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Physicochemical Characterization and Mineral Composition of "UENF SD 08": A Super-Sweet Corn Hybrid

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Academic Editor: Costantino Paciolla

Special Issue: Nutritional Quality Improvement Of Cereals and Their Derived Products

Recent Progress in Nutrition
2023, volume 3, issue 3
doi:10.21926/rpn.2303015

Received: December 30, 2022
Accepted: August 17, 2023
Published: August 27, 2023

Abstract

Sweet Corn (*Zea mays L.*) is possibly the most important commercial cereal originating in the Americas. Mutant genes are responsible for sweetness. The purpose of this study was to evaluate the physicochemical and mineral composition of the "UENF SD 08" cultivar, super-sweet corn developed at Darcy Ribeiro Northern Rio de Janeiro State University (UENF) and registered in the National Cultivar Register of the Ministry of Agriculture, Livestock, and Supply and to compare its content to commercial super-sweet corn and field corn. Grain analyses were conducted at the Food Technology Laboratory, Phytotechnics Laboratory, and Animal Science Laboratory, UENF. The pH, total soluble solids, proximate composition, and mineral content were determined. In addition to the "UENF SD 08" cultivar, the "Tropical Plus®" cultivar, and the "UENF 506-11", field corn cultivar were also studied. When comparing the mineral content, we observed there was not a great variability between the two super-sweet corn cultivars ("UENF SD 08" e "Tropical Plus®"). We highlight that both cultivars have higher soluble sugar concentration and less starch content for proximate composition. Therefore, having a cultivar adapted to the Northern Rio de Janeiro climatic conditions and knowing its nutritional characteristics is important for producers and individuals who will consume it, fresh or corn products.

Keywords

Zea mays L.; shrunken; plant breeding; characterization; mineral content; sweet corn

1. Introduction

Globally, sweet corn (*Zea mays L.*) is an economically important and popular crop. It is widely used for human consumption and by the seed-production industry. Sweetness in corn kernels is controlled by six recessive mutant genes expressed in the endosperm. Among the genes, the shrunken2, in particular, causes a significant increase in endosperm sugar levels, for this reason it is extensively used in sweet-corn cultivar development [1, 2].

Among the world's largest corn producers, Brazil is in the third position, being surpassed by the United States and China [3]. Corn has been in Brazilian history since its discovery, initially cultivated by indigenous tribes in the Midwest regions and, later, it would reach a traditional status in Brazilian cuisine [4].

At the beginning of its cultivation, corn was for human subsistence. Over time, it gained economic importance, characterized by the various forms of its use, which range from animal feed, passing through an important strategy for Brazilian food security, to reaching the high-tech industry, such as the pharmaceutical industry, production of biodegradable packaging, and bioethanol industry [5-8].

Although Brazil stands out in this production, not all states have consolidated corn cultivation. An example is the Rio de Janeiro State. Although the Northern Rio de Janeiro region has arable land with potential for the development of corn cultivation, it is known that part of the corn consumed in Rio de Janeiro comes from other states. If this situation changes, it will represent another source of income for farmers in the region, since a market to absorb local production exists [9, 10].

Darcy Ribeiro Northern Rio de Janeiro State University, which was implemented with one of the objectives of bringing progress and development to the Northern Rio de Janeiro region, has breeding programs that develop several corn cultivars to better adapt them to climatic conditions and, consequently, better serve region farmers and generate income [11].

Among the corn cultivars developed at UENF, there are super-sweet corn genotypes. The super-sweet corn sample used in this study has the recessive mutant gene shrunken (sh2), whose function is to retard or prevent the complete transformation of soluble sugar to starch, being this the main difference from the field corn [12]. This hybrid results from a breeding program for over 20 years and has been commercialized in Campos dos Goytacazes, Rio de Janeiro [13].

Super-sweet corn consumption either fresh, frozen, or in corn products, in the United States, and Canada has been widespread for a long time [14]. On the other hand, in Brazil, most of the super-sweet corn produced is for the canned food industry, despite a potential market for fresh consumption and processed products [15].

Characterizing the super-sweet corn cultivar is very important; since it has a high market value compared to field corn, it has advantages: greater harvest period and stays fresh longer [16]. The higher sugar concentration changes the sensory characteristics of the grain, including texture, flavor, and aroma [2].

It is also crucial for the processing industry to recognize cultivar characteristics. Since humans can detect traces of bitterness in food, removing this flavor from plant foods has long been a major sensory concern for food science [17, 18]. For field corn, it was necessary to add sugar to the cans. Nevertheless, as super-sweet corn is sweeter, processors do not have to add sugar, which saves them time, and money, pleases consumer preferences and can be used to develop new plant-based products such as snacks, corn flakes, lyophilized corn, and yogurts [19-21].

Therefore, the current study aimed to characterize the physicochemical properties and mineral content of the super-sweet corn hybrid “UENF SD 08” compared to commercial and field corn.

2. Materials and Methods

2.1 Samples

The samples used in this study were the super-sweet corn hybrid “UENF SD 08”, the control “Tropical Plus®” and the field corn “UENF 506-11”. “UENF SD 08” is a cultivar developed at UENF by a selection of diallel single crosses. Hybrids were grown at Escola Agrícola Antônio Sarlo of UENF, located in the municipality Campos dos Goytacazes, in the Norte Fluminense region, in the state of Rio de Janeiro, Brazil (21°24'48"S, 41°44'48"W, at 14 m of altitude), in the 2017/2018 harvests. According to Köppen-Geiger [22] the climate classification is Aw (tropical climate with summer rainfall). Since it is close to the coast, the climate is controlled by equatorial and tropical air masses with influence from the tropical maritime mass.

The soil in this region is predominantly Acrisols and Cambisols [22-24]. The base fertilization was performed with 800 kg ha^{-1} of the chemical fertilizer formulated N-P2O5-K2O 04-14-0. The first covering fertilization was performed 30 days after sowing with 300 kg ha^{-1} of the fertilizer formulated N-P2O5-K2O 20-05-20 and the second covering fertilization was performed with 200 kg ha^{-1} urea (45% N) 45 days after sowing. Harvesting was performed 22 days after female flowering, which was considered optimal for both productivity [25] and taste and texture quality [26].

On May 24th, 2018, it was registered (N. 38733) in the National Register of Cultivars of the Brazilian Ministry of Agriculture, Livestock, and Supply (RNC/MAPA), and it has been commercialized in Campos dos Goytacazes, Rio de Janeiro, Brazil. The main traits of this super-sweet corn have been described by [27]. “Tropical Plus® is a super-sweet corn cultivar developed by Syngenta (registered in 2005, with outstanding sweet corn production throughout the country). “UENF 506-11” is a field corn also developed at UENF that originated from the same parental populations as the “UENF SD 08” cultivar, but without the sh2 gene [10].

The analysis of samples supplied by the Laboratório de Melhoramento Genético Vegetal was performed at UENF's Laboratório de Tecnologia de Alimentos, Laboratório de Fitotecnia, and Laboratório de Zootecnia. The grain was utilized in all of the analyses.

2.2 Samples Characterization

2.2.1 Soluble Solids (SS) Determination

Soluble Solids were determined by placing drops of the homogenized and filtered pulps on the prism of an Atago® digital refractometry. Results were expressed in °Brix [28].

2.2.2 Potential of Hydrogen (pH) Determination

The pH was determined in homogenized and filtered pulps with pH meter (WTW pH330), after calibration with pH 4.0 and 7.0 buffer solution [29].

2.2.3 Proximate Composition

Moisture content was determined by an oven-drying method that dries the samples at 105°C until constant weight. Ash content was determined after sample burning in a muffle furnace at 550°C Protein content was determined by the Kjeldahl method, which includes three basic steps: digestion, neutralization and distillation, and titration. These procedures were carried out for the samples and the blank. Factor 6.25 was used to convert detected nitrogen into protein. The Bligh Dyer procedure determined lipid content. It is a method based on solvent usage for extraction (chloroform-methanol) and a separatory funnel [29].

2.2.4 Carbohydrate Content Determination

Fructose, Glucose, and Sucrose: High-Performance Chromatography with Refractive Index Detector (HPLC-RID) Shimadzu Prominence SPDM10A® determined water-soluble sugar content, sucrose, glucose, and fructose. This method gives both qualitative (identification of the carbohydrate) and quantitative analysis (peak integration). The samples were analyzed using an ion-exchange column (Rezex RCM-03B-0130-K0®) under an isocratic condition with type 1 water (Milli-Q Integral®, Millipore®, São Paulo SP, Brazil). The injection volume was 20 µL and the flow rate was 0.6 mL min^{-1}. The column temperature was 85°C and the detector 50°C. Sample detection was performed by comparing the retention time standard. Nine different concentrations (0.039%, 0.078%, 0.156%, 0.312%, 0.625%, 1.25%, 2.5%, 5%, 10%) of the standards (Sucrose, D-Glucose and D-Fructose purchased from Sigma-Aldrich) were used to make the calibration curve. Each sugar calibration curve was obtained by plotting the sample concentration versus the area of the respective peak.

Total Fiber Content Total Fiber Content was determined by the Neutral Detergent Fiber (NDF) method, according to [30].

Starch: According to Physical-Chemical Methods for Food Analysis, the Starch was determined using the Lane-Eynon method [28].

2.2.5 Minerals

Minerals measurements (P, K, Ca, Mg, S, B, Fe, Zn, Mn, Cu, Mo, and Ni) were quantified by the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) in dried samples after digestion with HNO_3 and H_2O_2, in an open digestion system. During the measurements, the instrument used the following operating parameters: plasma gas 8.0 L min^{-1}, auxiliary gas 0.70 L min^{-1}, and carrying gas 0.55 L min^{-1} [31]. This was the only analysis made in duplicate.

2.3 Statistical Analysis

All the analyses were performed in triplicates. The results were displayed using the averages and standard deviation. Analysis of variance (ANOVA) was used to assess the mean difference between different groups. When there was a difference, they were compared by the Tukey test. A p-value of <0.05 was considered statistically significant. ANOVA was performed using IBM SPSS Statistics 2019® software (Armonk, NY, USA). To better understand the relationship among variables, a principal component analysis (PCA) was performed using R software [32].

3. Results and Discussion

Brazil, one of the world's largest producers of field corn, also has great potential for producing sweet corn [33]. Sweet corn can be divided into two groups. When corn contains amylose extender, dull1, and sugary genes, they are called sweet corn and the characteristics are manifested as different types and amounts of polysaccharides from the endosperm and less starch when compared to field corn. On the other hand, when corn contains brittle1 (bt1), brittle2 (bt2) and shrunken2 (sh2) genes they are called super-sweet corn and the striking feature is a high concentration of sugars in the endosperm at the expense of starch production [16]. The sh2 gene was defined at least 72 years ago [34]. It encodes a large subunit of the adenosine diphosphate glucose pyrophosphorylase, a heterotetrameric, and rate-limiting enzyme in starch biosynthesis [35].

In this study, we analyzed three different corn samples: "UENF SD 08", super-sweet corn, "Tropical Plus", Syngenta commercial super-sweet corn, and "UENF 506-11", field corn. The results of physicochemical characterization are displayed in Table 1. Mineral content can be observed in Table 2. The carbohydrate chromatographic peaks were identified by comparing the retention time obtained by injecting individual standard solutions of each carbohydrate. The results are displayed in Figure 1.

Table 1 Proximate Composition of cultivars "UENF SD 08", "Tropical Plus®" and "UENF 506-11", Campos dos Goytacazes, RJ-2021.

Component	**Samples**		
	UENF SD 08	**Tropical Plus**	**UENF 506-11**
pH	6.90 (±0.15) ^{a}	7.20 (±0.01) ^{b}	6.67 (±0.01) ^{a}
SS	13.6 (±0.30) ^{c}	12.5 (±0.32) ^{b}	10.6 (±0.30) ^{a}

Moisture (%)	86.2 (±0.25) ^{c}	74.9 (±0.73) ^{b}	61.1 (±0.73) ^{a}
Protein (%)	31.67(±0.15) ^{b}	15.42 (±0.09) ^{a}	15.50 (±0.16) ^{c}
Total Lipid (%)	16.30 (±0.16) ^{b}	6.45 (±0.14) $^{a, b}$	3.24 (±0.42) ^{a}
Ash (%)	0.66 (±0.07) ^{a}	0.48 (±0.08) ^{a}	0.68 (±0.09) ^{a}
Sucrose (%)	52.75 (±0.005) ^{b}	34.26 (±0.02) ^{c}	7.27 (±0.01) ^{a}
Glucose (%)	14.71 (±0.01) ^{c}	5.82 (±0.01) ^{b}	2.29(±0.01) ^{a}
Fructose (%)	12.68 (±0.01) ^{c}	3.78 (±0.04) ^{b}	1.46 (±0.01) ^{a}
Fiber (%)	1.46 (± 0.9) ^{a}	1.83 (± 0.9) ^{a}	7.10 (±3.05) ^{b}
Starch (%)	37.68 (±0.2) ^{a}	24.90 (± 0.26) ^{b}	51.92 (±0.24) ^{c}

Note: SS: Soluble Solids.

[1] The constituent values found refer to the average of three repetitions,

( ) = standard deviation.

[2] Averages followed by the same letter in the same row do not differ statistically from each other, at 5% probability, by the Tukey test.

Table 2 Mineral content (mg. 100 g^{-1} dry weight), of "UENF SD 08", "Tropical Plus®" and "UENF 506-11" cultivars, Campos dos Goytacazes, RJ-2021.

Element (mg. 100 g^{-1})	**Samples**		
	UENF SD 08	**Tropical Plus**	**UENF 506-11**
Calcium (Ca)	6.63 (±0.39) ^{b}	5.90 (±0.57) ^{b}	3.63 (±0.11) ^{a}
Phosphorus (P)	356 (±8.9) ^{b}	345 (±2.47) ^{b}	203 (±8.13) ^{a}
Sulfur (S)	137 (±3.18) ^{b}	100 (±5.66) ^{a}	99.1 (±0.00) ^{a}
Potassium (K)	976 (±17.7) ^{b}	1021 (±3.54) ^{b}	450 (±22.6) ^{a}
Magnesium (Mg)	122 (±7.42) ^{b}	118 (±4.24) ^{b}	65 (± 3.89) ^{a}
Boron (B)	0.33 (±0.02) ^{b}	0.14 (±0.05) ^{a}	0.16 (±0.00) ^{a}
Copper (Cu)	0.13 (±0.00) ^{b}	0.17(±0.00) ^{c}	0.02 (±0.00) ^{a}
Molybdenum (Mo)	0.02 (±0.00) ^{b}	0.01 (±0.00) ^{a}	0.01 (±0.00) ^{a}
Nickel (Ni)	0.06(±0.00) ^{a}	0.07 (±0.00) ^{a}	0.06(±0.00) ^{a}
Iron (Fe)	1.17 (±0.13) ^{a}	1.29 (±0.01) ^{a}	1.26 (±0.23) ^{a}
Manganese (Mn)	0.60 (±0.03) ^{b}	0.61 (±0.06) ^{b}	0.19 (±0.02) ^{a}
Zinc (Zn)	2.50 (±0.12) ^{a}	2.75 (±0.60) ^{a}	1.47 (±0.08) ^{a}

Note:

[1] Values refer to the average of two repetitions, ( ) = standard deviation.

[2] Averages followed by the same letter in the same row do not differ statistically from each other, at 5% probability, by the Tukey test.

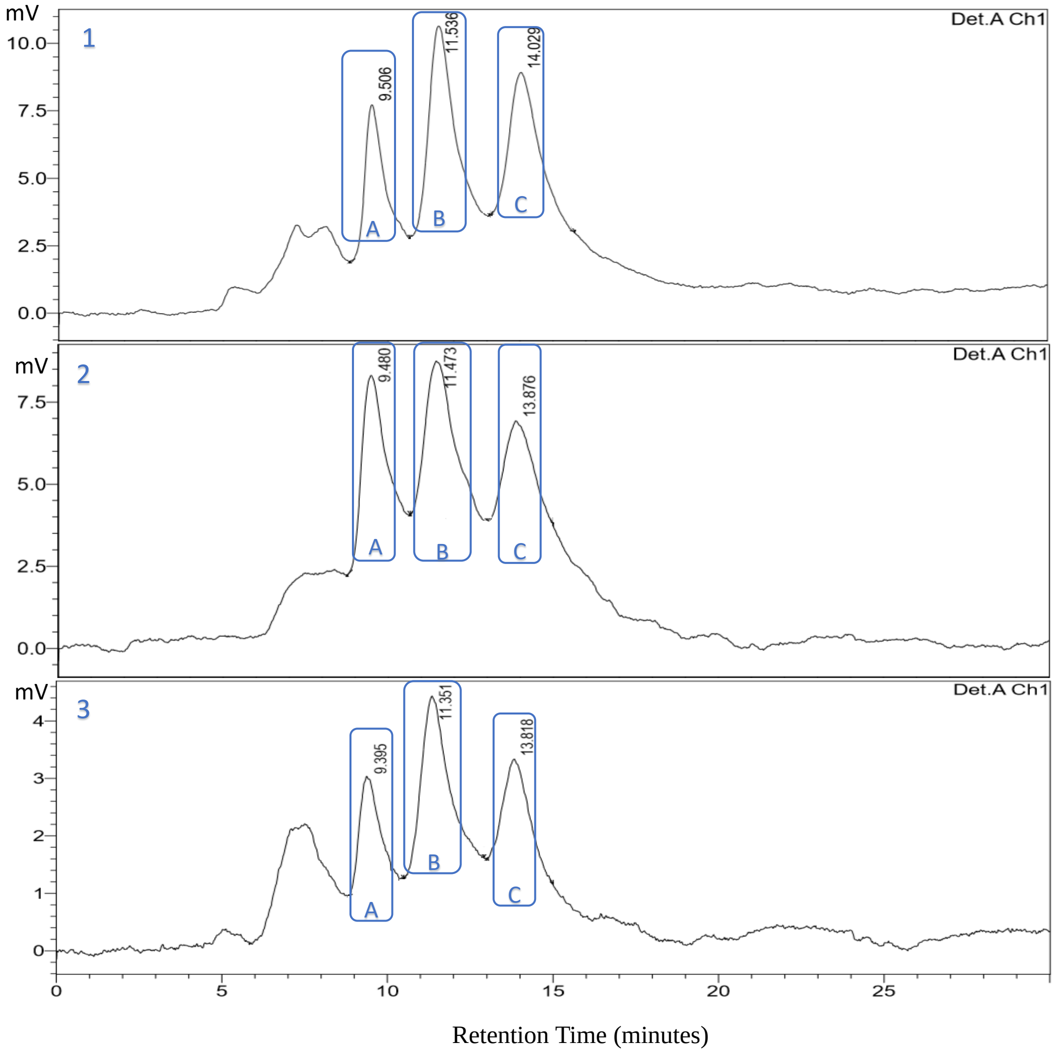

Figure 1 Carbohydrate profiles of “UENF SD 08” (1), “Tropical Plus” (2), and “UENF 506-11” (3). “UENF SD 08”: peaks: A, Sucrose (retention time: 9.40 minutes); B, D-Glucose (retention time: 11.53 minutes); C, D-Fructose (retention time: 14.02 minutes). “Tropical Plus”: peaks: A, Sucrose (retention time: 9.48 minutes); B, D-Glucose (retention time: 11.47 minutes); C, D-Fructose (retention time: 13.87 minutes). “UENF 506-11”: peaks: A, Sucrose (retention time: 9.39 minutes); B, D-Glucose (retention time: 11.35 minutes); C, D-Fructose (retention time: 13.82 minutes).

As expected, the presence of the gene sh2 was able to modify the carbohydrate profile in the samples. “UENF SD 08” and “Tropical Plus” had higher soluble sugar concentrations than “UENF 506-11”. On the other hand, the field corn had higher starch concentration than the super-sweet hybrids ($p < 0.05$). The results confirm what has been described by Tracy et al. [2], since the sh2 gene causes a failure in the conversion of soluble sugar into starch.

These characteristics are important for either fresh consumption or corn product development. The sweetness determines the flavor and higher soluble sugar levels result in a desirable creamy characteristic. It does not happen when a higher starch level produces an undesirable dry or gritty texture [36].

Moisture is another very important parameter because it relates to the concentration of soluble components and it is associated with the physical fragility of the cultivar [37]. The values ranged from 61.12% (UENF 506-11) to 86.20% (UENF SD 08) ($p \leq 0.05$).

Regarding the mineral content, Potassium was the most abundant mineral in all cultivars studied. The variety effect was significant ($p < 0.05$) for Calcium, Phosphorus, Potassium, Magnesium and Manganese content. The highest values were observed in super-sweet corn cultivars ($p < 0.05$). Regardless of the variety, Sulfur, Boron and Molybdenum contents were the highest in the “UENF SD 08” cultivar. There was no difference in Zinc, Iron and Nickel content among the cultivars ($p < 0.05$).

It is noteworthy that Food Composition Databases in Brazil [38], the USA [39] and Europe [40] do not have Sulfur, Boron, Molybdenum, Nickel and Manganese content described for either field corn or super-sweet corn. Therefore, it is the first study to describe corn cultivars' nutrient content.

To have information about these minerals is interesting because they have essential functions in the human body [41]. Sulfur is the third most abundant mineral in our body and participates in the formation of the amino acids cysteine and methionine which are essential amino acids [42]. Boron has a role in bone development, antioxidant defense system, and mineral and hormone metabolism [43]; Molybdenum cofactor is required in two mitochondrial and two cytosolic human enzymes [44]; Manganese plays an important role because it is a cofactor for various human enzymes as superoxide dismutase [45]. On the other hand, Nickel can cause hypersensitivity in patients with irritable bowel syndrome and nickel exposition might be a risk factor for breast cancer [46-48].

The differential accumulation of micronutrients can vary according to several factors, such as the stage of maturation, the genetic, and the availability of nutrients in the soil and the water, the time of harvest, fertilization practices, and climatic conditions [49-53]. The study of the proximate and mineral composition of foods is the starting point for understanding how different factors can affect the nutritional content, how the industry can use the feedstock to develop new products, or what characteristics will be interesting to the consumers that even more wonder healthier food [54].

The PCAs generated separately, among the results of proximate composition (Figure 2a) and mineral content (Figure 2b), were highly representative, considering the principal components 1 and 2. Regarding the chemical components, the field corn “UENF 506-11” are more related to higher levels of fiber, starch and ash, and lower levels of moisture, sucrose, pH and soluble solids. The super-sweet corn Tropical Plus is on the opposite side of “UENF 506-11”, on the cartesian plane, evidencing the differences due to the genetic composition and the effects of the sh2 gene. Regarding “UENF SD 08”, we can highlight the protein, fructose, glucose and total lipid as a more abundant components. These components collectively contribute to sweet corn’s nutritional profile and sensory experience, enhancing its quality. Higher protein content signifies better nutritional value, while natural sugars and small amounts of healthy fats improve taste, texture, and satiety. Considering only the vectors, we can highlight three associated components: i) fiber, starch and ash; ii) protein, fructose, total lipid and glucose; iii) moisture, sucrose and soluble solid.

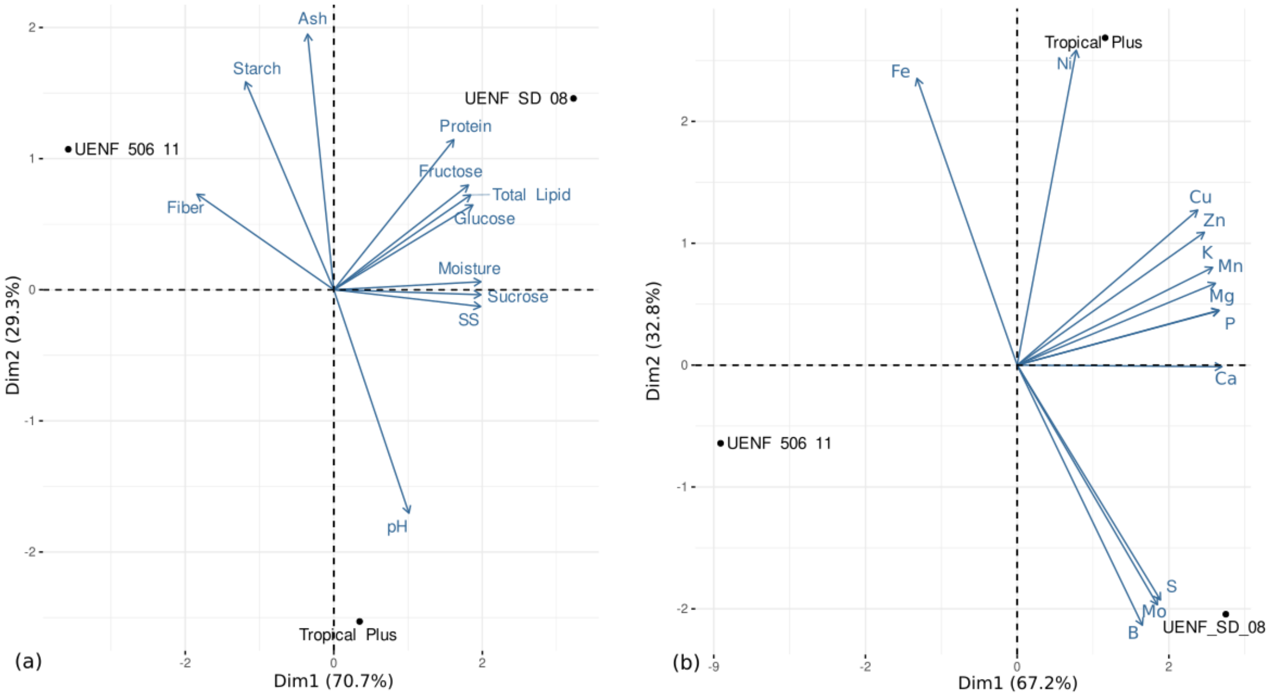

Figure 2 Principal component analysis biplot of corn hybrids and proximate composition (a) and mineral content (b).

In a study published by Goldman and Tracy [55], they reported that, considering near-isogenic inbred lines differing for the endosperm types, mutants sh2 and su1(sugary-1), the average across all inbreds, sh2 corn (17.6%) had a 30% greater protein concentration than su1 corn (13.5%). No studies indicate that the sh2 gene can alter the amount of lipids in grains.

As previously mentioned, the most abundant minerals in the "UENF SD 08" are Sulfur, Boron and Molybdenum. These minerals are positively associated, and negatively associated with Iron. Tropical Plus is associated with higher levels of Nickel, while "UENF 506-11" is not positively associated with any mineral. Calcium, Zinc, Phosphorus, Potassium, Copper, Magnesium, and Manganese are positively associated with each other, but not with any variety.

In a review article produced by Okumura et al. [16], results obtained by different authors regarding mineral content in samples of common corn and super sweet corn (sh2) were compared. The results do not show a relationship between the levels of Nickel, Phosphorus, Potassium, Calcium, Magnesium and Sulfur and the presence of the sh2 gene. However, a super-sweet grain composition in terms of endosperm size may affect quantification, as its content is much lower than that of common corn, and partly composed of soluble carbohydrates [55].

Sweet corn is widely used in human food. It is considered a feedstock with excellent sensory characteristics for the canning industry, therefore super-sweet corn use and consumption, in Brazil, is not widespread yet [56, 57]. One of the advantages of motivating the production and consumption of super-sweet corn hybrid is its sweetness. This attribute is desired for fresh consumption and industry use for product development [58].

It is worth mentioning that super-sweet corn sweetness makes it an extremely interesting feedstock for developing products for special purposes. It is known that according to how sucrose is consumed, for example, as table sugar or in a food matrix. However, the molecule is the same, once supplied through a food matrix, the digestion and absorption rate in the gastrointestinal tract is lower [59]. This condition is extremely interesting and desirable for food products that can be consumed by people with chronic diseases such as obese and diabetics individuals [60-63].

Syngenta has been the leading large-scale producer of super-sweet corn cultivars for many years. However, when the breeding programs of Brazilian Universities provide super-sweet corn cultivars, they expand the genetic diversity of super-sweet corn and the options to be commercialized [27].

Obtaining this hybrid for the Northern Rio de Janeiro region, also, to register another corn cultivar in MAPA, contribute to the diversification of varieties in the country, to the local economy, and also to food and nutritional security, since corn is one of the most consumed cereals in the world [64, 65].

Besides, when evaluating the physicochemical and mineral composition of the registered cultivar, it has a good nutritional value and could be incorporated as a source of nutrients for human consumption. It is recognized that there is a worldwide trend toward the adoption of a plant-based diet. This type of food has been highlighted as a good alternative for those seeking better eating habits and also contributes to less environmental impact as deforestation, land degradation, greenhouse gas emissions, and water pollution [66-68].

Finally, the possibility of producing and selling a cultivar adapted to Northern Rio de Janeiro's climatic conditions has several meanings. It demonstrates how science and researchers can contribute to the region and the family farmers' economic development, and it encourages the consumption of local products, which means access to fresh products and, at the same time, less food waste and less pollution during transportation [69-71].

4. Conclusions

The physicochemical and mineral determinations demonstrated that “UENF SD 08” as the commercial hybrid “Tropical Plus”, which is also super-sweet corn, has higher soluble sugar concentration and less starch content as expected in the presence of sh2 gene. In “UENF SD 08” carbohydrate concentrations are higher than in “Tropical Plus”. On the other hand, field corn, “UENF 506-11” has higher starch content and less soluble sugar concentration. Regarding mineral content, in addition to the minerals that already exist in Food Composition Databases emphasis is given to the description of Sulfur, Boron, Molybdenum, Nickel and Manganese. The super-sweet corn cultivar “UENF SD 08” is well-adapted to the Northern Rio de Janeiro region. Compared to field corn, super-sweet corn hybrids have a greater harvest period, and stay fresh longer. These characteristics are desirable for farmers, once they can increase the production and generate a natural consumption market, and encourage the development of new products, which means income generation for the region. Thinking about the food industry's search for more palatable products, the characteristic that most arouses interest in this cultivar is the higher content of soluble carbohydrates to the detriment of starch, once more soluble sugar levels represent better flavor and texture for the products. Therefore, “UENF SD 08” matches these characteristics.

Acknowledgments

We thank José Accacio for help in the laboratory mineral content analysis through Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

Author Contributions

Larissa Leandro da Cruz: conceptualization, methodology, investigation, formal analysis, writing-original draft preparation. Gabriel Moreno Bernardo Gonçalves: formal analysis, writing-Reviewing and Editing Silvia Menezes de Faria Pereira: methodology, investigation, formal analysis. Jamila Rodrigues Barboza: methodology, investigation Luana Pereira de Moraes: writing-Reviewing and Editing Marta Simone Mendonça Freitas: resources, formal analysis, writing-Reviewing and Editing Messias Gonzaga Pereira: finding acquisition, supervision, resources, conceptualization, writing-Reviewing and Editing Daniela Barros de Oliveira conceptualization, resources, writing-Reviewing and Editing, supervision, project administration, funding acquisition.

Funding

This work was supported by the Brazilian organizations: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) (E-26/200.584/2016). The authors are also grateful to the Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF).

Competing Interests

The authors have declared that no competing interests exist.

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