

STUDYING AND UTILIZATION OF PLANT GENETIC RESOURCES

Original article

UDC 636.086.15; 631.527

DOI: 10.30901/2227-8834-2025-3-92-101



Variability of grain color parameters among local maize cultivars in Azerbaijan

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Background. Aleurone and pericarp pigments in maize grain are regulated by the content of anthocyanins, carotenoids, tocopherols, and their various combinations, which determines their nutraceutical and coloring properties. Searching for sources of natural dyes to replace synthetic ones becomes increasingly popular and contributes to the development of hybrid maize breeding for food and dye production.

Materials and methods. A comprehensive study of Azerbaijani germplasm was used to select 112 diverse maize accessions and evaluate them for grain color. There were 5 blocks of study, conducted in two agroclimatic zones (Zaqatala in 2013, and Baku in 2014). The grain color gamut parameters were analyzed in the CIELAB system using the luminance coordinates ($L^* = 0$ for dark, and $L^* = 100$ for bright). The a^* coordinate denoted red/green, with $+a^*$ for red, and $-a^*$ for green, and the b^* coordinate denoted yellow/blue, with $+b^*$ for yellow, and $-b^*$ for blue. The hue angle and color in the a^*b^* plane were also measured.

Results. Five clusters with a wide grain color diversity were identified during the study of local maize accessions. The color intensity variation in the studied set was within the range of 42.36–66.49, the red/green values within 5.32–15.93, the blue/yellow values within 18.07–44.40, the color values in the a^*b^* plane within 18.98–46.12, and the hue angle values within 62.50–80.14. The ranking of colors into 5 clusters showed that 96 were concentrated in the 1st cluster, with the color brightness value of 58.16, the red/green value (a^*) of 10.45, and the blue/yellow value (b^*) of 32.82. Besides, the color value in the a^*b^* plane was 34.48, and the hue in the a^*b^* plane was 72.41. Some correlations were found between grain color and morphometric characters, and grain biochemistry.

Conclusion. The Azerbaijani local maize collection exhibits a wide diversity for the inbreeding of lines with various grain colors, promising for hybrid maize breeding.

Keywords: *Zea mays* L., clustering, diversity, CIELAB color system, hybrid maize breeding

Acknowledgments: this study was produced from Halima R. Mammadova's PhD thesis on "Selection and genetic certification of promising varieties and lines of corn with economically valuable characteristics, adapted to the conditions of Azerbaijan"; the studies were conducted within the framework of the theme plan of VIR, Project No. FGEM-2023-0003 "Developing new breeding forms of maize with biotechnology methods", in the context of assessing the quality of seed source material in Russia, and Project No. FGEM-2022-0009 "Structuring and disclosing the potential of hereditary variation in the global collection of cereal and grain crops at VIR for the development of an optimized genebank and its sustainable utilization in plant breeding and crop production", in the context of reproduction and conservation of the breeding material of maize.

The authors thank the reviewers for their contribution to the peer review of this work.

For citation: Mammadova H.R., Khatefov E.B., Ekinci R. Variability of grain color parameters among local maize cultivars in Azerbaijan. *Proceedings on Applied Botany, Genetics and Breeding*. 2025;186(3):92-101. DOI: 10.30901/2227-8834-2025-3-92-101

ИЗУЧЕНИЕ И ИСПОЛЬЗОВАНИЕ ГЕНЕТИЧЕСКИХ РЕСУРСОВ РАСТЕНИЙ

Научная статья

DOI: 10.30901/2227-8834-2025-3-92-101

Изменчивость параметров цвета зерна местных сортов кукурузы Азербайджана

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Актуальность. Окраска пигментами алейрона и перикарпия зерновки кукурузы определяется содержанием в них антоцианов, каротиноидов, токоферолов и их различным сочетанием, что определяет как нутрицевтические, так и красящие свойства. Поиск источников натуральных красителей для замещения синтетических набирает популярность, способствуя развитию селекции гибридной кукурузы для производства продуктов питания и красителей.

Материалы и методы. На основе комплексного исследования в зародышевой плазме Азербайджана собрали 112 различных образцов кукурузы и оценили их по признаку цвета зерновки. Исследование проводилось в 5 блоках в 2 агроклиматических зонах (Загатала в 2013 г. и Баку в 2014 г.). Изучали параметры цветовой гаммы зерна в системе CIELAB в координате яркости (L^* = 0 обозначает темный, L^* = 100 – яркий): a^* – координата красного/зеленого ($+a^*$ обозначает красный, $-a^*$ – зеленый), b^* – координата желтого/синего ($+b^*$ обозначает желтый, $-b^*$ – синий), а также угол оттенка и цвет в плоскости a^*b^* .

Результаты. При исследовании отобранных образцов по признаку «цвет зерна» выявлено 5 кластеров, характеризующихся большим разнообразием окраски зерновки. Варьирование в выборке интенсивности цвета находится в пределах 42,36–66,49, значения красного/зеленого – 5,32–15,93, значения синего/желтого – 18,07–44,40, значения цвета в плоскости a^*b^* – 18,98–46,12, значение угла оттенка – 62,50–80,14. Ранжирование цветности по 5 кластерам показало, что 96 сосредоточены в 1-м кластере со значением яркости цвета 58,16, значением a^* (красный/зеленый) 10,45 и значением b^* (синий/желтый) 32,82. Значение цвета в плоскости a^*b^* составило 34,48, а оттенка в плоскости a^*b^* – 72,41. Выявлены некоторые корреляции между окраской зерна, морфометрическими признаками и биохимическим составом зерновки.

Заключение. Коллекция образцов местных сортов кукурузы Азербайджана обладает широким разнообразием для инбридирования линий с различной окраской зерна с целью их вовлечения в гибридную селекцию кукурузы.

Ключевые слова: *Zea mays* L., кластеризация, разнообразие, цветовая система CIELAB, гибридная селекция кукурузы

Благодарности: исследование проведено в рамках диссертационной работы Х. Р. Мамедовой «Селекционно-генетическая паспортизация перспективных по хозяйственно ценным признакам сортов и линий кукурузы, адаптированных к условиям Азербайджана»; исследования выполнены в рамках тематического плана ВИР по проекту FGEM-2023-0003 «Создание новых селекционных форм кукурузы с использованием методов биотехнологии» в части оценки качества исходного семенного материала в России, а также FGEM-2022-0009 «Структурирование и раскрытие потенциала наследственной изменчивости мировой коллекции зерновых и крупяных культур ВИР для развития оптимизированного генбанка и рационального использования в селекции и растениеводстве» в части размножения и сохранения селекционного материала кукурузы.

Авторы благодарят рецензентов за их вклад в экспертную оценку этой работы.

Для цитирования: Мамедова Х.Р., Хатефов Э.Б., Экинджи Р. Изменчивость параметров цвета зерна местных сортов кукурузы Азербайджана. *Труды по прикладной ботанике, генетике и селекции*. 2025;186(3):92-101. DOI: 10.30901/2227-8834-2025-3-92-101

Introduction

In terms of production area, the most cultivated cereal plant in the world after wheat and rice in the family of Poaceae is maize (Vartanli, Emeklier, 2007). Maize has many different areas of utilization and serves as raw material for many sectors. It is used primarily in direct human nutrition, as green grass or silage, in the feed industry, in starch or starch-based products, in oil production, and also constitutes the raw material of many products (Öktem, Toprak, 2013).

World maize production was estimated to be 1,157 million tons in the 2022/2023 marketing year, 67 million tons below the previous period. Its total domestic use reached 1,197 million tons, and exports were 181 million tons. While the average maize price on international markets is \$ 278,9/ton, the range of change within the marketing year is very wide. China has the largest share in the world's maize cultivation area (over 198 million hectares), with the cultivation area exceeding 41 million hectares. The USA, with 33 million hectares, has about 20% less acreage than China, but it has become the world's largest maize producer with its high yields. In the last five marketing years, the global average maize yield was between 5.6 and 6.0 t/ha, but in certain countries, such as the USA and Turkey, this figure can reach 11 t/ha. One of the nations that has raised its output in Asia recently is India. Due to higher yields and larger area, India's maize output grew from about 29 million tons in 2019–2020 to 31.6 in 2020–2021. According to FAO and USDA figures, global maize output increased by 3.7% and 8%, respectively, making 2021/2022 the marketing year when the 1.2 billion ton maximum was surpassed. The major contributors to this surge were the United States, Argentina, China, Ukraine, and the European Union (TEPGE yayın..., 2023).

With its rich assortment, versatility, and product efficiency, maize is a significant agricultural plant worldwide: 27% of the world's maize production is utilized for human food, while 73% is used for animal feed. In developed countries, 10% of the maize produced by industrialized nations is utilized for human consumption and industry, whereas 90% is used for feeding animals (Öz et al., 2017). One of the major cereal crops, maize has oil content of 3.5–5.5%. Even though maize (*Zea mays* spp.) is not considered an oil crop, corn oil is widely used in industry and human nutrition worldwide. For this reason, increasing the oil content has become one of the important goals of maize breeders. High-oil maize (also known as High-Oil Corn, HOC) is defined as genotypes having grain oil content of more than 6% (Dumanovic, 1995; Wang et al., 2012).

Negative correlations were found between oil content and carbohydrate content, and positive correlations with protein content in some investigations (Kahrman et al., 2017). Therefore, it is essential to look at the changes in the characteristics in question and track the relationships between the features in breeding research that aims to improve oil content.

Maize grains' high carbohydrate (73%), protein (9%) and oil (4%) contents are the primary sources of their economic and nutritional worth (Özdemir, Sade, 2019). Maize is renowned for its diverse range of grain colors. The United Nations Bio-Trade Facilitation Program reports that between 1998 and 2002 the commerce in purple maize grew by around 467%. In Germany, France, Italy, and Japan, purple maize is very commonly used as a natural colorant. Anthocyanins, the main compound of purple maize, reduce the risk of cardiovascular diseases, obesity, diabetes, cancer, and some chronic diseases (Lao et al., 2017).

L*a*b* color values are a coordinate system where each color is represented by a single point, just like in the geographic coordinate system (latitude, longitude, and altitude). Therefore, three components (color coordinate values) are required to define each color in the color space. L, a*, b* color values are the most commonly used method for measurement and color communication. L, a*, b* values are designed to be close to human eye perception (Kirca, 2020).

The aim of this research was to characterize, classify and compare maize varieties and types (genotypes) in Azerbaijani germplasm according to color parameters, to help in the evaluation of corn cultivars according to their characteristics and enable their use in plant breeding investigations.

Materials and methods

This research used the germplasm population obtained from our previous study on the maintenance of homozygous single-plant maize lines. The plant material of 112 genotypes was used in the investigation; the information on the material is given in Table 1. In 2011, the material was acquired from the Genetic Resources Institute of the Azerbaijan National Academy of Sciences.

The research was conducted in Azerbaijan: Zaqatala in 2013, and Baku in 2014, in two different agroecological environments. Planting took place on April 15, 2013, in Zaqatala, and on April 18, 2014, in Baku. Harvesting occurred on September 20, 2013, in Zaqatala, and on September 25, 2014, in Baku. Grain samples were collected from ears grown under isolated conditions. Utilizing parchment isolators, controlled pollination was carried out on homozygous plants to avoid cross-contamination from foreign pollen among various accessions. The trial was conducted in 5 blocks in an extended experimental design. The plots were arranged in 2 rows, 6 m long, with the planting density of 70 × 20 cm (each plot was 8.4 m²). Fertilization was carried out with 18 kg of pure nitrogen, 8 kg of pure phosphorus, and 5 kg of potassium per decare (1 decare (da) = 1000 m²). The climatic data for Zaqatala (2013) and Baku (2014) were favorable for the maize harvest. Baku is a city located at the Caspian Sea, with four distinct seasons. The climate is generally hot, with dry summers and mild winters. The summer months (June, July, and August) are the warmest: temperatures frequently rise beyond 30°C. The weather is usually sunny and dry. The winter months (December, January, and February) are the coldest, with mean temperatures above 0°C. The transitional seasons, spring and autumn, provide more precipitation and warmer temperatures. Zaqatala has a mild, humid climate. Summers are cool and rainy, while winters are snowy and cold. Since the region is located at the foot of the Caucasus Mountains, topographic features also affect the climate. While winters are colder and snowier at higher altitudes, the climate in lower areas is milder. In 2013, precipitation in Zaqatala was generally quite low, but sometimes there was a sudden high value. The number of rainy days may have increased, especially in spring and autumn. It can be estimated that temperatures are close to the mean (+30°C) or slightly lower in the summer months, and at normal levels (+2°C) in the winter months. However, sharp temperature drops and cold waves were observed (https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/zaqatala_azerbaijan_584596). After harvesting, 10 ears were randomly selected from each plot and the following parameters were calculated. Such indicators as the L value, a* value, b* value, chroma value, and hue angle were analyzed in the research (Beetsma, 2024). The color analysis was performed using a HunterLab Color Flex EZ

Table 1. List of maize accessions used in the research**Таблица 1.** Список образцов кукурузы, использованных в исследовании

Description of the component composition of accessions / Характеристика компонентного состава образцов	Number of accessions / Число образцов	
	pieces / единиц	%
Number of maize accessions studied	112	100
Accession's subspecies/variety assignment: <i>Zea mays</i> subsp. <i>indentata</i> :		
var. <i>vulgata</i>	112	100
var. <i>flavodulcis</i>	1	0.89
var. <i>flavorubra</i>	1	0.89
var. <i>leukodon</i>	88	78.57
var. <i>poikilodon</i>	4	3.57
var. <i>rubropaleata</i>	2	1.78
var. <i>xantodon</i>	4	3.57
var. <i>alboapicularis</i>	10	8.92
	2	1.78
Country of origin:		
Azerbaijan	93	83.03
Russia	9	8.03
CIMMYT	7	6.25
Georgia	2	1.76
Yugoslavia	1	0.89
Source:		
AHM	28	25.00
EHM	15	13.39
UGSH	69	61.60

spectrophotometer at the Physiology Laboratory of the Faculty of Agriculture, Dicle University. Maize kernels were measured for $L^*a^*b^*$ values using the Color Flex EZ calibrated with standard white and black plates. The luminance value (L^*) defines a measurement that depends on the ability of the observed object to transmit or reflect light. When comparing color values, they can be grouped as lighter or darker: L^* , the luminance coordinate ($L^* = 0$ means black, and $L^* = 100$ means white): a^* is the red/green coordinate, $+a^*$ means red, $-a^*$ means green; b^* is the yellow/blue coordinate, $+b^*$ means yellow, $-b^*$ means blue (Fig. 2). The chroma (using equation 1) and hue angle (using equation 2) values were obtained by calculating the a^* and b^* values.

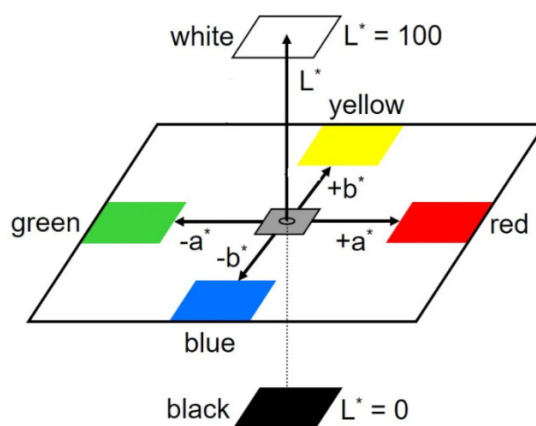
The values of chroma (using Eq1.) and hue angle (using Eq2.) were calculated according to the formulae:

$$\text{Chroma_Value} = \sqrt{a^{*2} + b^{*2}} \quad \text{Eq1.}$$

$$\text{Hue_Angle} = \tan^{-1}\left[\frac{b^*}{a^*}\right] \quad \text{Eq2.}$$

Colors are categorized and named using the hue angle, which indicates the apparent color of an item. It is defined according to the position of a color within the color space relative to the primary colors: red, green, and blue. Specifically, the hue angle of 0° corresponds to red, 90° to yellow, 180° to green, and 270° to blue (Fig. 3).

In visual perception, chroma – also known as color intensity, or clarity – denotes how pure a color is. It defines how

**Fig. 1.** CIELAB Color System in the L^* , a^* and b^* plane (from Kettler et al., 2016)**Рис. 1.** Цветовая система CIELAB в плоскости L^* , a^* , b^* (по: Kettler et al., 2016)

vivid or dull a color appears and indicates the extent to which a color deviates from gray or a neutral tone. The distance from the vertical (luminance) axis, which represents the color's saturation level, is how chroma is assessed in the color space. It provides insight into changes in color saturation without altering the direction of lightness or darkness (Fig. 1, 2).

Descriptive statistics of the data obtained as a result of investigating color trait characteristics employed such indicators as the minimum value, maximum value, and mean values, such methods as correlation analysis, principal component

analysis, and cluster analysis (UPGMA, the Unweighted Pair Group Method using Arithmetic Average), and a dendrogram using the JMP Pro 17.0.0 (Copyright © 2022, Statistical Discovery LLC) statistical software package (<https://www.jmp.com/en/home>). The extent to which the constructed dendrogram represented the similarity matrix was tested with Mantel's matrix correspondence test (Mantel, 1967). As a result of this test, the cophenetic correlation coefficient (r^* value) was obtained. The same similarity matrix was used for the principal coordinate analysis, and the distributions of the genotypes on the obtained principal coordinates were determined

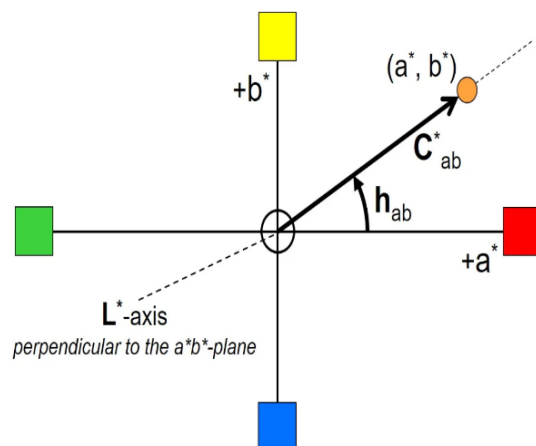


Fig. 2. Hue angle and chroma in the a^*b^* plane (from Kettler et al., 2016)

Рис. 2. Угол оттенка и цвета в плоскости a^*b^* (по: Kettler et al., 2016)

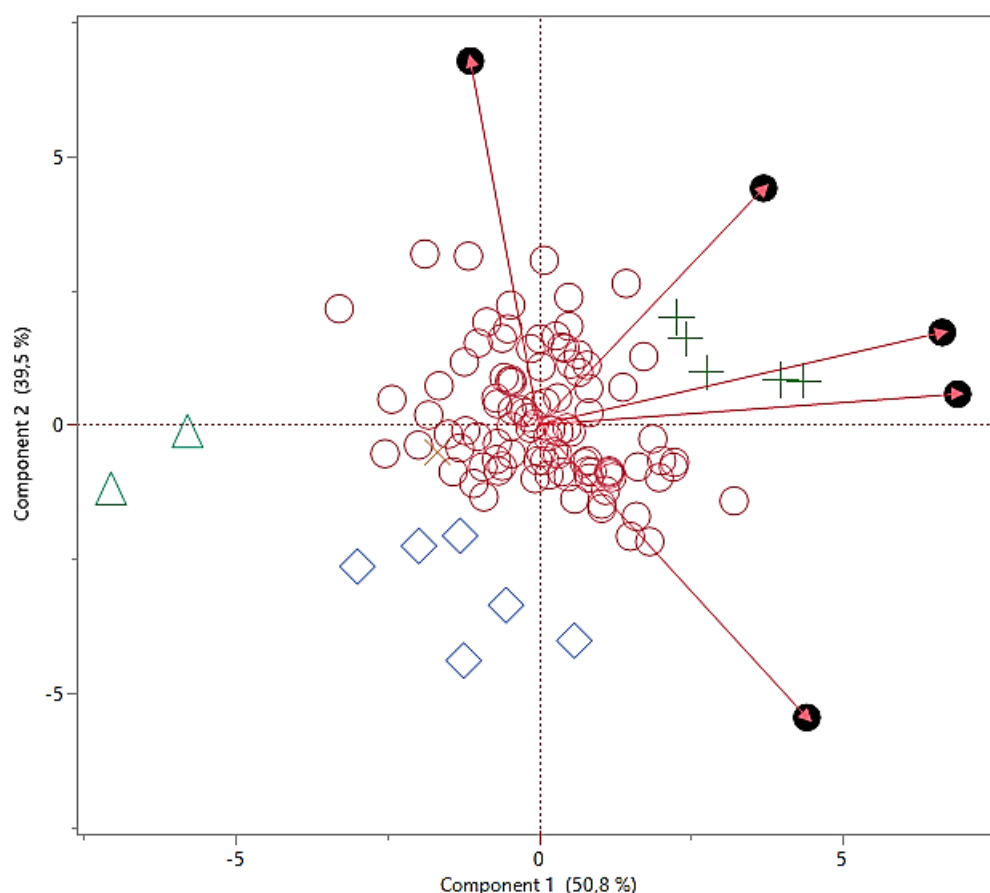


Fig. 3. Distribution obtained with PC1 and PC2

Рис. 3. Распределение, полученное с помощью PC1 и PC2

graphically. Grain nutrient content traits (oil, protein, starch, cellulose, and ash content), yield traits (grain yield, 1000-kernel weight, hectoliter weight, weight of seed per ear, and number of seeds per ear), and morphological traits (plant height, ear height, leaf length, leaf width, leaf area, and ear length) were analyzed using pairwise correlation analyses. The description of phenotypic characteristics is given according to the classification of UPOV (2009),

Results and discussion

The L* value (luminance): The L values of the maize accessions varied within the range of 42.36–66.49, and the mean value was 57.48 ± 0.28 . It was observed that the accessions showed low variation in terms of the L value of grain (Table 2). When researching the L* values in the grain of the accessions, the L* values of the AHM-481, AHM-484 and EHM-209 genotypes exceeded 65, while the L value of 95.58% (107 pcs.) of the population was equal or higher than 50. The L* values of the EHM-245, UGSH-167, UGSH-168, UGSH-175 and UGSH-291 genotypes were determined to be less than 50. As a result of the correlation analysis on the investigated genotypes, a positive correlation ($r = +0.27^{**}$) was found between the L value and the 1000-kernel weight. Statistically significant correlations were identified between the L value and other studied traits. While a negative correlation ($r = -0.28^{**}$) was observed between the L value and the a* value studied, a positive correlation was found between b* ($r = +0.33^{**}$), chroma value ($r = +0.22^{**}$), and hue angle ($r = +0.39^{**}$). A statistically insignificant correlation was noticed between the L value and nutrient content in grain, and negative correlations were found among all characters, except the starch level.

statistically significant connections were found between the a* value and the other features that were investigated, such as the hue angle ($r = -0.94^{**}$), chroma ($r = +0.46^{**}$), b* value ($r = +0.20^{*}$), and L* value ($r = -0.28$). The association between the a* value and the majority of grain nutritional content features was extremely weak and statistically insignificant, except for crude protein content ($r = +0.17$; $P = 0.07$) and crude ash content ($r = +0.18$; $P = 0.06$), which were marginally significant.

The b* value (blue/yellow): The b* values of the maize lines forming the population varied between 18.07 and 44.40, and the mean was 32.71 ± 0.21 . The b* values of the genotypes in the population showed a high variation in their characteristics (see Table 2). It was determined that the b* values of all genotypes in the population were positive, that is, in the yellow tone region. While the b* value of the UGSH-484, UGSH-357 and UGSH-22 genotypes was greater than or equal to 40, it was observed that the b* values of 97.35% (109 pcs.) of the population were less than 40. As a result of the correlation analysis performed with the genotypes forming the population, positive correlations were identified between the b* value and 1000-kernel weight ($r = +0.20^{*}$), hectoliter weight ($r = +0.18$; $P = 0.06$), and seed weight per ear ($r = +0.19^{*}$). The b* value and the other qualities that were analyzed showed statistically significant relationships (L* value, $r = +0.33^{**}$; a* value, $r = +0.20^{*}$; chroma value, $r = +0.96^{**}$). Statistically insignificant correlations were found between the b* value and grain nutrient content.

The chroma value: The chroma values of the maize lines forming the population varied within 18.98–46.12, and the mean was calculated as 34.41 ± 0.22 . The chroma value of the genotypes in the population showed a great variation in their characteristics (see Table 2). The chroma values of all geno-

Table 2. Changing values of color indicators in the studied accessions

Таблица 2. Изменение значений цветовых показателей изученных образцов

Parameters / Параметры	Chroma / Цвет				
	L value (luminance) / Значение L (яркость)	a* value (red/green) / Значение а* (красный/ зеленый)	b* value (blue/yellow) / Значение б* (синий/желтый)	Chroma value in the a*b* plane / Значение цвета в плоскости а*б*	Hue angle in the a*b* plane / Угол оттенка в плоскости а*б*
Min.	42.36	5.32	18.07	18.98	62.50
Max.	66.49	15.93	44.40	46.12	80.14
Means	57.48 ± 0.28	10.52 ± 0.20	32.71 ± 0.21	34.41 ± 0.22	72.18 ± 0.32

The a* value (red/green): The a* values of the maize lines forming the population varied between 5.32 and 15.93, and the mean was determined as 10.52 ± 0.20 . The values of the genotypes in the population showed a large variation in their characteristics (see Table 2). It was observed that the values of all genotypes in the population were positive, that is, in the red tone region. While the a* value of the UGSH-402 genotype was greater than 15, it was determined that the values of 99.12% (111 pcs.) of the population were less than 15. According to the correlation analysis performed on the genotypes of the population, the a* value was positively correlated with a number of characters, including 1000-kernel weight ($r = +0.31$), hectoliter weight ($r = +0.24^{**}$), seed weight per ear ($r = +0.23^{*}$), crude protein content ($r = +0.17$; $P = 0.07$), and crude ash content ($r = +0.18$; $P = 0.06$). Additionally,

types in the population were found to be positive. While the chroma value of the UGSH-485, AHM-87, AHM-477, UGSH-22, UGSH-276 and UGSH-357 genotypes were greater than or equal to 40, it was determined that the values of 94.69% (106 pcs.) of the population were less than 40. Positive correlations between the chroma value and 1000-kernel weight ($r = +0.27^{**}$), hectoliter weight ($r = +0.23^{*}$), and seed weight per ear ($r = +0.23^{*}$) were found as a consequence of the correlation study carried out with the genotypes comprised in the population. Statistically significant correlations were detected between the chroma value and other examined characters (L* value, $r = +0.22^{*}$; a* value, $r = +0.46^{**}$; b* value, $r = +0.96^{**}$), hue angle ($r = -0.13$; $P = 0.18$). Statistically insignificant correlations were identified between the chroma value and the content of nutrients in grain.

Hue angle: The color quality values of the maize lines forming the population varied between 62.50 and 80.14, and the mean was estimated as 72.18 ± 0.32 . The genotypes in the population did not show a great variation in the hue values (see Table 2). It was determined that the hue values of all genotypes in the population were positive. While the hue values of the UGSH-23 and UGSH-24 genotypes were greater than or equal to 80, the values of 98.23% (110 pcs.) of the population were found to be less than 80. As a result of the correlation analysis performed with the genotypes forming the population, negative correlations were detected between the hue value and 1000-kernel weight ($r = -0.24^*$), hectoliter weight ($r = -0.18^*$), and seed weight per ear ($r = -0.16$; $P = 0.09$). Statistically significant correlations were found between the hue value and other features examined (L^* value, $r = +0.39^{**}$; a^* value, $r = -0.94^{**}$). Negative correlations were observed between the hue value and crude protein ratio ($r = -0.17$; $P = 0.07$), cellulose ratio ($r = -0.16$; $P = 0.08$), and crude ash rate ($r = -0.19^*$).

Consideration of the characters revealed that there was no significant differences in the hue angle and L^* value indicators, but there were significant variations in the a^* value, b^* value, and chroma value characters.

Clustering analysis: Five clusters were arranged in the obtained model. The numbers of genotypes and mean values for these clusters are given in Table 3.

With the classification obtained, the studied genotypes were assembled in 5 different main clusters/classes. In addition, as a result of Mantel's matrix correspondence test (Mantel, 1967) conducted to specify the extent to which the dendrogram represents the correspondence matrix, the rate of 0.85 (very good) was found. The 1st cluster contains 98 genotypes (AHM-60, AHM-61, AHM-76, AHM-95 W, AHM-95 Y, AHM-160, AHM-181, AHM-191, AHM-204, AHM-213, AHM-214, AHM-230, AHM-238, AHM-243, AHM-269, AHM-294, AHM-340, AHM-439, AHM-455, AHM-457, AHM-458, AHM-475, AHM-478, UGSH-481, AHM-483, AHM-484, AHM-485, EHM-209, EHM-234, EHM-265, EHM-296, EHM-297, EHM-298, EHM-342, EHM-343, EHM-370, EHM-407, EHM-439, EHM-473, EHM-488, UGSH-15, UGSH-19, UGSH-24, UGSH-26, UGSH-28, UGSH-29, UGSH-31, UGSH-50, UGSH-51, UGSH-57, UGSH-65, UGSH-74, UGSH-78, UGSH-79, UGSH-100, UGSH-102, UGSH-104, UGSH-106, UGSH-123, UGSH-125, UGSH-128, UGSH-130, UGSH-131, UGSH-134, UGSH-143, UGSH-154, UGSH-159, UGSH-160, UGSH-165, UGSH-169, UGSH-176, UGSH-213, UGSH-241, UGSH-254, UGSH-266, UGSH-268, UGSH-272, UGSH-274, UGSH-276, UGSH-292, UGSH-341, UGSH-348, UGSH-349, UGSH-351, UGSH-371, UGSH-391, UGSH-393, UGSH-407, UGSH-424, UGSH-431, UGSH-454, UGSH-459, UGSH-470, UGSH-474, UGSH-476, UGSH-480, UGSH-484, and UGSH-490). The 2nd cluster contained 5 of them (AHM-87, AHM-477, UGSH-22, UGSH-357, and UGSH-

Table 3. Numbers of maize genotypes and mean values for their clusters

Таблица 3. Количество генотипов кукурузы и средние значения для их кластеров

Cluster No. / № кластера	Number of accessions / Количество образцов	L^* value (luminance) / Значение L^* (яркость)	a^* value (red/green) / Значение a^* (красный/ зеленый)	b^* value (blue/yellow) / Значение b^* (синий/ желтый)	Chroma value in the a^*b^* plane / Значение цвета в плоскости a^*b^*	Hue angle in the a^*b^* plane / Угол оттенка в плоскости a^*b^*
1	98	58.16	10.45	32.82	34.48	72.41
2	5	60.87	11.24	41.12	42.64	74.75
3	6	50.67	13.03	28.02	30.92	65.18
4	1	42.36	8.71	32.77	33.91	75.12
5	2	43.63	5.72	20.21	21.01	74.03
R^2		0.49	0.17	0.59	0.53	0.29

R^2 values were calculated in the cluster analysis as 0.49 for the L^* value, 0.17 for the a^* value, 0.59 for the b^* value, 0.53 for the chroma value, and 0.29 for the hue angle. The mean values in the 1st cluster were 58.16 for the L^* value, 10.45 for the a^* value, 32.82 for the b^* value, 34.48 for the chroma value, and 72.41 for the hue angle. The means in the 2nd cluster were 60.87 for the L^* value, 11.24 for the a^* value, 41.12 for the b^* value, 42.64 for the chroma value, and 74.75 for the hue angle. The means in the 3rd cluster were 50.67 for the L^* value, 13.03 for the a^* value, 28.02 for the b^* value, 30.92 for the chroma value, and 65.18 for the hue angle. The means in the 4th cluster were 42.36 for the L^* value, 8.71 for the a^* value, 32.77 for the b^* value, 33.91 for the chroma value, and 75.12 for the hue angle. The means in the 5th cluster were 43.63 for the L^* value, 5.72 for the a^* value, 20.21 for the b^* value, 21.01 for the chroma value, and 74.03 for the hue angle.

485); the 3rd contained 6 (EHM-245, EHM-325, UGSH-402, UGSH-68, UGSH-173, and UGSH-167); the 4th contained one (UGSH-168); the 5th contained two (UGSH-175, and UGSH-291) (see Table 3) (Fig. 3, 4). The percentage of the genotypes in cluster 1 was 87%. Clusters 2–5 were considerably weaker than cluster 1. There is not enough evidence to speak about a large variation in this case.

The results of the principal component analysis (PCA) conducted within the scope of the research are presented in Table 4. As a result of the PCA, two PC groups with eigenvalues above 1 were obtained (PC1 with 50.78%, and PC2 with 39.50%), and these 2 PCs accounted for 90.28% of the population variance (see Table 4; Fig. 3). The resulting distribution is shown in Fig. 3 and Fig. 4. Our findings are similar to those published by B. Gouesnard et al. (1997), K. Wei et al. (2009), J. Kumari et al. (2017), C. Nelimor et al. (2019), J. Goyanka et al. (2021), and J. Kumari et al. (2024).

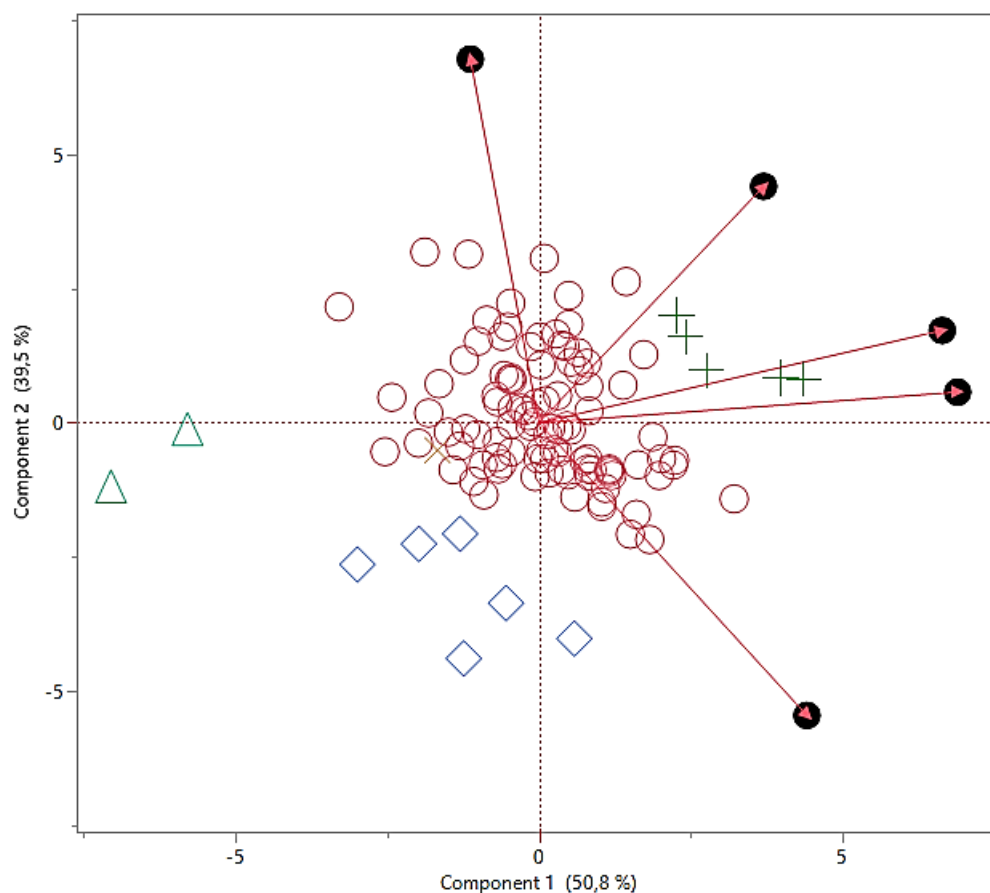


Fig. 3. Distribution obtained with PC1 and PC2

Рис. 3. Распределение, полученное с помощью PC1 и PC2

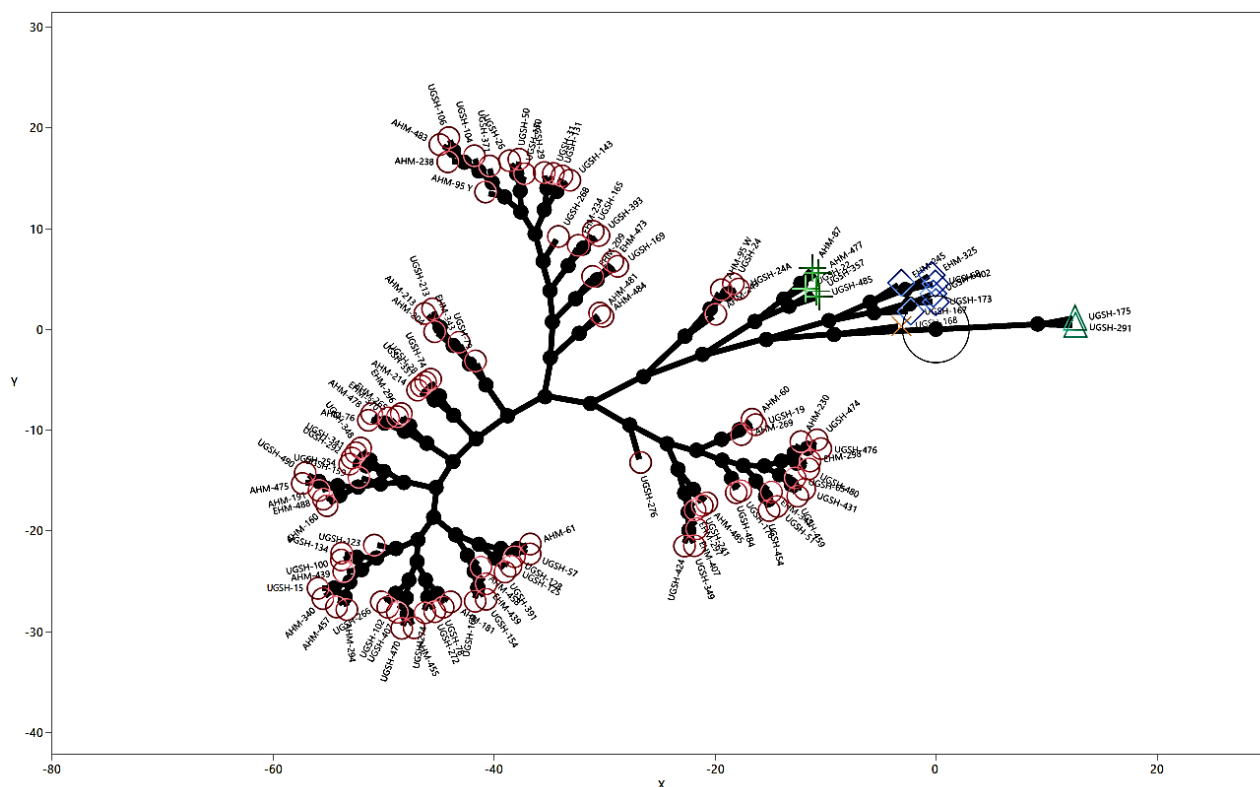


Fig. 4. Cluster analysis showing the distribution of the collection into groups (clusters 1, 2, 3, 4 and 5)

Рис. 4. Кластерный анализ, отображающий распределение коллекции по группам (кластеры 1, 2, 3, 4 и 5)

Table 4. Principal component analysis results**Таблица 4. Результаты анализа главных компонент**

Cluster No. / № кластера	Eigenvalue / Собственное значение	Percentage / Процент	Accumulation percentage / Процент накопления
1	2.538992	50.78	50.78
2	1.975012	39.50	90.28
3	0.481662	9.63	99.91
4	0.004048	0.081	99.99
5	0.000286	0.006	100.00

It is seen in the dendrograms based on grain color parameters data that the genotypes are gathered in 5 groups. Grain color parameters of the genotypes in Azerbaijani germplasm were assessed and genetic variation in these parameters was revealed. Consideration of the characters showed that there was no significant variance in the hue angle and L* value, but the variation was statistically significant for the a* value, b* value, and chroma value.

The information on allelic diversity obtained as a result of this study will help to determine the parents in future maize breeding investigations. Depending on the results, combining individuals with the same alleles with individuals carrying rare alleles (due to the narrowing of the gene pool), instead of each other, will increase genetic diversity. Again, by determining genetic distances, hybridization among completely distant individuals will increase variation in hybrid plants.

In this research, the grain color characteristics of homozygous maize accessions grown within the boundaries of Azerbaijani germplasm were compared. It is recommended that plant breeding investigations should be continued for some maize genotypes identified as promising in terms of their grain color parameters and that more detailed studies need to be conducted using other molecular marker techniques in future research efforts.

The classification methods (cluster analysis) used together with the regularization technique (PCA) applied to multivariate data confirmed five well-defined groups of accessions. Cluster 1 contained 87% of the genotypes. Clusters 2 to 5 were considerably weaker than cluster 1. There is not enough evidence to speak about the presence of a large variation. For this reason, no major variation in color properties was found in the examined grains.

Assessing genetic diversity also provides germplasm curators with the opportunity to identify gaps in the collection, identify traits where useful variability is limited in the source collection, and also maximize the diversity in the collection, thereby demonstrating the need for trait-specific research.

Conclusion

The dendrograms based on grain color parameters data demonstrate that the genotypes are assembled in 5 groups. Grain color parameters of the genotypes in Azerbaijani germplasm were assessed and genetic variation was revealed in these parameters. Descriptive statistics of the findings obtained from the population showed that there was a large variation in the variables representing the examined characteristics in the population.

The information on allelic diversity obtained as a result of this study will help to determine the parents in future maize breeding investigations. Depending on the results, combining

individuals with the same alleles with individuals carrying rare alleles (due to the narrowing of the gene pool), instead of each other, will increase genetic diversity. Again, by measuring genetic distances, hybridization of completely distant individuals will increase variation in hybrid plants (Aka-Kaçar et al., 2003).

In this research, homozygous maize genotypes located within the gene center borders of Azerbaijan were compared for some of their grain color parameters. It is recommended that breeding-oriented research should be continued for some maize genotypes identified as promising for their grain color parameters and that more detailed investigations using other molecular marker techniques need to be conducted in future research endeavors.

The classification methods (cluster analysis) used together with the regularization technique (PCA) applied to multivariate data confirmed five well-defined groups of accessions. In some cases, accessions originating from the same location fall into tight groups within clusters (1, 2, 3, 4 and 5). Assessing genetic diversity also provides germplasm curators with the opportunity to identify gaps in the collection, identify traits where useful variability is limited in the source collection, and also maximize the diversity in the collection, thereby demonstrating the need for trait-specific research.

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Contribution of the authors: the authors contributed equally to this article.

Вклад авторов: все авторы сделали эквивалентный вклад в подготовку публикации.

Conflict of interests: the authors declare no conflicts of interests.

Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

The article was submitted on 24.03.2025; approved after reviewing on 02.06.2025; accepted for publication on 21.07.2025. Статья поступила в редакцию 24.03.2025; одобрена после рецензирования 02.06.2025; принята к публикации 21.07.2025.