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ORIGINAL PAPER

Physicochemical, thermal, rheological and morphological characteristics of flour and starch from a non-conventional source: *Cucurbita foetidissima* Kunth roots

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Abstract

Starch is a biopolymer which demand has increased because of its multiple industrial applications. The present work was performed to characterize, both flour and starch obtained from *Cucurbita foetidissima* root as a non-conventional source. According to its physicochemical, rheological (flow curves), thermal and morphological properties. The flour was composed of a 77% total of carbohydrates, and the isolated starch showed 88% purity. Granules found in both samples exhibited birefringence and mixed morphology. Particle size distribution varied from 1 to 35 µm for flour and from 1 to 29 µm for starch. The *k* and *n* indices from their evaluated suspensions at 25, 50 and 70 °C indicated a non-Newtonian behavior of pseudoplastic type for both materials. Gelatinization temperature was 63.58 ± 3.08 °C with $\Delta H = 5.64 \pm 3.81$ J/g for flour, and of 66.50 ± 0.06 °C with $\Delta H = 12.27 \pm 0.17$ J/g for starch. XRD patterns were mixed A and B, characteristic of cereal starches and rubbers, with changes in the crystallinity percentage with each other. These materials characteristics are similar to those of other sources such as cassava (*Manihot esculenta*), but different from cereals as corn (*Zea mays*), and other tubers, as potato (*Solanum tuberosum*).

Keywords Calorimetry · Color · Flow curves · Starchy material · Viscosity

Introduction

Starch is a polysaccharide synthesized in the form of semi-crystalline granules stored in different organs of plants. Functionality and physical organization inside starch's granular structure is due to the proportion and arrangement of its components, known as amylose and amylopectin [1], which confer distinctive physicochemical and functional properties, according to the botanical source [2, 3]. Cereals are the main raw material for obtaining this polysaccharide, followed by tubers, such as potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*) [4]. For this reason, the most commercial starches are obtained from corn (*Zea mays* L.) and potato (*S. tuberosum*), and nowadays it is estimated that more than 80% of the starch produced worldwide is acquired from corn cereal [5].

In general, starch is the main component on the flours of many seeds, cereals and tubers [6]. Non-food ingredient is compared with this carbohydrate in terms of versatility and application in the industry since it is used as a binder,

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thickener, emulsifier, among other uses [7], with properties of pastes formation, gels and with the capacity of biodegradable films formation [8]. That is why, it is necessary to investigate about other non-conventional botanical sources of starch so as to be aware if those have functional properties with alimentary and no alimentary purposes [9, 10].

In these research, one of the non-conventional sources could be buffalo gourd (*Cucurbita foetidissima* Kunth), a weed plant with multiple advantages, among which stands out the one of being a wild xerophytic specie [11] which does not require demanding agronomic care, grows on flat land with variable texture soil, although it prefers burdensome [12], so it could be grown on abandoned land in order to make them productive, as has been shown in previous studies [13, 14]. Moreover, *C. foetidissima* Kunth may represent a potential starch's non-conventional source since it has been reported up to 52% of this carbohydrate (dry-base) in its tuberous roots [15–18]. Therefore, it is necessary to characterize both the flour and starch obtained from its roots, in order to visualize its feasible applications in the different fields of industry. This is important since the latest studies on this plant have been focused on other components, such as saponins and phytochemicals with bioactive properties, such as foetidissimin [19], foetidissimosides [20] and cucurbitacins [21], and there are no reports about their flour and starch. For this reason, in the present study a physicochemical, thermal, rheological and morphological characterization of both flour and starch obtained from *C. foetidissima* Kunth was carried out, since it is an alternative botanical source and harvested under different conditions from those materials already reported, so it is interesting to explore their potential as a raw material so as to obtain starch whose functional properties can be exploited in various fields of industry.

Materials and methods

Materials

Buffalo gourd (*C. foetidissima* Kunth) roots were collected at a wild area at 'Universidad Autónoma Agraria Antonio Narro', in Buenavista, Saltillo, Coahuila, Mexico, which geographical coordinates are 25° 2″ NL and 101° 02″ WL, at an altitude of 1742 mamsl [22]. Roots were extracted manually, preventing damage on the tissues, afterwards they were transported to the laboratory and washed with running water to mainly remove soil excess, stones and straw. Samples were disinfected by immersion in a 5% sodium hypochlorite solution for 30 min and washed with water, they were then barked, and tissue of interest was removed. A fresh sample was kept for proximal analysis. The remaining material was cut into thin slices (< 1 cm) to facilitate drying and subsequent grinding.

Buffalo gourd roots flour obtaining (BGRF)

The biological material was dried in a forced convection oven Novatech® (Avante Tecchnology, S.A. de C.V., Tlaquepaque, Mexico) at 40 °C for 24 h. It was then processed in a knife mill Wiley™ (Thomas Scientific, Swedesboro, NJ, USA) using a 1 mm mesh opening, it was screened in mesh No. 60 (eliminating most of the fiber), it was finally storage in medium tight bags of 18 × 20 cm (Ziploc®, Johnson y Sons, Inc., Racine, WI, USA).

Buffalo gourd root starch isolation (BGRS)

This stage was carried out through humid via, following the methodology reported by Tirado-Gallegos et al. [23], with variations. Just extracted roots, from ground, were washed with water barked and cut into buckets of 3 × 3 cm, they were ground three times in an Oster® blender (Newell Brands Mexico, S.A. de C.V., Mexicali, Mexico) with potable water, using a mesh strainer of 1 mm and subsequently filtered on linen cloth, decanting and filtering repeatedly with cold water (5 ± 1 °C) up to having pH ≈ 7.0 in the suspension (equivalent to the wash water).

Once the humid starch paste was obtained, it was dried in a forced convention stove Novatech® (Avante Technology, S.A. de C.V., Tlaquepaque, Mexico) at 40 ± 2 °C for 24 h. Starch was defatted twice with 250 mL of anhydrous petroleum ether ACS Fermont® (Productos Químicos Monterrey S.A. de C.V., Monterrey, Mexico) at a temperature of 25 ± 2 °C, in continuous stirring for 30 min in an extraction hood; then it was washed three times with 500 mL no distilled water and finally twice with absolute ethanol. The resulting paste was dried at the same temperature in an extraction hood to remove solvent residues, ground in porcelain mortar, screened in mesh #140 (ASTM) and storage in medium size tight bags of 18 × 20 cm (Ziploc®, Johnson and Sons, Inc., Racine, WI, USA). The procedure was repeated as many times as needed in order to have enough material.

Proximal characterization and color evaluation

Fresh root's pulp and both BGRF and BGRS samples were analyzed in triplicate, according to AOAC's official methods [24] to determine moisture content (method 925.45), protein (method 968.05), total fat (920.39 method) and total ashes (method 923.03). Color evaluation was carried out on a Minolta CR300 colorimeter (Konica Minolta Holding, Inc., Tokyo, Japan). Equipment was calibrated with a white standard provided by the manufacturer. Lectures were taken at random points on the sample's surface. Five lectures

per sample were registered and evaluation was reported on CIELab scale [25].

Morphological characterization and particle size using scanning electron microscopy (SEM) and polarized light optical microscopy

A dilution of each material was made at 1% (w/v) in distilled water at room temperature (20 ± 2 °C). An aliquot was taken and observed in polarized light microscope Carl Zeiss™ AXIO SCOPE.A1 at 400× (Oberkochen, Germany) to determine the presence of birefringence. Later, particle size distribution was analyzed in six fields using APHELION™ LAB (ADCIS 2017, Versión 4.4.0, Saint-Contest, France) software. Morphology was observed by SEM, samples were fixed on carbon tape and coated with silver in Denton Vacuum™ Desk V (Corporate Headquarters Denton Vacumm, Mooreston, USA) equipment. Samples were subsequently observed in a scanning electron microscope Jeol™ JMS-70000F (JEOL, Ltd., Tokyo, Japan) with a magnification of 1000 times with an intensity of 15 kV.

FTIR analysis

This analysis was carried out to confirm materials chemical structure (type of links as well as functional groups present in the sample). One FTIR Perkin Elmer SPECTRUM TWO (PerkinElmer Inc., Waltham, USA) spectrophotometer was used through the methodology reported by Mano et al. [26].

Rheological properties

Viscosity profile was determined in both materials using the technique established by the AACC [27] at temperatures of 25, 50 and 70 °C. An effort control rheometer AR1500ex (TA Instruments, New Castle, USA) was used. Methodology reported by Morales et al. [28] was conducted to obtain this determination. The rheological variables of consistency index were obtained (k) as well as flow behavior index (n) according to the model of Power Law.

Differential scanning calorimetry (DSC)

BGRF and BGRS thermal properties were determined in a differential scanning calorimeter Perkin Elmer DSC4000 (PerkinElmer Inc., Waltham, USA) following the methodology reported by Paredes-López et al. [29]. From the obtained thermograms, thermal properties of onset (T_i), peak (T_p) and end gelatinization temperature (T_f), as well as gelatinization enthalpy (ΔH), were obtained by using Pyris™ version 11.0 (PerkinElmer Inc., Waltham, USA) software. The range of gelatinization (ΔT) was determined by subtracting (T_i) from (T_f).

X-ray diffraction analysis (XRD)

Diffractogram for both samples, were obtained using the modify methodology reported by Tirado-Gallegos et al. [23], in a PANalytical model Empyrean (Malvern PANalytical Inc., Malvern, UK), with CuKα (λ = 1.54 Å) radiation in the range of 2θ = 10– 80° at 0.02°/s scanning speed, and 40 kV and 30 mA, at room temperature. Crystallinity percentage was calculated with the following equation: $Crystallinity\ \% = (crystalline\ area/total\ area) \times 100$. Diffractograms peaks were integrated with the software Origin® 8.0 (OriginLab Co., Massachusetts, USA), taking the interval of 2θ = 10–35°, where the materials main peak.

Statistical analysis

Determinations were made in triplicate with a completely randomized design. The results were subjected to a one-way variance analysis (ANOVA). Means were separated by Tukey Test ($p \leq 0.05$), using SAS 9.0 software (SAS System, Cary, NC, USA).

Results and discussion

Proximal characterization

Out of drying, grinding and sieving operation form fresh roots, a fine powder was obtained. Flours yield from whole and dry roots pulp was 33%, this yield may be attributed to fibers elimination during processing. Some researchers have reported that tuberoses roots and tubers contain some amount of insoluble fiber, these amounts may variate according to the specie [30, 31]. Total carbohydrates content in BGRF (Table 1) was higher than other tropical tubers such as cassava (62.23%), reported by Castaño-Peláez et al. [32], and a lower starchy content was evidenced in the studied material compared to Alonso et al. [33] reports for potato flour (92.56%). Charoenkul et al. [34] reports indicate a similar starch content of (85.99%) in cassava (starch known as tapioca); while in pre-cooked corn flour, Toro et al. [35] determined a starch content of 79.35%, which is lower than the one obtained in this.

BGRF protein's content decreased significantly on starch isolation, due to its solubility as it happened on ashes (mineral salts) content, which were eliminated on the successive washes, as well as fiber, that because of its lower density may be removed by decanting. Total fats were also decreased as a result of the material's degreasing process, leading to have a carbohydrate concentrated sample. These components elimination could cause various effects on the rheological and thermal characteristics of the final material, which are discussed in further sections.

Table 1 Bromatological profile of fresh buffalo gourd root, BGRF and BGRS

Material	Proximal composition (%)[A]				
	Protein	Fat	Ash	Moisture	Total carbohydrates[B]
Fresh root	3.99 ± 0.26^{b}	0.46 ± 0.10^{b}	0.87 ± 0.07^{b}	74.7 ± 0.01^{a}	19.98 ± 0.20^{c}
BGRF	10.90 ± 0.07^{a}	0.58 ± 0.08^{a}	2.58 ± 0.02^{a}	8.46 ± 0.01^{b}	77.48 ± 0.04^{b}
BGRS	$0.82 + 0.02^{c}$	$0.21 + 0.03^{c}$	$0.42 + 0.07^{c}$	$9.71 + 0.02^{b}$	$88.14 + 0.02^{a}$

[A]Arithmetic mean of three repetitions ± standard error. Equal letters in the same column are not significantly different according to Tukey's test ($p > 0.05$)

[B]Obtained by difference

Table 2 BGRF and BGRS color's profile

Material	Color variable[A]		
	L*	a*	b*
BGRF	94.54 ± 0.09^{b}	-0.60 ± 0.03^{b}	8.67 ± 0.21^{a}
BGRS	97.07 ± 0.04^{a}	-0.44 ± 0.01^{a}	2.85 ± 0.01^{b}

[A]Arithmetic mean of three repetitions ± standard error. Equal letters in the same column are not significantly different according to Tukey's test ($p > 0.05$) between materials at same temperature

Color

Color variable evaluation is shown in Table 2. BGRF exhibited, that luminosity (L*) and the valor of a* are similar to those reported by Rożnowski et al. [36] for potato native starch (L* = 93.71 ± 0.27, a* = -0.57 ± 0.04, b* = 1.86 ± 0.06), despite these researchers gotten lower *b** values, which suggests the presence of other different components to starch in BGRF. After starch's isolation, L* value increased having a higher whiteness (L* ≈ 97) in BGRS sample than the value reported for potato native starch (L* = 93.71), and the values of a* y b* decreased (compared to BGRF sample), which indicated non starchy components elimination present in BGRF, such elements may be natural pigments residues present in raw material, so according to Palomino et al. [31] this is indication of the purity.

Morphological characterization and particle size distribution

Starch granules present in BGRF (Fig. 1a and b) and BGRS (Fig. 1c and d) presented ovoid, spherical, semi-spherical, polyhedral and amorphous forms, congruent with what was reported by Hoover [18]. These starches showed different characteristics with respect to other types of starches such as corn [1] or potato [37, 38], which generally have mostly uniform geometric structures (homogeneous). Regarding to heterogeneity of the granules in the BGRF and BGRS samples, these are similar to those of other tubers, such as makal (*Colocasia esculenta*), the sago (*Maranta arundinacea* L.) or the occumo (*Xanthosoma sagittifolium*) [31, 39]. In the granules of both materials the characteristic Maltese cross due to the birefringence phenomenon was also observed, this as a result of the molecular structure of the semi-crystalline arrangement of amylose and amylopectin, generally found in native starches [40].

In Fig. 1a and c it can be observed some other smaller size particles, which may correspond to other components, mainly fiber residues, which constitutes the cellular structure, as this is an important part of the proximal composition in tuber meal and tuberous roots [41]. Once the BGRS isolation process was performed, granules of a mostly smooth and clean surface were observed (Fig. 1b and d), due to the elimination of the remains of non-starchy cellular structures, which resulted in the luminosity factor increment (L*) (Table 2). This is consistent with the results of the proximal analysis, which shows the elimination of non-starchy components and their concentration, affecting directly the rheological, thermal and structural properties.

In relation to particle size distribution (Fig. 1e), tendency was that of a normal type distribution with positive bias in both materials, consistent with the distribution reported by other authors in samples of flours and starches of other roots and tubers, such as cassava (tapioca), potato and jicama (*Pachyrhizus erosus*) [42–44]. The particle size range of the BGRF was 1–35 µm, with an average value of 7 µm, grouping 55% of the granular population with values µm of 4–10 µm; while for the particle size of the BGRS, the total range was from 1 to 29 µm, with an average value of 10 µm, grouping 57% of the granular population, with values ranging between 7 and 13 µm. These measures were lower than those reported for granules of potato starch, wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and banana (*Musa paradisiaca*) and similar in size with sweet potato starches, cassava and some varieties of corn and rice (*Oryza sativa*) [45–47]. The change in particle size distribution could be due to grinding and screening processes, which could cause mechanical damage and fragmentation of the granules, as was recently reported by Srichuwong et al. [6]. The particle size was consistent with the type of rheological properties determined for this material, and which are discussed below, because a smaller particle size is related to the decrease in *n* and *k* values, as reported in several studies [31, 48–50].

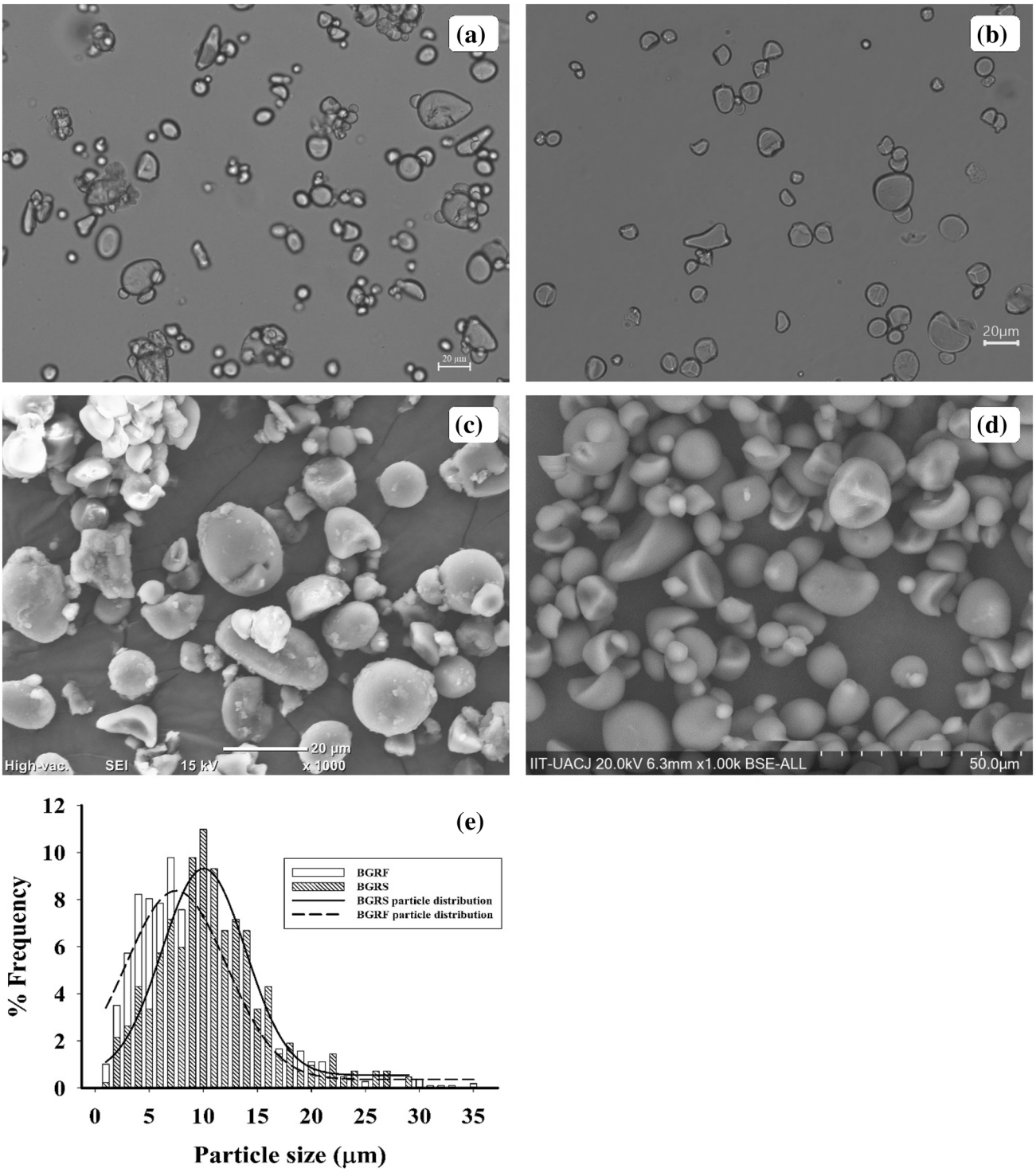

Fig. 1 BGRF and BGRS micrographs obtained by transmitted light optical microscope at 400 × (**a** and **b**, for BGRF and BGRS samples, respectively), micrographs obtained by scanning electronic microscope at 1000 × (**c** and **d**, for BGRF and BGRS samples, respectively) and **e** BGRF and BGRS particle size distribution

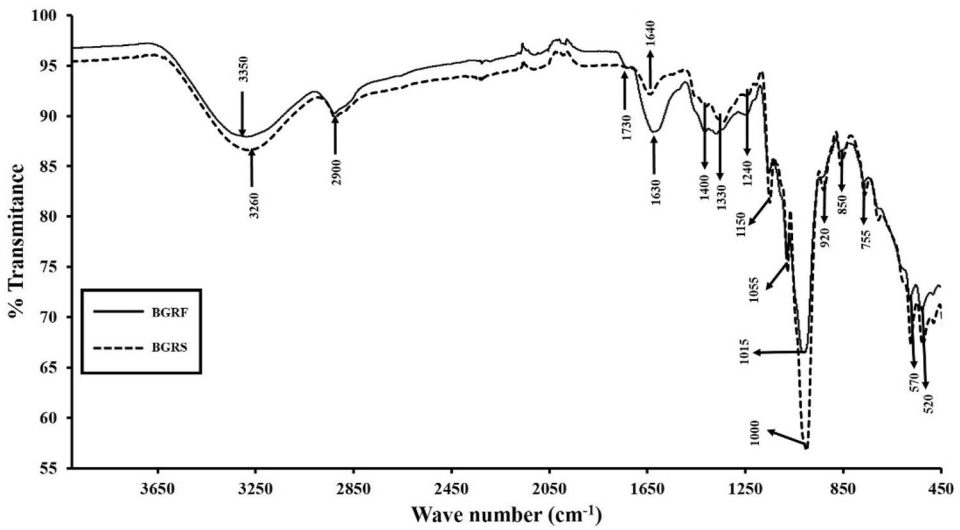

Fig. 2 BGRF and BGRS samples FTIR spectra

FTIR analysis

The resulting FTIR spectra for both materials (Fig. 2), exhibited bands and peaks characteristics for starch biopolymers [51, 52]. These signals are presence of a broad absorption band between 3,300–3,400 cm^{-1}, corresponding to the presence of OH^- groups. Likewise, a band at 2,900 cm^{-1} attributed to the CH_2 groups was observed. Around 1600 cm^{-1} there was a stretch related to the water bound. In the region of the "fingerprint" peaks were observed in the area of 1000 cm^{-1} corresponding to the vibrations of the C–O–C junctions of glucose and close to 900, 800, 700 and 550 cm^{-1}, which are attributed to the pyranic ring [53]. The difference in intensity in the 1600–1700 cm^{-1} band is noteworthy, which is related to the presence of amide groups of secondary proteins [54]. This was more intense for the BGRF due to a greater amount of proteins present in the composition of this flour (Table 1). Kumar et al. [55] state that the presence and composition of proteins and starches affect the quality and properties of food products, such as the case of the rheological and thermal properties described below.

Rheological properties

Regarding to the rheological variables, the flow curves of the two materials were adequately adjusted to the model of the Power Law ($R^2 \geq 0.95$). The trends of shear stress *vs* shear rate (Fig. 4) resulted in a negative correlation of *k* value with respect to the temperature increment for both BGRF and BGRS, that is, the *k* value decreased as temperature increases in both samples analyzed (Table 3).The material obtained from other botanical sources, such as cassava [56] showed a similar behavior, and in starches of the chayote (*Sechium edule*) and potato tubers [57] the same behavior

Table 3 Rheological variables of the BGRF and BGRS obtained by the Power Law model at three temperatures

Material	Temperature (°C)	Rheological variables[A]		
		k (Pa × s^n)	*n*	R^2
BGRF	25	7.54 ± 0.85a	0.54 ± 0.05b	0.950
BGRF	50	4.21 ± 1.08b	0.60 ± 0.08a	0.964
BGRF	70	2.33 ± 0.94b	0.62 ± 0.09a	0.970
BGRS	25	0.56 ± 0.01[a]	0.57 ± 0.01[a]	0.997
BGRS	50	0.42 ± 0.01[b]	0.56 ± 0.01[b]	0.998
BGRS	70	0.29 ± 0.01[c]	0.57 ± 0.01[a]	0.999

[A]Arithmetic mean of three repetitions ± standard error. Equal letters in the same column in each material (BGRF and BGRS) are not significantly different according to Tukey's test ($p > 0.05$)

was determined using a concentration similar to that used in this study; but with higher values in the shear stress (≈ 200 and 120 Pa), so, in practical terms, it was shown that the dispersions of the materials obtained from *C. foetidissima* Kunth root have a lower viscosity with respect to those obtained from other sources, although an increase in the value of this variable could be observed once the BGRS was isolated (Fig. 3).

On the other hand, the flow values behavior index (*n*) evidenced a non-Newtonian behavior of the "shear thinning" type known as pseudoplastic in both materials (Fig. 3a), with the characteristic viscosity reduction *vs* the increase in shear stress (Fig. 3b), as referenced by Morales et al. [28] and Enríquez-Castillo et al. [58] For the BGRF sample, a negative correlation with the increase in temperature, similar to that observed with the *k* index, in the value of *n*, was observed (Table 3), without difference between the values determined at 50 and 70 °C, but at 25 °C, which could be related to the presence of components other than

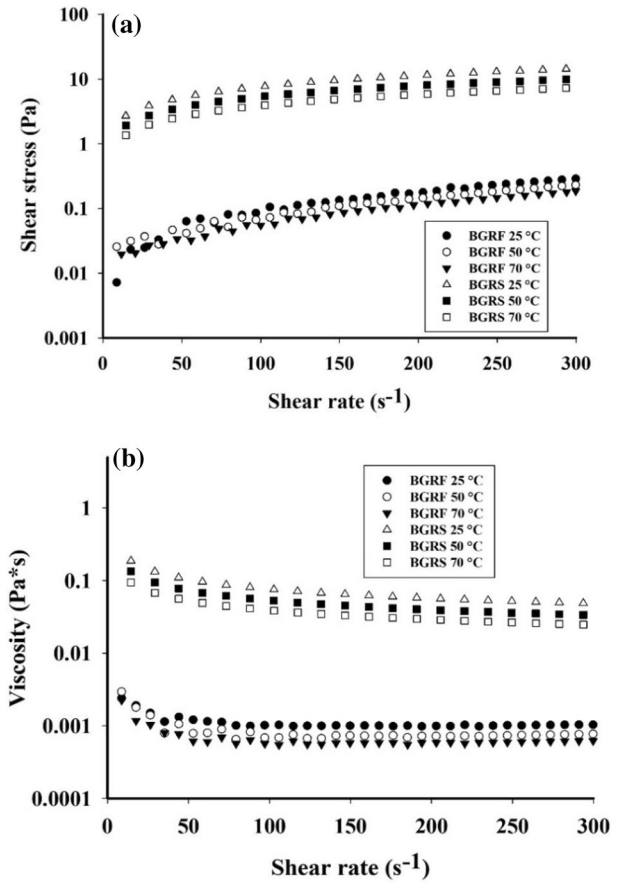

Fig. 3 **a** Variation of shear stress *vs* shear rate (0.600 and 300 s^{-1}) and **b** Viscosity variation *vs* shear rate in BGRF and BGRS at three different temperatures (25, 50 and 70 °C)

starch in the analyzed material, such as fat, protein or even fiber residues, which structural morphology, composition and, mainly material's physical state at room temperature, would impede the transit between particles in the dispersion used [40], which would be modify with the temperature increment; however, this was not observed in the BGRS sample, which presented independent values with respect to temperature (Table 3), with greater adjustment to model of the Power Law that the BGRF sample, with values of $R^2 > 0.99$, suggesting the existence of homogeneity in the particles composition within the dispersion used, resulting in less hindered flow and, therefore, of greater uniformity. Which is interesting from the point of view of the possible applications that the BGRS could have.

In agreement with Casarrubias-Castillo et al. [59] the flow properties are related to the size of the granules, but to a greater extent with the internal structure of its components; that is, with the proportion and ratio of amylose/amylopectin [57, 60]. Therefore, it can be deduced that the difference between the materials studied, regarding the behavior of the rheological variables was caused by the purification process of the BGRF sample to obtain BGRS, since during the starch isolation process several small particles were removed, most of them being non-starchy components, in addition to the fact that larger starch granules were fragmented, which was evidenced in the variations observed in the particle size distribution analysis (Fig. 1e).

Thermal properties by DSC

The gelatinization transition of BGRF sample (Table 4) occurred at a peak temperature (T_p) of 63.58 ºC, similar to that T_p reported by Zamudio-Flores et al. [61] for oatmeal flour (61.90 °C), but lower to that observed by Pineda-Gómez et al. [62] (70.95 °C) for raw corn flour (without thermal treatment) and by Charoenkul et al. [34] for cassava flour (73.95 °C). Besides, this transition happened in a temperature interval ($\Delta T = T_f - T_i$) of 11.84 °C, which is lower than that reported for this variable in cassava flour (13.71 °C) and raw corn (24.29 °C), and higher than that for oatmeal flour (10.03 °C), according to the previously mentioned authors. The enthalpy, which represents the necessary energy to carry out the phases change process (gelatinization), was 5.64 ± 3.81 J/g for BGRF, lower than that reported for cassava flour (11.4 ± 0.1 J/g) [34] and oatmeal (8.25 ± 0.81 J/g) [61]; but superior to that for raw corn (1.429 J/g) [62], reported by the same authors.

In a study on the thermal properties of cornmeal [62], it was concluded that these may be associated with the characteristics of the granule, which is similar to that reported by Narváez-González et al. [52]; thus, in this study, in comparison with BGRF sample, the BGRS presented an increase in the values of its thermal properties (Table 3), which may be consequence of other components elimination, as fats and proteins, that may impact the thermal properties, exhibited on lower values of these properties in BGRF. The variable

Table 4 Thermal analysis of the BGRF and BGRS by DSC

Material	Thermal variables[A]				
	T_i (°C)	T_p (°C)	T_f (°C)	ΔT (°C)	ΔH (J/g)
BGRF	59.35 ± 2.41[b]	63.58 ± 3.08[b]	71.19 ± 4.54[b]	11.84 ± 2.13[b]	5.64 ± 3.81[b]
BGRS	62.06 ± 0.09[a]	66.59 ± 0.05[a]	75.33 ± 0.17[a]	13.27 ± 0.07[a]	12.61 ± 0.17[a]

[A]Arithmetic mean of three repetitions ± standard error. Equal letters in the same column are not significantly different according to Tukey's test ($p > 0.05$) between materials at same temperature

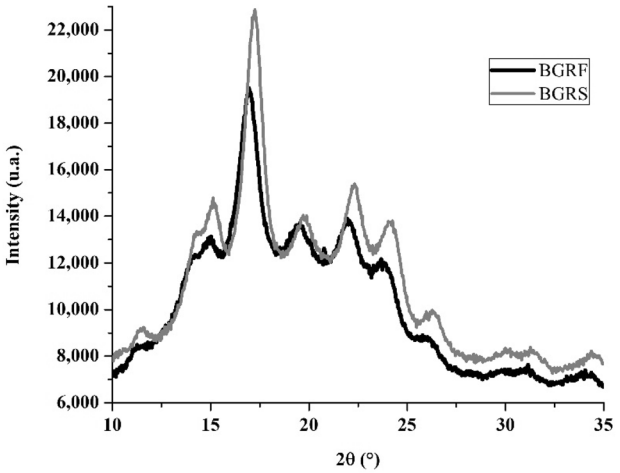

Fig. 4 X-ray diffraction patterns for buffalo gourd (*C. foetidissima* Kunth) root flour and starch

T_p was 2.92 °C above the value obtained for BGRF, and the thermal variables T_i y T_f also increased 2.86 and 3.81 °C, respectively, in BGRS sample compared to BGRF. An increment of 1.43 °C was also observed in the thermal variable of ΔT, and an increase in ΔH, obtaining a difference of 6.63 J/g in BGRS with respect to BGRF. This is consistent with a less orderly arrangement of polysaccharide chains in small granules, such as those on BGRF and BGRS, whose crystals might be less stable [51, 63]. The increase in these thermal variables extends the feasibility of using the BGRS sample in the same applications as other tuber starches such as yam (*Dioscorea alata*), cassava (*M. esculenta*) and potato (*S. tuberosum*), reported by Alvis et al. [64].

XRD analysis

X-ray diffractograms (Fig. 4) obtained from each material showed that the crystalline structure corresponds to mixed type amylaceous material. Maniglia et al. [65] identified type A starch by the presence of the peak at 2θ = 12° and Ramos et al. [66] reported that this type of starch is typical of cereals. Nowadays, Tirado-Gallegos et al. [23] identified type B by the presence of peaks at 2θ = 15, 17, 18 and 22°, referring to it as type of tubers, despite these authors refer that a mixed pattern A + B, corresponds to type C, characteristic of starch from fruits and legumes. On the other hand, there were differences in crystalline and amorphous fractions between both materials; for the BGRS an increase in the crystalline fraction (23.93%) with respect to BGRF (17.11%), was observed, probably due to the elimination of components present in the flour, such as fiber and proteins, since in both materials the predominant starch crystal structure, which is associated with double helix that originate in branched amylopectin, as described by Hoover et al. [18].

Ramos et al. [66] reported that the relative crystallinity percentage in starches is probably related in direct proportion to the increase or decrease of amylopectin chains, which seems to correspond in this study to the effect of BGRS isolation, where components present in the BGRF were eliminated, increasing starch concentration. This is consistent with the FTIR spectra (Fig. 3), as well as with the difference observed in the chemical composition of the materials studied, which had an impact on BGRF and BGRS samples' rheological and thermal properties.

Conclusions

BGRF was obtained whose bromatological characteristics and color values indicated the presence of components other than starch, which were removed during the starch isolation process, improving their optical properties. The morphology of the starch granules of this botanical source and their size distribution were similar to those obtained from other cereals and tubers with small granules. FTIR analysis revealed the elimination of protein compounds during the starch isolation process, which was also confirmed with the change in the percentage of crystallinity and patterns revealed in X-ray diffractograms, which corresponded to mixed crystalline pattern starch A and B, typical of cereals and tubers. The rheological and DSC results revealed a material with properties similar to those of flour and starch from other starchy sources; and it was shown that the components present in the BGRF (other than starch) affected the color, thermal and rheological properties of the material, which improved once the starch was isolated. Results suggest that *C. foetidissima* Kunth root's represents an unconventional source of starch with interesting rheological and thermal properties, so it could represent a suitable material for the formation of biodegradable films or packaging, among other potential applications in the food and non-food industries.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

Research involving human and animal participants The study does not involve any human or animal testing.

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