

Nutrient composition and chromatic parameter of Bolita pigmented maize (*Zea mays* L.)

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ABSTRACT

Objective: To determine the nutrient composition and chromatic parameters of two pigmented (blue and red) Bolita maize varieties from the communities of the Valles Centrales region, Oaxaca, Mexico.

Design/Methodology/Approach: The grains of two maize varieties were evaluated to determine their moisture, ash, crude fiber, ether extract, protein, and carbohydrates content, as well as their chromatic parameters. In addition, their macro- and micro-elements were established. Data were analyzed with the Student's-t test for independent samples with a >95% confidence level ($p \leq 0.05$).

Results: A significant difference ($p \leq 0.05$) was recorded in the nutrient composition of each parameter: 7.46-9.70% (moisture), 1.33-1.61% (ash), 5.43-6.6% (fat), 8.32-9.3% (proteins), 3.25-4.38% (fiber), and 70.83-71.78% (carbohydrates). Macro- (Mg, Ca, K, Na, and P) and micro-elements (Cu, Fe, Zn, and Mn) were identified. In addition, the L*, a*, b*, C*, and h chromatic parameters were determined.

Study Limitations/Implications: This study had no limiting factors.

Findings/Conclusions: The blue and red Bolita maize varieties recorded a nutrient composition that matched the findings of other authors. The differences may be mainly the result of genetic factors and the development conditions of the plants.

Keywords: *Zea mays* L., nutrient composition, color.

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INTRODUCTION

Maize (*Zea mays* L.) is an extensively grown cereal worldwide. It is used to feed both humans and animals. Maize is native to Mexico, where it was domesticated and diversified (Mendoza-Mendoza *et al.*, 2020), leading to different morphological characteristics (plants) and chemical composition (grains) (Mex-Álvarez *et al.*, 2016). In addition, it is the most popular cereal in the country, due to its taste and year-long availability (Peña *et al.*, 2017) and it is used in a wide variety of dishes (Salinas-Moreno *et al.*, 2024).



Maize is a staple crop worldwide, because it provides macro- and micro- nutrients that meet the requirements of the human metabolism (Jaradat and Goldstein, 2018). It is one of the most important food sources of the population and it provides nutrients that complement human diet, such as minerals, dietary fiber, and unsaturated fats (Chan-Chan *et al.*, 2021).

As a result of its topography and different climates, Mexico houses 64 different maize varieties (Salinas-Moreno *et al.*, 2024), out of which, 59 are native to the country (CONABIO, 2020). These native species include accessions with different grain color and pigment modifications (Serna-Saldívar *et al.*, 2013), including shades of yellow, blue, black, orange, and red (Salinas *et al.*, 2013). Thirty-five native varieties have been identified in Oaxaca. They have a high genetic variation (Aragón *et al.*, 2006) that improves the basic diet of rural and indigenous communities (González-Cortés *et al.*, 2016). In addition, these varieties have been traditionally commercialized, providing an important source of income (Peña *et al.*, 2017). Native maize is a source of a great variety of secondary metabolites, including flavonoids, anthocyanins, stilbene, phenolic acids, coumarins, and tannins (Francavilla and Joye, 2020), which are fundamental for the functioning of the plant and are part of its defense mechanism against pathogens. In addition, maize has nutraceutical and antioxidant properties (Cabrera-Soto *et al.*, 2009). However, based on the stress conditions undergone by the plant during its development, these compounds may vary (Peña, 2013). Nevertheless, biotic and abiotic factors, as well as variety, influence the presence and amount of the phenolic compounds in the plant. Consequently, their chemical composition and properties, as well as their final use are different, as a result of the great diversity of maize varieties (Méndez *et al.*, 2005).

The secondary metabolites of maize have been the subject of several researches, given their biological activities. However, the characteristics of native maize from Oaxaca require further studies: its remarkable genetic variability and preservation favor food security and guarantee an income for thousands of families from indigenous communities. Therefore, the objective of this study was to determine the nutrient composition and the chromatic parameters of two pigmented maize varieties (blue and red Bolita maize) grown in the communities of the Valles Centrales region, Oaxaca, Mexico. The hypothesis was that the pigmented grains of native maize are an improved source of macro- and micro-nutrients that can complement daily diets.

MATERIALS AND METHODS

Collection and variety identification

Red maize and blue maize samples were collected from San Francisco Telixtlahuaca (17.3176416 N, -96.9070607 E) and Trinidad Zaachila (16.9372.1 N, -96.7967.1 E), respectively. Both towns are located in the Valles Centrales region, Oaxaca, Mexico. The germplasm samples of the two varieties were harvested in October-November, 2023. The germplasm was classified within the Bolita variety group, based on the criteria described by Aragón *et al.* (2006) and CONABIO (2020), which include morphology, cob size, and number and grains per row, as well as grain size and shape.

Nutrient composition

In order to analyze the nutrient content, 100 g of grains were ground in a homogenizer to obtain flour. The official AOAC methods (2005) were used to determine the nutrient content of the grains. The Kjeldahl method (method 984.13) was used to establish the total protein content, while methods 962.09, 942.05, 920.039 (Soxhlet method), and 930.15 were used to determine crude fiber, ash, ether extract, and moisture content, respectively. Meanwhile, the method established by Nielsen (2017) was used to obtain the total carbohydrate content, subtracting the sum of protein, crude fiber, ash, ether extract, and moisture percentage from 100%.

Mineral content

Ten g of ashes from each maize sample were analyzed to determine their mineral content in the Departamento de Química Analítica, Servicio Geológico Mexicano, Centro Experimental Oaxaca, using the dissolution method with four acids: hydrochloric acid (HCl), nitric acid (HNO₃), perchloric acid (HClO₄), and hydrofluoric acid (HF).

Analysis of the color of maize grains

Reflectance was used to analyze the color of maize grains. A HunterLab UltraScan[®] Vis spectrophotometer and the EasyMachQC software in the #2-RSIN Reflectance Specular Included-9.525 mm mode were used for this purpose. The chromatic parameters of the CIE-LAB system (L*, a*, and b*) were obtained. L* (luminosity) indicates if the color is light ($51 \leq L \leq 100$) or dark ($0 \leq L \leq 50$) (Mendoza-Mendoza *et al.*, 2017). Meanwhile, a* and b* stand for the following chromaticity coordinates: a* (+) red and a* (-) green and b* (+) yellow and b* (-) blue (Rodríguez-Salinas *et al.*, 2020). The b* (+) and b* (-) parameters were used to calculate h° (hue), which is the hue angle that indicates the sample color quadrant: 0°=red-purple, 90°=yellow, 180°=greenish blue, and 270°=blue (García-Campos *et al.*, 2020). In addition, this parameter is deeply associated with the visual assessment of color (Salinas-Moreno *et al.*, 2021). Chromaticity (C*) refers to the color saturation index, which indicates that high values are pure colors, while low values stand for matte or less pure colors. The $h^\circ = \arctg(b^*/a^*)$ and $C^* = (a^{*2} + b^{*2})^{1/2}$ expressions were used (Ballesteros *et al.*, 2019). The values of each evaluated sample were input in the ColorHexa website to obtain the color image.

Statistical analysis

The mean result of three replicates—including the nutrient composition, color analysis—was recorded per sample. The PSPP v. 3 Software for Windows was used to calculate the mean and standard deviation. Data were analyzed with the Student's-t test for independent samples with a >95% confidence level ($p \leq 0.05$). Based on the methodology established by the Servicio Geológico Mexicano, the geochemical analysis was performed in duplicate.

RESULTS AND DISCUSSION

Nutrient composition

Significant differences were recorded between the two Bolita varieties regarding moisture, ash, ether extract, protein, and fiber content (Table 1). Overall, the two varieties recorded normal concentrations for each of the evaluated parameters.

The nutrient composition analysis establishes the main components and percentages of macro-nutrients of a given species to describe its characteristics (Cadena *et al.*, 2024). The moisture content of blue Bolita was higher than in red Bolita; however, the percentage found in both varieties fell below the critical value. A higher moisture content (>14%) is a major hazard for all cereal species (Cadena *et al.*, 2024). A low moisture value is fundamental, because low moisture content helps cereals to develop a higher resistance to the deterioration caused by microorganisms and insects during their storage (García-Campos *et al.*, 2020). These results match the findings of Mex-Álvarez *et al.* (2016), who reported values between 7.45 and 10.43% for maize varieties from Campeche. For their part, Rodríguez-Salinas *et al.* (2020) recorded 7.98-9.67% values for pigmented genotype maize. Red Bolita recorded a higher ash and fat content than blue Bolita. The first parameter is related to mineral content, most of which can be found in the germ, just like fat (Bello-Pérez *et al.*, 2016). Rodríguez-Salinas *et al.* (2020) reported a pigmented maize ash and fat content of 1.00-1.46% and 3.38-6.15%, respectively. Meanwhile, Chan-Chan *et al.* (2021) recorded an ash and fat content of 1.36-1.50% and 5.01-5.05%, respectively, for varieties from Yucatan. The differences in ash content can be the result of the use of fertilizers and environmental factors. In addition, a good quality maize must not record a >2% ash content. Higher percentages are associated with calcium and salt pollution and the lack of cleanness during harvest and sample collection (Rodríguez *et al.*, 2023).

The protein and carbohydrate content were higher in red Bolita. A significant amount of the protein content is found in the endosperm (8.2-9.4% in pigmented maize). Some segregating forms of the Bolita variety have a positive ratio between the hardness of the grain and the protein content, which has been attributed to a higher presence of the storage proteins (prolamins) that surround the starch granules (Bello-Pérez *et al.*, 2016). Mex-Álvarez *et al.* (2016) reported a lower protein percentage in purple (6.76%) and red (7.45%) varieties. However, Rodríguez-Salinas *et al.* (2020) reported a higher protein content (9.72-12.75%), which contrasts with the results of this study. Carbohydrates are the main component of maize grains. Starch is the main carbohydrate found in maize and it is formed by amylose (linear constituent) and amylopectin (branched polysaccharide) (Bello-Pérez *et al.*, 2016). Mex-Álvarez *et al.* (2016) reported a higher carbohydrate content for the red (72.31%) and purple (74.30%) varieties.

Table 1. Nutrient content of two pigmented maize varieties from the Valles Centrales region, Oaxaca, Mexico.

Variety	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Carbohydrates (%)	Fiber (%)
Bolita azul	9.70±0.097 ^a	1.33±0.012 ^b	5.43±0.282 ^b	8.32±0.095 ^b	70.83±0.340 ^b	4.38±0.297 ^a
Bolita rojo	7.46±0.127 ^b	1.61±0.049 ^a	6.60±0.310 ^a	9.30±0.295 ^a	71.78±0.372 ^a	3.25±0.402 ^b

^{a,b} Means with different superscripts in the same column are significantly different ($p \leq 0.05$).

Fiber content is related to the plant material that is resistant to digestive enzymes (Dhingra *et al.*, 2012). In the case of maize, this material is located in the pericarp and is mainly made up of arabinoxylans, heteroxylans, cellulose, and phenolic acids (Bello-Pérez *et al.*, 2016). The phenolic compounds of dietary fiber are chemically bond with various insoluble macromolecules; therefore, grains with a higher fiber content can be linked to the presence of bound phenolic compounds (Gálvez *et al.*, 2021). The content of this parameter was higher in blue Bolita. It was even higher than the range (1.2-1.76%) reported by Rodríguez-Salinas *et al.* (2020). However, Mex-Álvarez *et al.* (2016) reported a higher percentage of fiber in red maize (6.39%) and in purple maize (3.32%). Each parameter has a wide nutritional range, because the ratio of each macronutrient in maize depends on genetic and environmental factors, as well as on the conditions of the crop.

Mineral content

The following macro-elements (minerals) —which are necessary for the development of the plant— were found in the grains of red and blue Bolita maize: magnesium (Mg), phosphorous (P), calcium (Ca), potassium (K), and sodium (Na) (Table 2).

Table 3 shows the essential micro-elements whose physiological function is also fundamental for the organism and which significantly contribute to the mineral content of the diet (Saulnier, 2012; Caballero *et al.*, 2014). The said minerals include iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn).

The macro- and micro-elements identified in the grains of red and blue Bolita are important for human and animal diet and health (Jordan-Meille *et al.*, 2021). Additionally, they play a major role in seed quality (Jaradat and Goldstein, 2018). The predominant compounds in both varieties were P, K, and Mg. The same results were reported by Rodríguez-Salinas *et al.* (2020), who analyzed 15 genotypes of pigmented native maize and recorded the following results: P (334.40-719.99 mg 100 g⁻¹), K (314.20-397.18 mg 100 g⁻¹), and Mg (116.24-146.75 mg 100 g⁻¹). Chí-Sánchez *et al.* (2021) reported lower Ca concentrations in native maize grown in several regions of Yucatan, Mexico: 3.8 and 5.61 mg 100 g⁻¹ for purple and red maize, respectively.

Table 2. Macro-element content in the grain of two pigmented maize varieties in the Valles Centrales region, Oaxaca, Mexico.

Variety	Macroelements (mg 100 g ⁻¹)				
	Mg	Ca	K	Na	P
Bolita azul	108.66	5.32	271.72	1.53	309.89
Bolita rojo	135.72	7.41	258.73	1.10	365.63

Table 3. Micro-element content in the grain of two pigmented maize varieties in the Valles Centrales region, Oaxaca, Mexico.

Variety	Microelements (mg 100 g ⁻¹)		
	Cu	Fe	Zn
Bolita azul	0.22	2.00	1.98
Bolita rojo	0.24	2.58	2.87

In contrast, Rodríguez-Salinas *et al.* (2020) detected higher concentrations than those reported in this study: 24.58 to 32.63 mg 100 g⁻¹. Likewise, they reported 24.08 to 70.30 mg 100 g⁻¹ Na concentrations.



Meanwhile, red Bolita had a higher concentration of micro-elements (Table 3). The Cu content of the two varieties under study fell within the range (0.20-0.53 mg 100 g⁻¹) reported by Rodríguez-Salinas *et al.* (2020). However, it exceeded the concentrations (0.0073-0.1169 mg 100 g⁻¹) reported by Chí-Sánchez *et al.* (2021). For its part, the Fe content ranged from 0.454 to 1.8 mg 100 g⁻¹ concentrations. However, Qamar *et al.* (2017) reported higher concentrations in white (8.20 mg 100 g⁻¹) and yellow (11.5 mg 100 g⁻¹) maize. The Zn and Mn concentrations in blue Bolita were slightly lower than those reported by Rodríguez-Salinas *et al.* (2020), who recorded 2.80 to 4.50 mg 100 g⁻¹ (Zn) and 0.3 to 0.73 mg 100 g⁻¹ (Mn) concentrations. In this case, the varieties under analysis fell within this range.

Several factors determine the nutrient concentration of the grain. Therefore, although both blue and red Bolita belong to the same variety, they showed differences in mineral content. Dourado *et al.* (2015) reported that the concentration of nutrients is impacted by their availability in the soil, which in turn is determined by such factors as texture, organic matter, and pH. In this regard, soil texture is particularly important. For example, compared with sandy soils, clay soils are more frequently associated with grains with a higher mineral content (Jordan-Meille *et al.*, 2021). Likewise, pH differences in the soil influence the solubility of minerals and consequently their absorption by the plant and the composition of the grain (Gálvez *et al.*, 2021). For example, an increase in soil pH reduces the availability of Cu, Mn, and Zn. These elements are particularly important, because Cu and Mn are part of the defense mechanisms of plants and can provide them with various levels of resistance (Dourado *et al.*, 2015). Meanwhile, Zn and Fe are essential micro-elements for human metabolism. Therefore, the biogeochemistry of the soil has a massive impact and influences mineral solubility, their potential absorption by crops, and the mineral content of its grains and tissues. Nevertheless, other factors also impact this availability, including agricultural practices (*e.g.*, fertilization and lime application), consequently neutralizing soil acidity (Jordan-Meille *et al.*, 2021). Additional fertilization interacts with other nutrients and soil pH, diminishing certain micronutrients or increasing the solubility of the nutrient provided (Chí-Sánchez *et al.*, 2021). The presence of P in maize grains is influenced by the application of phosphorous fertilizers, while the Ca content can be influenced by its concentration in the soil where the crop was sown (Martínez *et al.*, 2017).

Analysis of the color of maize grains

Table 4 shows the values of the color parameters of the grains of both maize varieties. All the parameters recorded significant results and, overall, showed that both varieties have a dark color. However, red Bolita had a lower L* value (luminosity or brightness of the sample), while its hue (h°) and chroma (C*) fell within the red scale. For its part, blue Bolita recorded a lower chroma, with a hue angle that places this variety in the greenish yellow area, with some grey hues.

Table 4. Chromatic properties of two varieties of pigmented maize in the Valles Centrales region, Oaxaca, Mexico.

Variety	Color parameter					Color image
	L*	a*	b*	C*	h°	
Bolita azul	37.36±0.52 ^a	0.44±0.30 ^b	2.58±0.59 ^b	2.62±0.64 ^b	81.05±4.51 ^a	
Bolita rojo	32.43±0.43 ^b	26.85±1.39 ^a	14.60±0.90 ^a	30.57±1.65 ^a	28.76±0.59 ^b	

^{a,b} Means with different superscripts in the same column are significantly different ($p \leq 0.05$).

The L* values indicated that the germplasm under study has dark grains and that red Bolita was more luminous than blue Bolita. Rodríguez-Salinas *et al.* (2020) reported L* values ranging from 25.13 to 42.75 for purple grain genotypes. Blue Bolita falls within this range. In contrast, Mendoza-Mendoza *et al.* (2017) recorded L* values of 5.7-24.5 in dark purple and reddish-purple grains (darker grains). Red Bolita recorded an L* value of 32.43, closer to the mean reported by Salinas-Moreno *et al.* (2021) for cherry red grains (34.41) and lower than the value recorded by Rodríguez-Salinas *et al.* (2020) for a red genotype (38.22). Meanwhile, Salinas *et al.* (2012) reported higher values for magenta red (38.5) and light red (51.4) varieties. The color of red Bolita was more saturated, since high values of C* (degree of saturation) indicate pure colors, while lower values point out matte or less pure colors (Ballesteros *et al.*, 2019). Therefore, the color of the blue Bolita grain was less pure. For their part, Rodríguez-Salinas *et al.* (2020) established that the C* of purple genotypes fluctuated between 2.42 and 22.17. Blue Bolita fell within this range. In addition, the value of two genotypes was similar to the value reported in this study (2.41 and 3.63). Likewise, Mendoza-Mendoza *et al.* (2017) reported dark purple grains with a low saturation (1.8 and 2.5). Red Bolita was brighter than the colors reported by Mendoza-Mendoza *et al.* (2017): reddish purple, red, and dark blue grains (6.2 and 11.8). Finally, Rodríguez-Salinas *et al.* (2020) recorded a 16.54 color for a red genotype.

Meanwhile, the value of the h° (hue or hue angle) parameter in purple blue maize can be similar to the value associated with a yellow or greenish yellow hue (Salinas-Moreno *et al.*, 2021), due to the uneven color of the grain surface. Areas such as the pedicel and the germinal area usually lack pigments. Additionally, since the pericarp is translucent, the values of the surface of the grain do not match the characteristics of the purple-blue hue (Salinas-Moreno *et al.*, 2024). The red Bolita grain had a more even color and fell within the red hue area. However, the h° value of the blue Bolita placed it in the greenish yellow hue area. The color of the grain and the content of anthocyanin compounds are correlated: as the L*, C*, and h° values decrease, the anthocyanin content increases (Rodríguez *et al.*, 2020). Therefore, darker grains have a higher content of these compounds.

CONCLUSIONS

Significant variations were reported in the concentration of minerals between both maize varieties and the data reported by other authors, particularly in macro-elements (*e.g.*, Ca and Na) and micro-elements (*e.g.*, Cu, Fe, and Zn). The grains recorded remarkable differences in protein content, as well as low luminosity (L*); therefore, they were classified

as dark, due to the pigments in the pericarp or the aleurone layer. The location where they were sown or the agricultural practices employed could explain these differences between samples from the same variety. Therefore, these pigmented maize varieties—which are grown in several communities of the state of Oaxaca— should be the subject of further studies, because they are an abundant source of macro- and micro-nutrients.

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