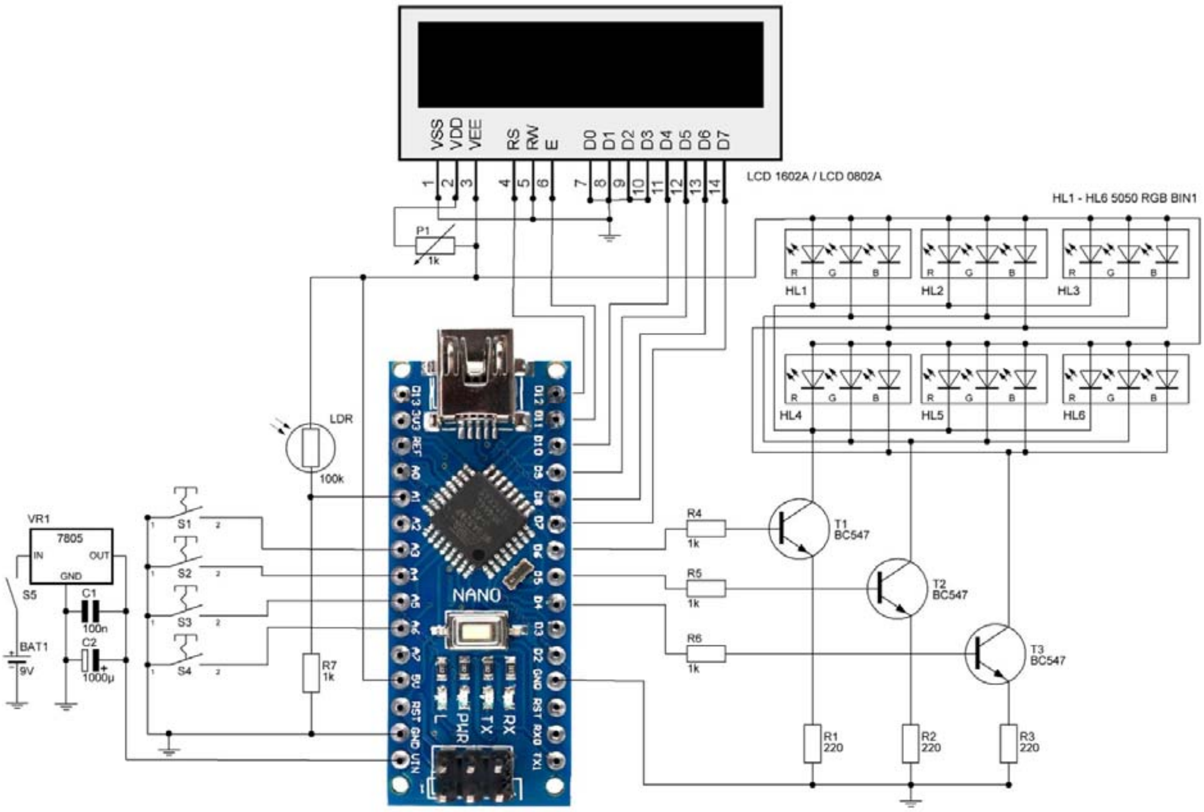

Figure 6. Electrical schematic diagram of DDCIFF-1.

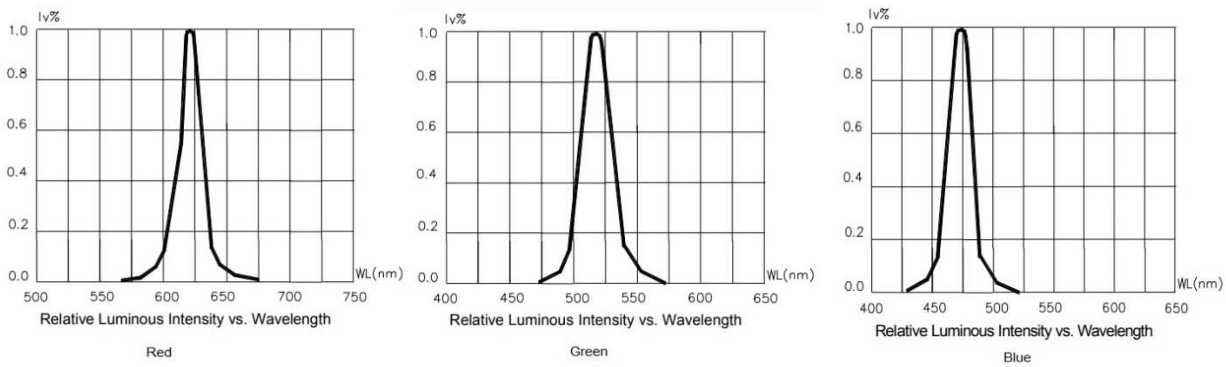

Figure 7. Optical Characteristics Curves – Relative Luminous Intensity vs. Wavelength (Ta=25°C).

The signal of the photoresistor, which sequentially measures the intensity of red, green and blue light reflected from the test material, is fed to the ADC input of the microcontroller, where it is processed according to the developed algorithm and output to a digital indicator. Buttons S1 - S4 are used to select the operating modes of the device.

Special RGB LEDs with fixed spectral characteristics are used in the device to illuminate the surface of the sample under study. Enabling one or another color to illuminate the sample and analyzing the illumination of the photosensor is performed by the microcontroller. Light fluxes of red, green and blue colors, having reflected from the surface of the sample, alternately fall on the photoresistor, which changes its resistance depending on the intensity of the light flux. For the convenience of calculations, the results of measuring the intensity of basic colors are reduced to a single-byte value with limits of 0-255, using the equations

$$R = R'\frac{255}{k};\; G = G'\frac{255}{k};\; B = B'\frac{255}{k} \tag{4}$$

where *R´* – red light intensity, *G´* – green light intensity, *B´* – blue light intensity, *R* – single-byte value of red light intensity, *G* – single-byte value of green light intensity, *B* – single-byte value of blue light intensity, k is the maximum digital value obtained after analog-digital conversion.

When working in RGB mode, the indicator displays the values of the intensities of red, green and blue colors, as well as calculated for (4) the intensity of reflected light, taking into account the relationship between the intensity of base colors according to television standards

$$Y = 0{,}299 \cdot R + 0{,}587 \cdot G + 0{,}112 \cdot B \quad (5)$$

where Y represents its luminance signal, R – red light intensity, G – green light intensity, B – blue light intensity.

A standard algorithm is used to convert the obtained color coordinates from RGB to HSB in the developed device [17]. In the HSB mode, the value of Hue H, Saturation S and Brightness B is displayed on the indicator. In accordance with DSTU 4015-2001, the color of the fiber is divided into four groups. For convenience, color groups that contain multiple colors in their description have been divided into subgroups. The result is a table. 1, on the basis of which the list of colors used in the evaluation of flax fiber is determined.

Analysis of table. 1 show that the cylinder, which represents the color model HSB, for our purpose can be divided into parts (Fig. 1). There are zones in which the color saturation varies from minimum to maximum value, ie from zone S0 to S3, as well as three zones of Brightness - respectively B0, B1, B2. A similar assessment of visual parameters is used in zonal spectroscopy methods. These methods provide the possibility of differentiation of the studied samples and automation of the processing of the obtained data, based on the spectral information obtained from the object of study.

The developed device uses three spectral zones in which the study of the studied material is carried out. These spectral bands of radiation are: red with a wavelength of λ_r = 700 nm, green with a wavelength of λ_g = 546 nm and blue with a wavelength of λ_b = 436 nm.

Zonal spectroscopy methods can be attributed to the so-called computer qualimetry, because they are characterized by high speed and efficiency of information. As a result of zonal spectroscopy of flax fiber, you can get spectral prints of the test material formed in the N-dimensional space, where N is the number of spectral zones in which the sample is studied. To describe such data, petal diagrams are used, with which you can visually compare the samples with each other or find a degree of similarity of these samples, using (6)

$$M = \sqrt{(R_v - R_r)^2 + (G_v - G_r)^2 + (B_v - B_r)^2}$$
$$P = 100 - \frac{M}{K} \cdot 100, \quad (6)$$

where M is the degree of similarity of the samples; K is the reading of the instrument that characterizes the maximum value of the difference between the samples, P – similarity of samples in %, R_r, G_r, B_r – calculated values of color coordinates, R_v, G_v, B_v - measured values of color coordinates.

To determine the sensitivity of the developed device, standards from the color catalog were used, where different shades of basic colors were selected, as well as standards of shades of gray (Fig. 8) with predefined coordinates (Table 1). Since a ten-bit analog-to-digital converter is used in the proposed device, the maximum value of voltage conversion to digital form will be equal to 1024. It is known that monochromatic colors in the RGB system are calculated for a maximum value of 255, therefore, for the convenience of further calculations and presentation of measurement results, automatic conversion is provided in the device values according to the formula

$$R_r, G_r, B_r = R_v, G_v, B_v \cdot \frac{255}{1024}, \quad (7)$$

where R_r, G_r, B_r – calculated values of color coordinates, R_v, G_v, B_v - measured values of color coordinates.

After measuring of the reference samples, a summary table of results was obtained (Table 2). Equation (7) is used to analyze the intensity of reflected light. You can make sure that the device captures different intensities of reflected light and clearly distinguishes the shades of the selected standards.

According to the description, the color of the fourth standard corresponds to gray, the color of standards 1-3 according to the description can be attributed to light gray, 5 and 6 to dark gray, and the seventh to black. The results of analysis of measurements of selected standards using the developed DDCIFF-1 device in HSB format are shown in the Table 3.

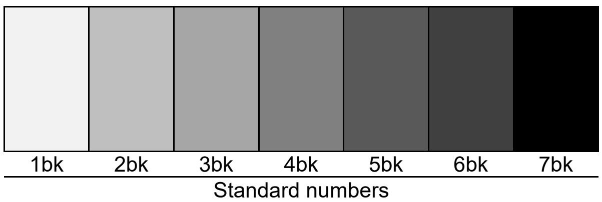

Figure 8. The palette of shades of gray of seven experimental standards for determining the parameters of the device.

Table 1. Color coordinates of selected standards.

Base color	Designation of color standards	Color coordinates of standards		
		X	*Y*	*Z*
Light gray	1bk	73,08	74,55	84,41
	2bk	68,05	69,36	80,47
Gray	3bk	49,02	49,85	58,25
	4bk	34,95	35,72	41,68
	5bk	22,51	22,81	26,78
Dark gray	6bk	8,29	8,46	10,08
	7bk	2,14	2,17	2,75

Table 2. Measurement results of selected standards.

The results of the experiment	Designation of color standards						
	1bk	2bk	3bk	4bk	5bk	6bk	7bk
Average value *R*	221,6	215,5	166,6	126,5	86,4	32,6	43,3
Average value *G*	222,0	216,0	178,6	140,0	100,4	37,9	28,4
Average value *B*	217,9	207,8	163,0	118,1	73,8	6,3	0
The average square deviation, σ_R	0,49	0,50	0,49	0,50	0,49	0,49	0,65
The average square deviation, σ_G	0,59	0,59	0,60	0,59	0,60	0,60	0,59
Standard deviation, σ_B	0,65	0,70	0,65	0,56	0,69	0,70	0,02
$\pm m_R$	0,30	0,31	0,30	0,31	0,30	0,30	0,34
$\pm m_G$	0,37	0,37	0,37	0,37	0,37	0,37	0,37
$\pm m_B$	0,40	0,44	0,40	0,35	0,43	0,44	0,10
C (coefficient of variation) *R*	0,23	0,24	0,31	0,42	0,60	1,58	1,57
C (coefficient of variation) *G*	0,28	0,29	0,35	0,44	0,63	1,67	2,19
C (coefficient of variation) *B*	0,26	0,30	0,33	0,37	0,62	1,48	2,07

Table 3. Results of analysis of measurements using the developed DDCIFF-1 instrument in HSB format.

The results of the experiment	Designation of color standards						
	1bk	2bk	3bk	4bk	5bk	6bk	7bk
Average value *H*	66,5	64,8	105,3	97,0	91,7	69,7	39,6
Average value *S*	2,0	4,1	8,8	16,0	26,7	82,9	100,0
Average value *B*	87,0	84,9	71,0	55,0	39,5	16,7	15,0
σ_H	10,05	9,31	2,05	1,61	1,79	1,10	1,11
σ_S	0,63	0,54	0,40	0,00	1,10	1,14	0,00
σ_B	0,00	0,30	0,00	0,00	0,50	0,00	0,46
$\pm m_H$	6,23	5,77	1,27	1,00	1,11	0,68	0,69
$\pm m_S$	0,39	0,33	0,25	0,00	0,68	0,70	0,00
$\pm m_B$	0,00	0,19	0,00	0,00	0,31	0,00	0,28

From the obtained results (Table 3), it is possible to preliminarily determine the limits corresponding to the brightness zones B_0, B_1, B_2, which include the numerical ranges describing black and dark gray color, when B_0 = 0-50, gray color - B_1 = 51 -70 and light gray – B_2 = 71-100.

In order to determine the sensitivity of the device to colors, 3 groups of standards with 7 shades of the base color in each group were selected. For convenience, they were labeled R_1–R_7, G_1–G_7, B_1–B_7, respectively. As a result of research with color standards, the average values of the color coordinates in the *RGB* format and the *HSB* format were determined, which made it possible to place the standards in the *SB*-space without taking into account the H coordinate, which is responsible for the color.

The point diagram (Fig. 10) shows how the standards were located, taking into account the brightness and color saturation. If this space is conditionally divided into four parts, then you can imagine the color and describe it. For example, if we take light standards R_1, G_1, B_1, and then they are in the upper left part of the SB space, and dark R_7, G_7, B_7 - in the lower right part. Based on the obtained data, the intensity of light reflected from the surface of the standards was calculated.

The summary results of the calculations are graphically displayed in Fig. 11. Analysis of Fig. 11 shows that in cases where it is not necessary to take into account the color components of the sample, the degree of whiteness can be determined with the help of the developed device.

When analyzing the data, it should also be taken into account that the standards have a uniform color and glossy coating, and the investigated samples of the flax fiber are a set of parallel fibers, so the light falling on their surface will be reflected randomly. As a result, the intensity of reflected light in basic colors will be much lower compared to standards. In addition, the color of the fibers may differ along the entire length, or may be approximately the same, which will characterize the degree of heterogeneity of the sample in terms of color.

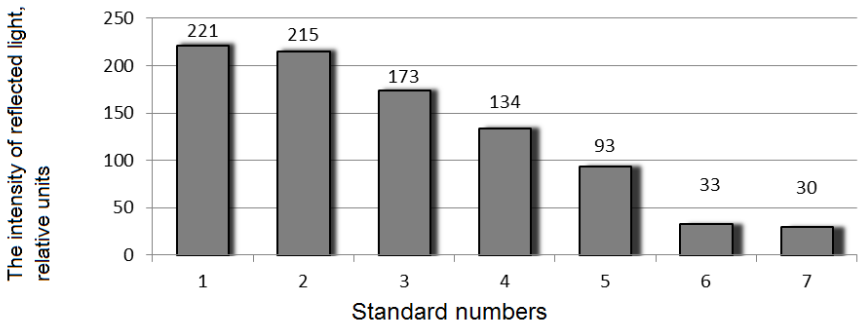

Figure 9. Shade diagram of seven experimental standards for evaluating the sensitivity of the developed device.

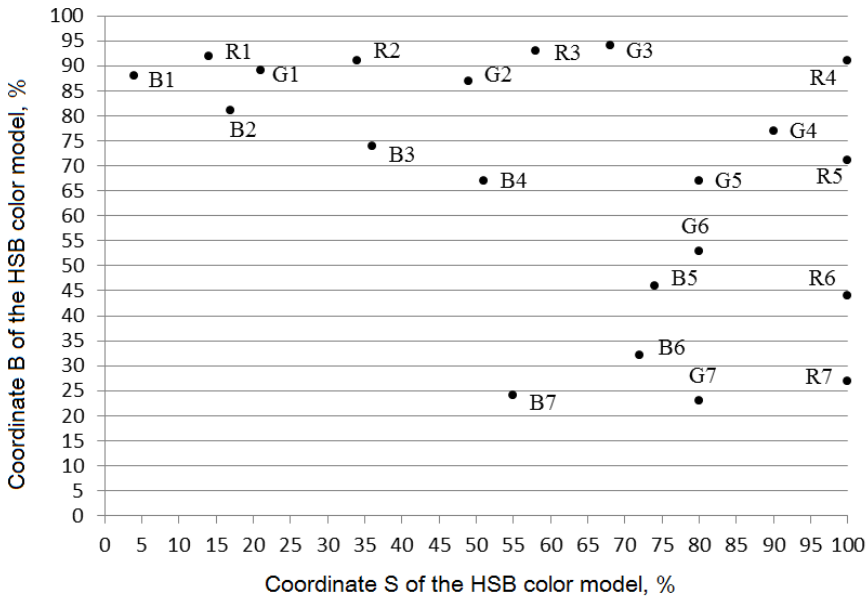

Figure 10. Distribution of selected standards in the SB-space.

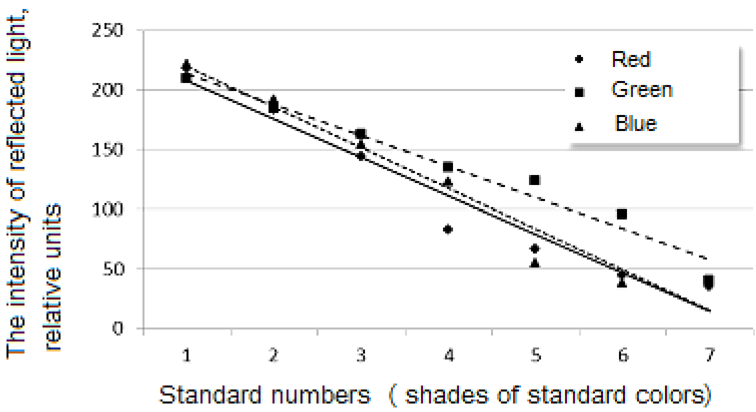

Figure 11. Dependence of the intensity of the reflected light on the brightness of the shade of the selected standard.

Thus, as a result of the conducted experiments, it was established that the developed DDCIFF-1 device is sensitive to the color, shades of color, and the degree of whiteness of the samples under study.

To study the color indicators using the developed device, it is necessary to determine the mass of the sample. For this, a homogeneous in color sample No. 6 was chosen. The length of the staple was equal to 85 mm, and the mass of the formed weights was 0.5-3.0 g, with an increase in mass by 0.5 g. The obtained result (Fig. 12) indicates that an increase in the mass of the sample to 1.5 g or more contributes to the stabilization of the obtained data according to the basic green color.

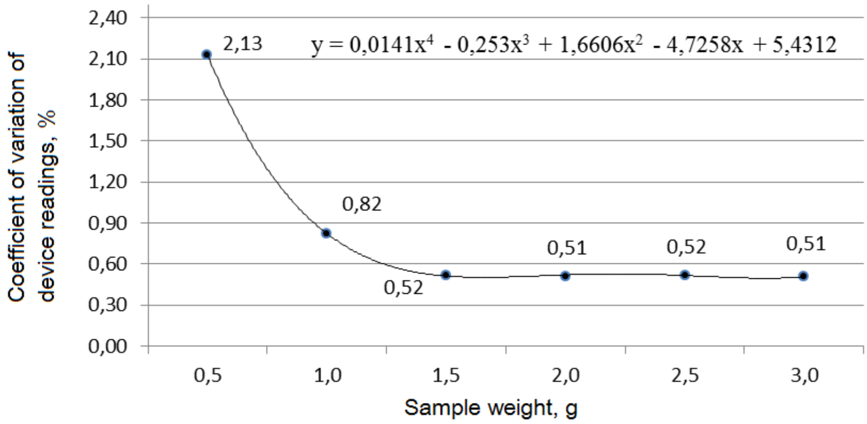

Figure 12. Dependence of the intensity of the reflected light on the brightness of the shade of the selected standard.

Table 4. Determination of the minimum number of repetitions during the measuring the color indicators of flax fiber.

The results of the experiment	Fiber sample number		
	1	2	3
Average value R	125,40	116,20	121,50
Average value G	119,56	108,50	113,31
Average value B	100,32	90,21	87,81
σ^2_R	0,49	0,87	2,16
σ^2_G	0,59	0,72	3,52
σ^2_B	0,96	1,20	2,64
Student's criterion	2,26		
Permissible relative error, %	5		
Coefficient of variation C_R, %	0,41	0,79	1,87
Coefficient of variation C_G, %	0,52	0,70	3,27
Coefficient of variation C_B, %	1,01	1,41	3,16
Number of experiments, R	1,03	1,13	1,74
Number of experiments, G	1,05	1,10	3,00
Number of experiments, B	1,20	1,40	2,91
Total number of experiments	3		

Proof of this is the low coefficient of variation, which is 0.51-0.52%.

The analysis of the research results shows that an increase in the mass of the sample from 0.5 to 1.5 g ensures a decrease in the coefficient of variation of the measurement result from 2.13% to 0.52%. A further increase in the mass of the tested sample from 1.5 to 3.0 g does not affect the coefficient of variation; it remains at the level of 0.51-0.52%.

This is explained by the fact that when the mass of the sample is less than 1.5 g, the window of the measuring chamber is incompletely filled. This leads to partial reflection of radiation from the sample and the surface of the protective cover of the camera. This circumstance causes an increase in the coefficient of variation of the measurement results and significant inaccuracies of the obtained result. A sample with a minimum mass of 1.5 g and a length of 85 mm completely and evenly fills the window of the measuring chamber. However, to obtain stable measurement results, it is recommended to prepare a sample of 2.0 g.

In order to objectively assess the fiber color indicator during work with the developed device, it is necessary to determine the number of repetitions. Using the methods of mathematical statistics and a known relative error, it is possible to calculate the number of experiments according to the existing methodology by formula (8):

$$n = \frac{t^2\sigma^2}{\varepsilon^2} + 1. \tag{8}$$

A series of studies was conducted to determine the required number of experiments *n*. For this, 3 fiber samples were prepared with a tenfold repeatability. In each repetition, color coordinates were determined in RGB format for the apical, middle, and basal parts. The color coordinates were first determined on one side, and then the sample was turned to the other side relative to the longitudinal axis of rotation and the coordinates were again determined in three places. The obtained experimental material was mathematically processed and with a given relative error of the experiment of 5%, the required number of repetitions was calculated (Table 4).

The obtained results (Table 5) show that the calculated values of the number of measurements of the intensity of each of the basic components of light are different and are in the range of 1.03-3.00, therefore, to ensure the accuracy of the measurements with an error of no more than 5%, we choose the maximum value from by rounding it to a whole number.

Thus, to determine the color coordinates using the developed DDCIFF-1 device, it is necessary to prepare at least three fiber samples weighing more than 20 g, each sample should be analyzed from both sides and in three zones: apical, middle, basal. The average value for each coordinate is taken as the measurement result.

The use of the developed device DDCIFF-1 for the purpose of analysis and quality control of raw materials fits well into the concept of qualimetry and its modern directions.

To determine the sensitivity of the developed device, standards from the color catalog were used, where different shades of base colors were selected, as well as standards of shades of gray with predefined coordinates. Since the proposed device uses a ten-bit analog-to-digital converter, the maximum value of voltage conversion to digital form will be 1024. It is known that monochromatic colors in the RGB system are designed for a maximum value of 255, so for convenience of further calculations values.

Table 5. Color groups and their division into subgroups.

Color group	Color subgroup	Color description
1	a	Brown
	b	Green
2	a	Yellow
	b	Yellow with hints
	c	Gray with hints
	d	Dark gray with hints
3	a	Gray
	b	Dark grey
4	a	Light gray

The methods outlined in DSTU 4015-2001 are used to determine the parameters of felted flax fiber. This standard applies to long staple fiber intended for the textile industry and obtained in factory and non-factory conditions. The quality of beaten flax of each number must correspond to standard samples compiled and approved according to the established procedure. Standard samples are checked by the method of instrumental evaluation of the quality of beaten flax depending on the color group. Samples for research are selected according to the method described in the standard. If the actual moisture content of the beaten flax is lower than 9%, the lot is accepted by the actual weight, taking into account the content of pith. Acceptance of beaten flax in terms of quality is carried out by organoleptic comparison of it with standard samples. For this, 5% packs are selected and unpacked from each batch of beaten flax, but not less than three packs. In case of inconsistency of the quality of the beaten flax with the standard sample and when resolving the issue of complaints, an instrumental assessment is used and the number of the flax is set in accordance with Tables 1 and 4 of DSTU 4015-2001 [1].

For this, 15 balls are taken from those selected under this point. In the case of acceptance of beaten flax unpressed, 15 balls are taken from a batch weighing up to one ton, and from a batch of larger weight - another 15 balls for each new ton started. Then 30 handfuls are selected from 15 balls - 2 from each ball. To determine the color group of beaten flax, it is necessary to assign the number of the group to which it is closest in color to each of the 30 handfuls prepared earlier (Table 1). The result of the test is taken as the average arithmetic value of the color group number from thirty determinations, calculated to the second decimal place with subsequent rounding to the first decimal place.

As mentioned above, when measuring color indicators and determining the color group of a fiber, it is necessary to determine the limit values of the S and B coordinates of the HSB color model, since the fiber reflects less light than the previously studied color standards. During the DDCIFF-1 tests, the S and B coordinate values of the HSB color model were determined because the fiber reflects less light than the color standards previously studied. During the research, standard samples (standards) of long typed fiber were analyzed, which correspond to the State Standard of Ukraine 4149: 2003 “Flax stock. Specifications”.

For our purpose, the cylinder that represents the HSB color model can be conditionally divided into parts (Fig. 13).

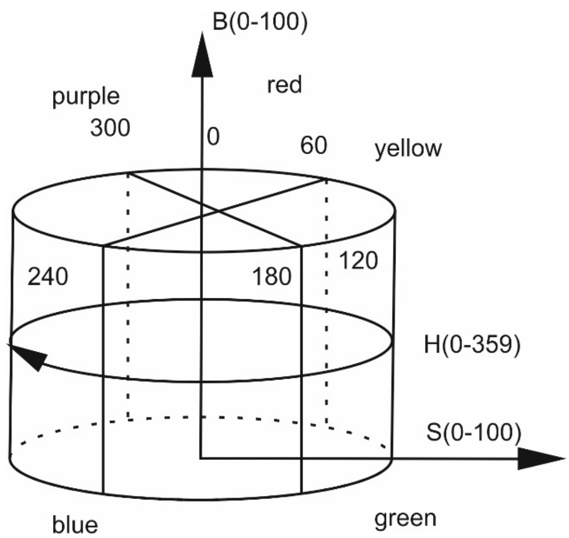

Figure 13. Division of the HSB color model into conventional parts by saturation and brightness.

There you can distinguish zones in which the color saturation varies from the minimum to the maximum value, that is, from the S_0 to S_3 zone, as well as three brightness zones - B_0, B_1, B_2, respectively.

Based on this, we get four conditional cylinders S_0, S_1, S_2, S_3, divided into three parts B_0, B_1, B_2. The color of the inner cylinder S_0 changes from black to white. Conditionally dividing it into three parts by brightness, we will get the following ranges: B_0 – color range that

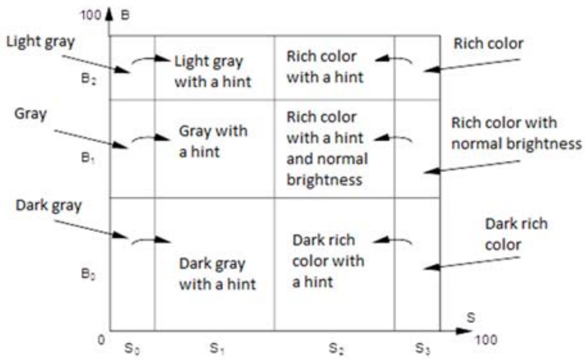

Figure 14. Distribution of shades and colors in the HSB color model.

includes black, dark and dark gray colors; B_1 – layer of colors with normal brightness; B_2 – a layer of bright colors and hints. According to these parts, the inner cylinder of the S_0 model can be divided by color into black and dark gray, gray and light gray zones.

Conventional cylindrical parts S_0, S_1, S_2, S_3 allow you to determine the saturation of the obtained color, that is, part S_0 is responsible for the color with its minimum saturation - gray color, S_1 - for gray with hints, S_2 - for color with hints, S_3 - for pure color. The H parameter is responsible for the color tone, which shows the angle relative to which the color is determined (Fig. 13).

Based on this, knowing the color coordinates of the sample under study in the HSB system, one can easily imagine which part of the cylinder these coordinates belong to and thereby objectively determine the color group.

If you take a section of a cylinder, you can fix groups of colors in certain places. Using the table 5, place the color group on the section of the color model according to DSTU 4015-2001 (Fig. 14).

A similar assessment of visual parameters is used in zonal spectroscopy methods. These methods provide the possibility of differentiating the studied samples and automating the processing of the received data, based on the spectral information obtained from the research object.

When measuring color indicators and determining the color group of a fiber, it is necessary to determine the limit values of the S and B coordinates of the HSB color model, since the fiber reflects less light than the previously studied color standards. During the research, samples of long woven fiber that correspond to GOST 2975-73 "Flax stock. Specifications" and DSTU 4149:2003 "Flax stock. Specifications".

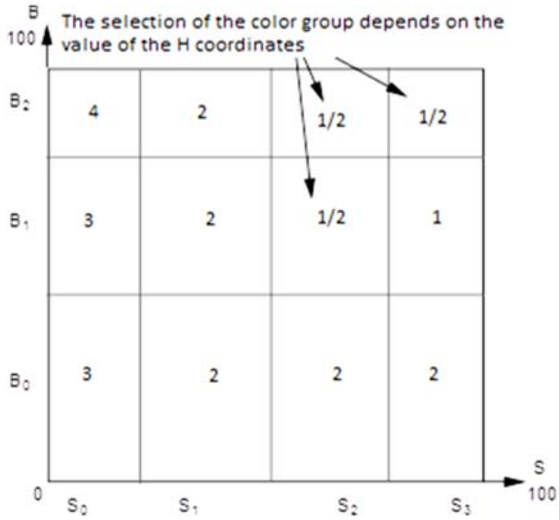

Figure 15. Distribution of color groups according to DSTU 4015-2001 in the *HSB* color model.

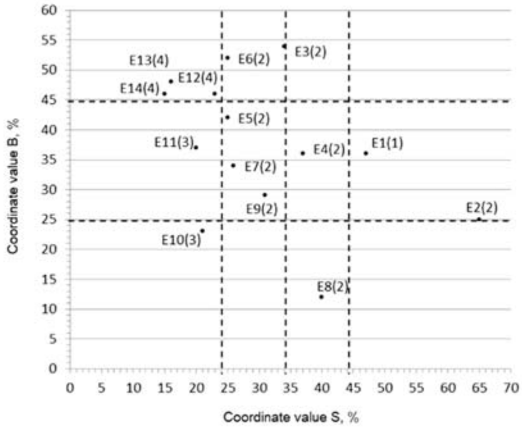

Figure 16. Distribution of standards in the SB color space (color group is indicated in parentheses).

As a result, we obtained the average values of the color coordinates and color group of those standards that are described as meeting the above standards. To identify the standards, they were designated as *E_1-E_{14}* (Table 6 and Table 7).

According to the obtained data, a scatter plot was constructed (Fig. 16), which shows the distribution of fiber samples by color groups and determined the boundaries of the distribution of the proposed color model space. The obtained limits have numerical values: S_0 = 0-24, S_1 = 24-34, S_2 = 34-44, S_3 = 44-100, B_0 = 0-25, B_1 = 25-45, B_2 = 45-100. The degree of reproducibility and precision of the proposed device was assessed according to current methods. The stability of the color measurement results was assessed using Schuhart maps.

Table 6. Description of color indicators of fiber standards.

Number of a standard	Defined color indicators						
	average values of color coordinates in RGB format			*average values of color coordinates in HSB format*			**color group**
	$\overline{X}_R$	$\overline{X}_G$	$\overline{X}_B$	$\overline{X}_H$	$\overline{X}_S$	$\overline{X}_B$	
E_1	91	76	48	39	47	36	1
E_2	63	40	22	26	65	25	2
E_3	137	116	90	33	34	54	2
E_4	91	81	57	41	37	36	2
E_5	106	96	79	44	25	42	2
E_6	133	125	100	45	25	52	2
E_7	87	82	64	47	26	34	2
E_8	30	26	18	40	40	12	2
E_9	74	69	51	47	31	29	2
E_{10}	58	58	46	60	21	23	3
E_{11}	95	91	76	47	20	37	3
E_{12}	117	109	90	41	23	46	4
E_{13}	122	122	103	60	16	48	4
E_{14}	118	117	100	57	15	46	4

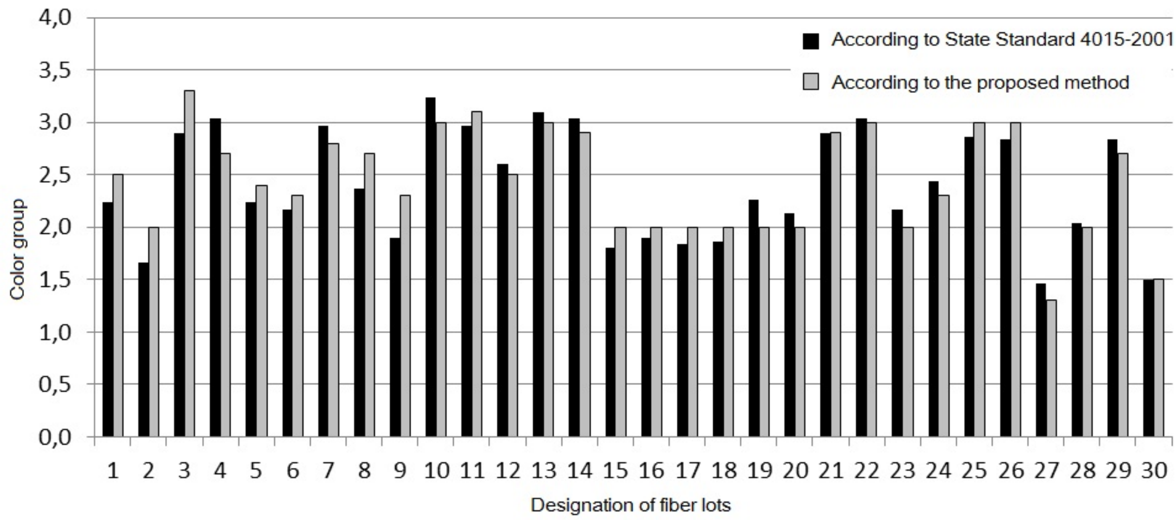

Figure 17. Color groups obtained by two methods.

When analyzing the data, it should also be borne in mind that the standards have a uniform color and glossy coating, and the studied samples of flax fiber are a set of parallel fibers, so the light falling on their surface will be reflected chaotically. As a result, the intensity of the reflected light in the base colors will be much lower compared to the standards. In addition, the color of the fibers may differ along the entire length, and may be approximately the same, which will characterize the degree of heterogeneity of the sample in color.

To determine the color coordinates using the developed device DDCIFF-1 it is necessary to prepare at least three samples of fiber weighing more than 20 g, each sample to be analyzed on both sides and in three zones: apical, middle, basal. The measurement result is the average value for each coordinate.

30 different batches were selected to determine the color heterogeneity of the fiber. From each batch took 10 samples of 20 g. Given that the average length of a handful of different batches of fibers ranges from 48.2 cm to 93.0 cm, each sample was conventionally divided into 10 parts and in each part measured by the developed device DDCIFF-1. Analyzing the obtained measurement results, we can conclude that the characteristic of color unevenness in length can be described by the coefficient of variation. The high value of the coefficient of variation indicates that the fiber was obtained from trusts, which was cured unevenly, which indicates the heterogeneity of physical and mechanical quality of the fiber.

Thus, as a result of the conducted experiments it was established that the developed device DDCIFF-1 is sensitive to color, color shades and the degree of whiteness of the studied samples. In order to verify the conformity of the boundaries defined for each color group, a comparative analysis was performed.

Table 7. Color coordinates of the selected samples, which were determined using the DDCIFF-1 device.

Batch number	**Color**	**The results of the experiment**												
		$\overline{X}_1$	$\overline{X}_2$	$\overline{X}_3$	$\overline{X}_4$	$\overline{X}_5$	$\overline{X}_6$	$\overline{X}_7$	$\overline{X}_8$	$\overline{X}_9$	$\overline{X}_{10}$	**σ**	**±m**	**Coefficient of variation, C**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	**R**	111	111	103	111	112	108	107	110	111	112	2,69	1,67	2,59
	G	114	112	101	110	112	108	109	113	114	113	3,75	2,32	3,57
	B	90	88	81	83	85	86	84	83	84	83	2,53	1,57	3,15
2	**R**	97	99	93	97	96	95	94	92	93	98	2,24	1,39	2,48
	G	88	89	84	83	87	86	86	88	84	88	1,95	1,21	2,38
	B	67	69	65	70	66	69	65	68	65	67	1,76	1,09	2,76
3	**R**	117	106	111	109	107	114	114	116	118	114	3,95	2,45	3,70
	G	117	110	113	118	117	110	110	115	117	110	3,29	2,04	3,05
	B	97	90	93	89	95	97	96	90	90	90	3,10	1,92	3,53
4	**R**	94	105	98	99	100	93	98	99	95	105	3,88	2,40	4,15
	G	99	106	97	102	99	107	101	97	98	106	3,68	2,28	3,84
	B	77	85	76	77	75	79	81	85	77	84	3,67	2,27	4,85
5	**R**	118	115	112	118	118	114	113	115	114	111	2,40	1,49	2,20
	G	112	108	107	107	112	111	106	112	109	108	2,23	1,38	2,15
	B	88	85	84	84	84	83	85	89	88	87	2,00	1,24	2,46
6	**R**	97	103	94	101	98	103	98	103	98	93	3,46	2,14	3,69
	G	101	99	94	93	97	95	97	97	99	100	2,48	1,54	2,69
	B	78	77	71	75	74	76	70	70	76	75	2,75	1,70	3,91
7	**R**	94	93	100	95	97	94	101	95	98	92	2,84	1,76	3,13
	G	94	91	100	95	97	94	98	91	94	96	2,72	1,69	3,02
	B	75	71	78	78	74	72	71	77	74	78	2,71	1,68	3,82
8	**R**	115	104	107	107	110	113	116	113	106	105	4,15	2,57	3,99
	G	116	106	107	114	110	107	108	107	105	117	4,15	2,57	3,99
	B	94	83	84	85	94	94	85	92	95	86	4,71	2,92	5,56
9	**R**	102	104	101	100	104	104	100	101	104	104	1,69	1,04	1,73
	G	100	99	95	94	98	97	97	98	97	101	2,01	1,25	2,17
	B	78	75	71	75	74	78	77	79	74	79	2,49	1,54	3,45
10	**R**	101	102	101	102	102	101	100	103	102	101	0,81	0,50	0,84
	G	101	100	100	102	99	100	99	101	100	102	1,02	0,63	1,07
	B	81	79	77	80	80	79	82	82	82	80	1,54	0,95	2,02
11	**R**	112	109	110	108	109	110	113	108	113	108	1,90	1,18	1,82
	G	117	112	112	113	114	111	114	111	111	112	1,79	1,11	1,68
	B	96	89	90	96	92	92	94	95	88	91	2,72	1,69	3,11
12	**R**	58	56	63	57	64	65	58	61	59	59	2,93	1,82	5,15
	G	59	54	60	54	60	60	54	55	58	58	2,52	1,56	4,65
	B	45	41	48	41	41	45	48	48	45	41	2,93	1,82	6,98
13	**R**	77	89	79	80	78	82	82	88	78	77	4,12	2,56	5,37
	G	89	99	88	88	89	89	88	95	98	98	4,53	2,81	5,18
	B	76	85	76	76	80	85	80	76	77	85	3,83	2,37	5,07
14	**R**	95	103	95	100	98	96	95	95	101	95	2,87	1,78	3,10
	G	95	103	97	102	103	98	100	95	95	96	3,17	1,96	3,39
	B	76	85	82	82	82	85	76	76	75	85	3,98	2,47	5,22
15	**R**	91	90	85	84	90	89	90	86	85	91	2,62	1,63	3,14
	G	84	81	73	75	75	84	81	82	75	84	4,18	2,59	5,54
	B	66	60	54	55	60	64	66	58	55	62	4,27	2,64	7,49
16	**R**	127	120	123	122	120	125	124	124	125	125	2,16	1,34	1,84
	G	128	124	108	127	125	125	109	108	107	108	8,97	5,56	8,09
	B	89	84	72	75	80	74	75	72	73	75	5,37	3,33	7,37
17	**R**	112	98	107	100	98	103	100	108	105	99	4,58	2,84	4,69
	G	95	87	87	85	88	87	84	88	90	86	2,90	1,80	3,49
	B	71	61	60	65	63	62	65	62	61	62	3,03	1,88	5,05
18	**R**	166	164	166	164	165	162	168	164	169	164	1,99	1,23	1,27
	G	142	140	138	141	140	140	142	140	140	144	1,55	0,96	1,16
	B	117	118	119	118	116	120	115	120	119	115	1,81	1,12	1,62
19	**R**	127	126	126	127	124	129	127	125	130	127	1,66	1,03	1,38
	G	117	116	114	117	119	118	116	115	119	118	1,58	0,98	1,42
	B	89	90	88	93	89	87	93	91	91	89	1,90	1,18	2,22
20	**R**	102	100	104	101	104	102	103	102	103	102	1,19	0,74	1,22
	G	89	89	90	89	90	89	87	91	90	89	1,00	0,62	1,19
	B	66	66	65	65	68	64	67	65	65	63	1,36	0,84	2,19
21	**R**	79	80	81	79	80	80	80	79	78	79	0,79	0,49	1,05
	G	77	78	77	79	76	78	77	77	78	78	0,79	0,49	1,08
	B	63	63	61	62	61	62	62	64	63	62	0,88	0,55	1,49

22	**R**	58	56	60	58	58	56	60	58	58	56	1,40	0,87	2,55
	G	59	58	60	61	61	61	58	61	58	58	1,35	0,84	2,39
	B	49	49	47	50	49	49	50	49	47	48	1,00	0,62	2,17
23	**R**	87	95	91	85	81	85	90	86	93	95	4,49	2,78	5,33
	G	85	90	87	82	78	83	87	84	89	90	3,67	2,27	4,52
	B	61	66	65	55	54	59	64	63	66	67	4,40	2,73	7,49
24	**R**	81	57	62	65	88	69	90	96	96	99	14,95	9,27	19,63
	G	79	55	60	63	84	64	91	95	94	96	15,33	9,50	20,69
	B	55	32	39	40	63	43	70	73	72	78	16,01	9,92	29,86
25	**R**	44	34	28	39	47	42	26	39	53	54	8,99	5,57	23,34
	G	47	36	29	43	52	43	26	43	53	54	9,22	5,72	22,82
	B	37	29	24	35	42	36	22	35	45	43	7,37	4,57	22,33
26	**R**	63	71	77	64	65	69	65	65	66	64	4,09	2,53	6,44
	G	64	73	77	64	66	72	69	66	66	65	4,19	2,60	6,48
	B	53	57	65	49	54	59	57	52	53	52	4,32	2,68	8,27
27	**R**	110	101	103	103	103	98	96	82	82	86	9,29	5,76	10,15
	G	91	78	77	76	77	72	71	59	67	70	7,93	4,92	11,33
	B	65	53	51	47	52	46	48	36	46	47	6,93	4,30	14,89
28	**R**	99	94	95	89	105	95	92	89	83	84	6,33	3,92	7,21
	G	82	78	82	78	96	84	82	78	70	72	6,78	4,20	8,91
	B	58	55	59	57	71	65	60	59	49	51	6,02	3,73	10,87
29	**R**	91	85	85	78	89	96	98	115	110	99	10,91	6,76	12,16
	G	93	85	85	77	88	95	96	117	110	105	11,78	7,30	13,05
	B	71	63	63	55	66	73	76	95	89	88	12,42	7,70	17,72
30	**R**	104	95	109	101	102	99	108	113	125	125	9,77	6,06	9,53
	G	84	75	89	77	78	79	90	87	99	98	8,10	5,02	9,98
	B	58	48	60	51	51	52	64	59	69	70	7,35	4,55	13,30

To do this, organoleptically determined the color group of the selected fiber samples according to the method described in the above standard, and also determined the color coordinates of each sample using the device DDCIFF-1.

Statistical processing of experimental data based on the determination of the correlation coefficient (*r = 0.98, t_p = 1.1 < t_m = 2.05*), confirmed the presence of a strong direct relationship between the results and high predictive power of the proposed method (Fig. 17).

30 different batches were selected to determine the heterogeneity of the fiber in terms of color. From each batch, 10 samples of 20 g were taken. Taking into account that the average length of a handful of different batches of fiber ranges from 48.2 cm to 93.0 cm, each sample was conditionally divided into 10 parts, and in each part, measurements were made with the developed device DDCIFF-1. Analyzing the obtained measurement results (Table 7), we can conclude that the characteristic of color unevenness along the length can be described by the coefficient of variation. A high value of the coefficient of variation indicates that the fiber was obtained from the stock, which was laid unevenly, and this indicates the heterogeneity of the physical and mechanical indicators of the quality of the fiber, as well as the unsatisfactory quality of the products made from it.

The results of research have shown that this method is suitable for determining the color characteristics of flax fiber. The proposed technique allows to automate the process of analysis of color characteristics of flax fiber and to sort flax materials by groups. The objectivity of the assessment is increased by increasing the number of measurements and the use of sensory analysis based on modern electronic equipment. Automation of the evaluation process eliminates subjectivity and at the same time accelerates the process of obtaining color characteristics of the fiber.

Design and research work and testing of devices were performed on the basis of the Institute of Bast Crops of the National Academy of Agrarian Sciences of Ukraine. In the process of approbation (testing) of the equipment it is established:

a) the proposed *HSB* (Tone-Saturation-Brightness) color model is suitable for describing the color coordinates of flax fiber. This allows you to clearly determine the color group of the test sample by the calculated coordinates;
b) the correlation between the readings of the device and the physical and mechanical quality of flax fiber is established, which allows to use the obtained mathematical dependences to predict the physical and mechanical properties of flax fiber;
c) experimentally determined the main parameters of the prototypes of the device DDCIFF-1, and developed recommendations for its practical application, in particular, the mass of the measured fiber sample should be 20 g, and measurements should be performed in triplicate in three places on both sides of the sample;
d) studies have confirmed the feasibility of using the developed device DDCIFF-1 in the process of assessing the quality of flax fibers according to the developed method, the relevance of the development is confirmed by the obtained patent of Ukraine № 83772.

CONCLUSION

The proposed color model HSB (Tone-Saturation-Brightness) is suitable for describing the color coordinates of flax fiber. This allows you to clearly determine the color group of the prototype by the obtained coordinates.

Experimental studies have confirmed the feasibility of using the device DDCIFF-1 in the process of assessing the quality of flax fibers according to the developed methods. The novelty of technical solutions proposed during the development of the device DDCIFF-1 is confirmed by the patent of Ukraine and testing in production.

To use the DDCIFF-1 device in production, it is necessary to improve its performance characteristics - to ensure the display of the fiber color group defined by the standard, rather than RGB or HSB color coordinates

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