Abstract: Teosinte (Dioon mejiae) is a dioecious tree native to Honduras, whose seeds are used to make flour for the preparation of traditional foods and beverages. The objective was to evaluate the nutritional and physicochemical composition of teosinte flour for the first time. Using diverse techniques, teosinte flour was found to be a high-calorie food rich in total carbohydrates and mainly composed of starch, with an amylopectin:amylose ratio of 2:1 and a concentration of resistant starch greater than 50%. Its proteins were similar to other cereals in which the essential amino acids glutamic acid, leucine, and especially lysine were the most important. Some 75% of its total dietary fiber was insoluble. The fatty acid profile was characterized by a high unsaturated fatty acid content in which oleic acid (C18:1) and linoleic acid (C18:2) predominated. As for minerals, teosinte flour had higher iron content, lower sodium concentration, and similar zinc, calcium, and phosphorus content to other cereal flours. We highlight that teosinte flour has nutrients and qualities that convert it into flour with excellent nutritional abilities and health benefits; it is also a very good industrial and technological alternative to be mixed mainly with types of flour from other sources.

Keywords: Dioon mejiae; teosinte; flour; physicochemical composition; nutritional composition
quicklime, washed on repeated occasions, dried, and then ground to get flour. This cycad species flour is used to prepare typical foods such as bread, donuts, tamales, and tortillas. In addition to the seed, the starch called sago is obtained and used as a dietary supplement by indigenous communities [2]. This cycad species’ seeds have high starch contents and other components of nutritional interest that need to be characterized [3]. To date, no bibliographical information exists in which this cycad species flour is characterized or its nutritional contributions are compared with frequently used products. Based on this assumption, the objective of the present study was to establish the physicochemical and nutritional characterization of teosinte flour.

2. Materials and Methods

2.1. Raw Material

Teosinte seeds (Dioon mejiae) from the community of Rio Grande in the municipality of Gualaco, Olancho, Honduras, were used. Collected seeds were treated with water and quicklime, washed on repeated occasions, dried in the shade at ambient temperature, and then ground in a hand mill to obtain flour, which was sifted in a Mesh 35 (500 μm) sieve. Finally, the flour was stored in sealed plastic bags until further analysis.

2.2. Proximate Analysis

Moisture content (method 935.29), fat (method 954.02), ash (method 923.03), and proteins (method 991.20) were determined according to the AOAC [4]. The total carbohydrate content was calculated by difference [5] and the calorie content was calculated by the Atwater coefficient [6]. Analyses were repeated twice, and each analysis was undertaken in triplicate.

2.3. Determination of Free Sugars

Fructose, glucose, and saccharose were determined by weighing 10 g of this cycad species flour in a 50 mL falcon tube and adding 30 mL of Milli-Q water; ultrasound was applied for 30 min, the tube was heated at 80 °C for 10 min, 5 mL Carrez I and 5 mL Carrez II reagent were added, and the solution was diluted to 50 mL with Milli-Q water. The solution was centrifuged at 5000 rpm for 5 min, 1 mL solution was put in an Eppendorf tube, and underwent ultracentrifugation at 12,000 rpm for 10 min. The previously mentioned sugars were determined with high-performance liquid chromatography (HPLC) equipment consisting of a gradient pump (L-6200A), differential refractometer detector (RI-71, Merck-Hitachi), autosampler (717 plus, Waters®), column oven (Waters®), equipped with a column (Purospher STAR-NH2, 250 × 4.6 mm, 5 μm, Merck) and a precolumn (Purospher STAR-NH2, 4 × 4 mm, Merck), and PC chromatography software (Clarity). The separation was achieved using the method described by Doughty [7], and the injection volume was 10 μL. Acetonitrile-water was used as a mobile phase at a 75:25 ratio in an isocratic mode; the flow was adjusted to 1.2 mL/min, and the column oven temperature was set at 30 °C. Each compound was identified by comparing retention times with the reference standards fructose, glucose, and saccharose (Merck).

2.4. Determination of Fatty Acid Profile

Lipids were extracted using the methodology proposed by Bligh and Dyer [8]. Basically, 10 mL organic phase (lower phase) was filtered with Whatman filter paper N° 1; the filtrate was evaporated in a rotary evaporator at 60 °C and then dried in an air oven at 60 °C for 2 h. Fatty acid methylation was performed using the procedure proposed by Hartman and Lago [9]; the fatty extract was put in a 10 mL glass tube with screw cap, 1 mL NaOH 0.5 N in methanol was added, and it was heated under reflux for 10 min in a water bath at 100 °C. Methylation was then performed by adding 1 mL methylation reagent (1 g NH4Cl in MeOH:H2SO4, 30:1.5) and heated under reflux for 10 min in a water bath at 100 °C. The fatty acid methyl esters were recovered by adding 2 mL saturated NaCl and 1 mL hexane to the methylation tubes. Finally, the tubes were centrifuged until phase separation.
Afterward, 1 mL of the upper phase (hexane) was transferred to 1.5 mL vials and these were analyzed in a gas chromatograph (GC-2010, Shimadzu) equipped with an autosampler (AOC-20i), auto-injector (AOC-20i), FID detector, and a capillary column (100 m × 0.25 mm × 0.20 μm, Rt-2560, Restek) using helium as a gas carrier. The temperature of both injector and detector (FID) was 250 °C. The column oven was programmed with temperature ramps from 120 to 220 °C. The fatty acid methyl esters were identified by comparing with the retention times of a mixture of reference standards of saturated fatty acid (C4-C24) (1000 µg/mL in hexane, analytical standard, 49453-U, Supelco), unsaturated fatty acids (C4-C24) (wt.% varied, analytical standard, 18919-1AMP, Supelco), linoleic acid methyl esters combined with cis-9 and trans-9,11 isomers, and octodecadienoic acid methyl esters cis-10 and trans-12 (05632, Sigma).

2.5. Determination of Amino Acid Profile

The total amino acid profile was determined using the method described by Cohen et al. [10]. A 1 g sample was hydrolyzed with 10 mL 1% phenol in HCl 6 N in a hermetically sealed glass tube and heated at 120 °C for 24 h. Samples were derivatized with phenylisothiocyanate (PITC). Quantification was performed by HPLC with a detector (L-4250 UV-VIS, Merck-Hitachi), 254 nm wavelength, and a column (Hibar® RT 100-4,6 LiChrospher® 100 RP-18 endcapped, 5 μm, Merck). An acetonitrile gradient acetate buffer (pH 6.4) at 30 °C was used as the mobile phase, and the analysis was completed in 37 min.

2.6. Minerals

Iron (Fe), zinc (Zn), calcium (Ca), and sodium (Na) were determined by atomic absorption spectrophotometry (AAS) and flame emission spectrometry according to AOAC 985.3 [4]. The calcined samples were hydrated with 1 mL Milli-Q water and 1 mL concentrated hydrochloric acid for complete solubilization. After 1 h, it was filtered with Whatman filter paper N° 1, diluted to 50 mL with 15 MΩ cm−1 Milli-Q water. The solutions were taken to the AAS (SpectrAA 55, Varian); the quantity of minerals was measured at the corresponding wavelengths with the respective hollow cathode lamps. Iron was determined by a calibration curve with ion concentrations between 0 and 10 ppm. Oxidant flame generated by an air/acetylene mixture was used and readings were taken at a wavelength of 284.3 nm. Zinc was determined by a calibration curve with ion concentrations between 0 and 1 ppm. Oxidant flame generated by an air/acetylene mixture was used and readings were taken at a wavelength of 213.9 nm. Calcium was determined by a calibration curve with ion concentrations between 0 and 5 ppm. Oxidant flame generated by an NO2/acetylene reduction mixture was used and readings were taken at a wavelength of 222.7 nm. Sodium was determined by a calibration curve with ion concentrations between 0 and 2 ppm. Oxidant flame generated by an air/acetylene mixture was used and readings were taken at a wavelength of 589.0 nm.

Phosphorus (P) was determined by the ammonium molybdate spectrophotometric AOAC 995.11 [11] method; the calcined samples were used and hydrated with 5 mL Milli-Q water and 5 mL concentrated hydrochloric acid. The sample was covered with watch glass and then carefully boiled for 5 min on a heating plate to completely solubilize it, filtered (Whatman filter paper N° 1), transferred to a flask, and diluted to 100 mL with 15 MΩ cm−1 Milli-Q water. Finally, the blank, calibration curve, and sample absorbance readings were taken with a UV-VIS spectrophotometer (2PC, Spectronic Genesys) at a wavelength of 660 nm.

2.7. Determination of Dietary Fiber

Dietary fiber was determined by the enzymatic-gravimetric method described in AOAC 991.43 [12]. The dietary fiber fractions, insoluble and soluble, were obtained as non-digestible residues after enzymatic digestion (α-amylase, protease, and amyloglucosidase) of non-fiber components. The dietary fiber composition was determined after acid hydrolysis of the total dietary fiber (TDF) residues. Acid hydrolysis was carried out following the method described by Benítez et al. [13].
2.8. Starch, Resistant Starch, Amylose, and Amylopectin

Starch was extracted using the methodology described by Lucas et al. [14] with some modifications. A 2 ± 0.001 g sample was taken, and 20 mL of Milli-Q water added; it was homogenized with a magnetic stirrer for 10 min and then left to stand for 1 h. The homogenized sample was filtered through a 100 µm mesh and washed with Milli-Q water. Finally, the filtrate was centrifuged at 4000 rpm for 15 min with a centrifuge (Rotofix 32A, Hettich). The precipitate obtained, starch, was oven-dried at 40 °C for 24 h. Resistant starch was determined by the RSTAR 10/15 kit (Megazyme) [15,16]. Amylose was determined using the K-AMYL 12/16 methodology (Megazyme). Amylopectin was determined by the difference between total starch and amylose established in the previous step.

2.9. Scanning Electron Microscopy (SEM)

The morphology of the flour and starch granules was evaluated by SEM (SU 3500, Hitachi). Samples were placed on double-sided carbon adhesive tape, attached to metal slides, and sealed with carbon. The images were taken at an accelerating voltage of 10.0 kV.

2.10. Differential Scanning Calorimetry (DSC)

Differential scanning calorimetry (DSC) was performed on flour and starch samples. The DSC was determined according to the methodology described by Pineda-Gómez et al. [17] with a calorimeter (DSC1, Mettler Toledo). The equipment was calibrated for temperature and enthalpy using indium as a standard (Tm: 156.6 °C; ∆Hm: 28.45 J/g). Samples were placed in hermetically sealed 40 µL aluminum capsules. Approximately 10 ± 0.5 mg flour and starch with 75% moisture content was weighed on an electronic balance (XS205 Dual Range, Mettler Toledo). Once prepared, the samples were left to stand for 30 min. The heating rate was 5 °C/min and heating was controlled from 25 to 130 °C in a nitrogen atmosphere.

2.11. pH

A 20 g sample was mixed with 100 mL Milli-Q water (previously boiled to eliminate CO₂). The pH was measured with a pH meter (A 214, Orion Star,) calibrated at pH 4.0, 7.0, and 10.0. Once calibrated, the equipment was used to take measurements [12].

2.12. Titratable Acidity

Titratable acidity was measured following AOAC 975.11 [4]. An approximate 10 ± 0.001 g sample was weighed, and 10 mL Milli-Q water was added to form a paste; 90 mL hot water was then added and the mixture was homogenized for 5 min. Afterward, it was cooled and 1 mL phenolphthalein was added. The resulting solution was titrated with NaOH 0.1 N until a persistent pale pink color was observed for more than 30 s.

2.13. Water Activity (a_w)

The water activity (a_w) was determined with the equipment (S4TE, AquaLab) and values were recorded at a constant temperature (20 °C).

2.14. Statistical Analysis

Statistical analyses were performed with the STATGRAPHICS Centurion XVI software and α = 0.05 (95% confidence interval). All the experiments were repeated twice and each one was made in triplicate; data were expressed as mean and standard deviation.
3. Results and Discussion

3.1. Chemical and Nutritional Composition

Table 1 shows the nutritional composition of this cycad species flour. It should be noted that the moisture (13.11%), ash (1.56%), and protein (9.67%) content was within established intervals for corn flour, wheat flour, and other botanical sources of flour [17–21], and was similar to values obtained for wheat, green banana, and mesquite flour [20,22]; however, it was lower than for whole wheat flour, which exhibits higher fat content values [21]. Total carbohydrate content in teosinte flour was high, approximately 70%, indicating that this cycad species flour is an important source of carbohydrates, mainly as starch, and its content was similar to values obtained for flour from different wheat cultivars, rice flour varieties, and various cereals [19,21,23].

| Parameters               | g/100 g |
|--------------------------|---------|
| Moisture                 | 13.11 ± 0.20 |
| Ash                      | 1.56 ± 0.03 |
| Proteins *               | 9.67 ± 0.08  |
| Fat                      | 1.16 ± 0.23 |
| Total dietary fiber      | 6.24 ± 0.32  |
| Soluble dietary fiber    | 1.47 ± 0.16  |
| Insoluble dietary fiber  | 4.77 ± 0.19  |
| Total carbohydrates **   | 68.26 ± 0.45  |
| Total starch             | 67.90 ± 0.68  |
| Free sugars              | 0.36 ± 0.01  |
| Glucose                  | 0.12 ± 0.01  |
| Fructose                 | 0.24 ± 0.01  |
| Energy (Kcal/100 g)      | 343.68 |

The values are expressed as mean ± standard deviation; each determination was made in triplicate; *(N × 6.25), ** calculated by difference: 100 – (moisture + protein + fat + ash + fiber).

Likewise, TDF content was greater than 6% (see Table 1) of which three quarters corresponded to insoluble dietary fiber (IDF) and the rest to soluble dietary fiber (SDF). The TDF content found in this cycad species flour was similar to the value observed for rice flour [24] but lower than for whole wheat flour from white sorghum, quinoa, red sorghum, millet, corn, and wheat [21]. However, its high IDF ratio could contribute to bowel regulation, decrease lipid absorption, and lower cholesterol levels [25,26].

The only free sugars identified in teosinte flour were fructose and glucose with concentrations less than 1% (Table 1). Values did not differ from those determined for the same sugars in quinoa or green banana flour [22,27].

As for the caloric contribution of this cycad species flour, the 343 kcal value (see Table 1) was very similar to results obtained in other flour sources, such as in findings reported previously [26,28]. In this way, teosinte flour can be considered as a very good source of caloric intake.

Table 2 shows the composition of teosinte flour starch; starch has a high amylose concentration compared with amylpectin, approximately 2:1. The ratio of these two polymers that constitute starch is technologically relevant, especially for the aging of bread and the thermal properties that starch can have; however, it is also an important nutritional characteristic of starch [26]. This amylose content is important for resistant starch (RS) production because it has been determined that starches with high amylose content have a greater retrogradation ability and therefore higher RS [29,30]. Table 2 also shows the percentage of RS in this cycad species flour, which corresponds to a very high value, more than 30 g of RS in 100 g of teosinte flour; these RS values are much higher than those found in starches native to banana or mango [31] or those determined in green banana flour or legumes [22,32]. According to current literature, the RS value for this cycad species flour would be the highest value detected for plant...
flour for human consumption. This could undoubtedly contribute in many technological aspects of the food industry because this type of starch is being widely used as a thickening and gelling agent and colloidal stabilizer, which are applied in many food, industrial, and pharmaceutical products [33,34].

Table 2. Composition of teosinte flour starch.

| Component     | g/100 g Starch |
|---------------|----------------|
| Amylose       | 30.61 ± 1.13   |
| Amylopectin   | 69.39 ± 1.13   |
| Resistant starch | 52.47 ± 0.83 |

Table 3 displays the values for \( a_w \) and the acidity index for teosinte flour. The \( a_w \) value was 0.59 and it is much lower than the 0.7 value proposed for different types of flour [35]; it can therefore be inferred that this cycad species flour will have a long shelf life if it is stored in a dry environment. Likewise, the acidity index for teosinte flour was 0.1, which is lower than the maximum acidity limit allowed for flour for human consumption in Chile according to the Chilean Food Sanitary Regulations [36], and makes it possible to establish whether or not a product has sustained any deterioration, whether physicochemical or microbiological [37].

Table 3. Water activity and acidity index of teosinte flour.

| Parameter       | Value          |
|----------------|---------------|
| Water activity (\( a_w \)) | 0.59 ± 0.00   |
| Acidity index (%)  | 0.10 ± 0.00   |

3.2. Fatty Acid Profile

The fatty acid profile of teosinte flour is indicated in Table 4. The most abundant fatty acids were oleic acid (18:1), palmitic acid (16:0), and linoleic acid (C18:2). Hager et al. [26] demonstrated that cereals such as oats, wheat, rice flour, and pseudocereal (buckwheat) contained a considerable quantity of oleic acid, while palmitic acid in wheat, oats, and rice was the most abundant saturated fatty acid; these results concur with those obtained in the present study for this cycad species flour. Therefore, consuming teosinte flour would provide health benefits because it has been shown that the intake of oleic and palmitic acid is associated with decreased LDL cholesterol and increased HDL cholesterol, as well as being vasodilators, which lower blood pressure [38]. The quantity of linoleic acid (18:2) found in this cycad species flour was lower than in sorghum, corn, teff, and whole wheat flour in which this fatty acid was more abundant [26].

Table 4 indicates that teosinte flour has a high \( \omega-6 \) content compared with \( \omega-3 \) (32:1 ratio). It is usually recommended that the \( \omega-6/\omega-3 \) ratio be 1:1-2:1 to provide health benefits. However, it has been determined that healthy Western diets can have much higher \( \omega-6/\omega-3 \) ratios ranging from 15:1 to 16.7:1 [39,40]. Thus, this cycad species flour consumption would not cause any serious health problems, although it has been demonstrated that PUFA \( \omega-6 \) and \( \omega-3 \) often compete with each other for the metabolism and act in opposite ways, so that a certain “balance” between the two is required for good health [41,42].
Table 4. Fatty acid profile of teosinte flour.

| Fatty Acids          | g/100 g       |
|----------------------|---------------|
| C4:0                 | 0.02 ± 0.01   |
| C6:0                 | 0.01 ± 0.00   |
| C8:0                 | 0.03 ± 0.01   |
| C11:0                | 0.03 ± 0.00   |
| C12:0                | 0.02 ± 0.00   |
| C12:0                | 0.17 ± 0.01   |
| C15:0                | 0.05 ± 0.00   |
| C16:0                | 21.91 ± 0.14  |
| C16:1                | 0.84 ± 0.00   |
| C17:0                | 0.24 ± 0.00   |
| C18:0                | 5.43 ± 0.03   |
| C18:1-trans (n-9)    | 0.06 ± 0.00   |
| C18:1-cis (n-9)      | 47.16 ± 0.06  |
| C18:2-trans (n-6)    | 0.08 ± 0.00   |
| C18:2-cis (n-6)      | 14.95 ± 0.04  |
| C20:0                | 1.42 ± 0.01   |
| C20:1                | 0.51 ± 0.06   |
| Cla2                 | 0.36 ± 0.00   |
| Cla3                 | 0.29 ± 0.00   |
| C20:2                | 0.79 ± 0.01   |
| C22:0                | 2.35 ± 0.02   |
| C22:1n-9             | 0.10 ± 0.01   |
| C23:0                | 0.14 ± 0.00   |
| C20:5n-3             | 0.46 ± 0.01   |
| C24:0                | 0.14 ± 0.01   |
| ΣSFA *               | 31.99 ± 0.10  |
| ΣMUFA **             | 48.70 ± 0.11  |
| ΣPUFA ***            | 16.95 ± 0.03  |
| Σω-3                 | 0.46 ± 0.01   |
| Σω-6                 | 14.95 ± 0.04  |
| n-6/n-3              | 32.5          |
| ΣCLA                 | 0.65 ± 0.01   |
| ΣMUFA + PUFA         | 65.64 ± 0.09  |

The values are expressed as mean ± standard deviation; each determination was made in triplicate; * SFA: saturated fatty acids; ** MUFA: monounsaturated fatty acids; *** PUFA: polyunsaturated fatty acids.

3.3. Amino Acid Profile

The amino acid composition is shown in Table 5. Higher amino acid concentrations were detected for leucine, glutamic acid, proline, tyrosine, phenylalanine, and arginine, but they were lower for aspartic acid, valine, lysine, isoleucine, alanine, glycine, and serine. It has been established that in cereals such as wheat, rice, maize, sorghum, and barley, lysine was a limiting amino acid [43,44]. This is not the case for this cycad species flour, which has considerable quantities of this essential amino acid, 0.51%, doubling the content when compared with the previously mentioned cereals and whose content was only surpassed by the quinoa, amaranth, and buckwheat pseudocereals with substantially higher lysine and histidine. Just as for legume flour, teosinte flour is deficient in amino acids such as methionine and cysteine, but high in arginine compared with cereals. The significant differences in the essential amino acid content between the results obtained in the present study and those reported previously [43,44] in cereal grains and pseudocereals could be attributable to multiple factors. However, we believe that it was mainly due to variations in genomic expression caused by plant type and environmental and soil conditions; these factors directly influenced the chemical composition. Given the high lysine and low methionine content present in this cycad species flour, we consider that its use in a mixture with other types of flour could contribute to enriching flour that is low in lysine, such as...
cereal flour. As for essential amino acids, we emphasize that teosinte flour was rich for most of them. According to the requirements established by the World Health Organization [45], 100 g of this cycad species flour could contribute more than 25% of most amino acids for a 70 kg adult, as is the case with the histidine, lysine, isoleucine, leucine, threonine, valine, phenylalanine, and tyrosine. This reinforces the idea that mixing teosinte flour with other types of flour would be a very interesting nutritional and technological alternative.

Table 5. Amino acid profile of teosinte flour.

| Amino Acid   | g/100 g  |
|--------------|----------|
| Lysine       | 0.51 ± 0.03 |
| Phenylalanine| 0.71 ± 0.02 |
| Tyrosine     | 0.73 ± 0.02 |
| Methionine   | 0.08 ± 0.01 |
| Cystine      | ND *     |
| Threonine    | 0.48 ± 0.01 |
| Leucine      | 1.37 ± 0.04 |
| Isoleucine   | 0.49 ± 0.01 |
| Valine       | 0.51 ± 0.01 |
| Aspartic acid| 0.57 ± 0.03 |
| Glutamic acid| 1.28 ± 0.06 |
| Serine       | 0.43 ± 0.01 |
| Histidine    | 0.18 ± 0.02 |
| Arginine     | 0.62 ± 0.01 |
| Alanine      | 0.44 ± 0.00 |
| Proline      | 0.81 ± 0.01 |
| Glycine      | 0.43 ± 0.02 |
| ΣTotal       | 9.63 ± 0.33 |

The values are expressed as mean ± standard deviation; each determination was made in triplicate; * ND: not detected.

3.4. Mineral Content

Some mineral contents are displayed in Table 6, indicating that this cycad species flour is rich principally in P, Ca, and Fe. Hager et al. [26] reported the mineral composition for different types of flour, including whole wheat and buckwheat in which the P and Ca contents were similar to those obtained in the present study. However, the Ca content in teosinte flour, 14.86 mg/100 g flour, was lower than the content in amaranth, chia, green banana, oat, quinoa, rye, sesame, soybean, sunflower seed, and white bean flour [46]. The value of Fe determined in this cycad species flour was similar to that obtained in amaranth, corn, and eggplant flour [46]. The Zn and Na values for teosinte flour were also similar to those found for buckwheat, corn, rice, chestnut, and wheat flour [47].

Table 6. Mineral content of teosinte flour.

| Mineral       | Content (mg/100 g) |
|---------------|-------------------|
| Iron (Fe)     | 6.85 ± 0.63       |
| Zinc (Zn)     | 1.46 ± 0.13       |
| Calcium (Ca)  | 14.86 ± 1.86      |
| Sodium (Na)   | 0.86 ± 0.07       |
| Phosphorus (P)| 241 ± 0.01        |

3.5. Teosinte Flour and Starch Morphology by Scanning Electron Microscopy (SEM)

Figure 1 illustrates the first teosinte flour micrographs (Figure 1a) and starch granules (amyloplasts) (Figure 1b). Figure 1a,b shows that the flour and starch particles are ovoid. The teosinte flour granules (Figure 1a) were irregular, deformed, and truncated particles adhered to the starch granules, which could be associated mainly with protein aggregates and other cell debris components, as opposed to
extracted starch granules (Figure 1b) that showed amyloplasts free of particulate matter. Starch granule size in this cycad species flour (Figure 1b) ranged from approximately 5 to 18 µm, and had a mean size close to 13 µm. Starch granule morphology can be attributable to botanical origin, amyloplast biochemistry, fruit ripeness, and plant physiology; it has been verified that the granule size in some starches was related to the amylose/amylopectin ratio [48]. Starch granule size of this cycad species flour was similar to findings in other cereal species such as maize, waxy maize, wheat, and sago [49], as well as those determined in *Xanthosomas agittifolium*, sweet potato, yucca, and mango starches [50,51].

![Figure 1](image-url)  
*Figure 1.* Micrographs obtained by scanning electron microscopy (SEM) for teosinte flour (a) and teosinte starch (b).

### 3.6. Teosinte Flour and Starch Gelatinization Thermal Properties

Table 7 displays the gelatinization transition temperatures as onset temperature (T₀), peak temperature (Tₚ), and conclusion temperature (Tₖ), as well as the transition enthalpies ΔH (J/g) determined by DSC for this cycad species flour and starch. Temperatures showed that as temperature increased, starch granules tended to collapse until finally, their amorphous part (amylose) was completely solubilized, while the crystalline part of the starch was kept in aqueous solution; as the process approached the end, the system returned to a state in which there were no changes in the phase or composition of the sample, and this was similar to findings described previously [14,52]. The T₀, Tₚ, and Tₖ values for teosinte flour and starch were higher than those for hard and soft corn endosperm [53]; however, they were similar to values for starch isolated from white sorghum, red sorghum, millet, and corn [21].

|        | T₀ (°C) ± SD | Tₚ (°C) ± SD | Tₖ (°C) ± SD | ΔH (J/g) ± SD | ΔT (Tₖ-T₀) ± SD |
|--------|-------------|-------------|-------------|---------------|-----------------|
| Flour  | 77.92 ± 0.35| 82.28 ± 0.72| 87.13 ± 0.91| 1.37 ± 0.25   | 9.21            |
| Starch | 70.97 ± 0.08| 75.07 ± 0.00| 79.60 ± 0.06| 1.21 ± 0.05   | 8.69            |

T₀ = onset temperature, Tₚ = peak temperature where the highest values of heat absorption are recorded, Tₖ = conclusion temperature, ΔT = gelatinization temperature range. The values are expressed as mean ± standard deviation; each determination was made in triplicate.

Enthalpy values for teosinte flour and starch were relatively low; this can be attributed to starch gelatinization and the crystalline structure preserved by some starch granules, as well as to the lack of homogeneity of the ordered structures of the granules [14,54]. These enthalpy values also concurred with those found in different varieties of rice flour [23]; however, values were lower than enthalpies for white sorghum, red sorghum, corn, wheat, quinoa, amaranth, and millet whole flour [21].
4. Conclusions

Our results show that this cycad species flour is a highly caloric food with high total carbohydrate content that mainly consists of starch, highlighting its high amylopectin content (2:1 ratio to amylase) as well as its high concentration of resistant starch (more than 50%). The protein concentration of teosinte flour was similar to that of other cereals, which included glutamic acid, leucine, and especially lysine, providing more than 25% of these essential amino acids for a 70 kg adult. Some 75% of total dietary fiber was insoluble. Starch granules (amyloplasts) had an ovoid morphology and an approximate mean diameter of 13 µm. The starch gelatinization temperature in this cycad species flour was 82.28 °C, while it was 75.07 °C for extracted starch. The quantity of lipids was 1.16 g/100 g and the fatty acid profiles were characterized by the high unsaturated fatty acid content predominated by oleic acid (C18:1) and linoleic acid (C18:2). As for minerals, teosinte flour had a higher Fe content, lower Na concentration, and similar Zn, Ca, and P content as other types of cereal flour. Therefore, teosinte flour has nutrients and qualities that provide it with excellent nutritional and health benefit abilities, as well as a very good industrial and technological alternative to be used mainly in mixtures with other types of flour from other sources.

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