PJN

ISSN 1680-5194

PAKISTAN JOURNAL OF NUTRITION

ANSInet

308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Mob: +92 300 3008585, Fax: +92 41 8815544

E-mail: editorpjn@gmail.com

OPEN ACCESS

Pakistan Journal of Nutrition

ISSN 1680-5194
DOI: 10.3923/pjn.2019.201.210

Research Article

Evaluation of Functional Properties and Physicochemical Characteristics of Flours Composed by Corn Grits and *Oxalis tuberosa* Flour, for Future Applications in the Elaboration of Nutritious Foods

[1]L. González-Victoriano, [1]N. Güemes-Vera, [2]J.J. Chanona-Pérez, [1]S. Soto-Simental, [3]A. Bernardino-Nicanor, [3]L. González-Cruz and [1]J.P. Hernández-Uribe

[1]Instituto de Ciencias Agropecuarias, Universidad Autónoma del Estado de Hidalgo, Av. Universidad km 1, Tulancingo, Hidalgo, CP 43600, México
[2]Departamento de Graduados e Investigación en Alimentos, Escuela Nacional de Ciencias Biológicas del Instituto Politécnico Nacional, Prolongación de Carpio, Plan de Ayala s/n, Col. Santo Tomas D.F, CP 11340, México
[3]Departamento de Ingeniería Bioquímica. Instituto Tecnológico de Celaya, Antonio García Cubas Pte. #600 esq Av. Tecnológico, Celaya Guanajuato, CP 38010, México

Abstract

Background and Objective: *Oxalis tuberosa* is a nourishing tuber characterized by having vitamins, minerals and natural antioxidants. The objective of this study was to evaluate the effect of the level of substitution of corn grits by *Oxalis tuberosa* flour, on the functional, nutritional and physicochemical characteristics. **Methodology:** Through optical microscopy was analyzed the particle size and morphology of the flours; also, the analysis of color and content of total phenols was carried out, the antioxidant activity were determined by the DPPH technique. Finally, the rheology of doughs was studied through a texture profile analysis. **Results:** Regarding the particle size, three different fractions were found for corn grits (2-10, 10-20 and 20-40 μm) and two in *Oxalis tuberosa* flour (5-30 and 30-42 μm); the color analysis showed a decrease in luminosity, while an increase in the content of total phenols was observed. In antioxidant activity, *Oxalis tuberosa* flour showed higher percentage of inhibition (50.62%) using 15 g of sample and for T5 it was 51.14% (0.30 g of sample). Likewise, the hardness, adhesiveness, cohesivity and springiness increased as a function of *Oxalis tuberosa* flour concentration. According to a proximal chemical analysis it was observed that, *Oxalis tuberosa* flour contains high percentage of fiber and lower lipid content (5.30 and 0.99 g/100 g respectively). **Conclusion:** These results indicate that, when corn grits were replaced by *Oxalis tuberosa* flour, flours with high antioxidant activity were obtained, which could be used for the development of products that, in addition to nourish, provide functional properties.

Key words: Antioxidant activity, corn grits, morphology, Oxalis tuberosa, texture profile analysis, total phenols

Received: August 08, 2018 Accepted: October 08, 2018 Published: February 15, 2019

Citation: L. González-Victoriano, N. Güemes-Vera, J.J. Chanona-Pérez, S. Soto-Simental, A. Bernardino-Nicanor, L. González-Cruz and J.P. Hernández-Uribe, 2019. Evaluation of functional properties and physicochemical characteristics of flours composed by corn grits and *Oxalis tuberosa* flour, for future applications in the elaboration of nutritious foods. Pak. J. Nutr., 18: 201-210.

Corresponding Author: Dra. Norma Güemes Vera, Instituto de Ciencias Agropecuarias, Universidad Autónoma del Estado de Hidalgo, Av. Universidad km 1, Tulancingo, Hidalgo, CP 43600, México

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Research on local crops to develop new products has a renewed interest throughout the world and represents an opportunity to improve regional economies and promote health[1], since at present the consumer is attracted not only by foods with good sensory characteristics but also by those who contribute components beneficial to health[2]. The potato is a raw material of particular interest as it increasingly offers a wider range of semi-products that are used for the manufacture of various produce such as fresh, refrigerated, frozen or ready-to-eat fried products. In the Andean region there is a wide variety of tubers, however, the potato (*Solanum tuberosum* spp. *andigenum*) that is best known worldwide, followed by oca (*Oxalis tuberosa*), which outside the Andean region is only produced in Mexico and New Zealand[1,3].

Oxalis tuberosa is a tuber that is characterized by being a good source of carbohydrates, vitamins, minerals and natural antioxidants; also present antibacterial and antifungal properties produced by their protein (ocatin) and offer a broad profile antioxidant[4]. Potatoes are generally a rich source of antioxidant compounds such as polyphenols, ascorbic acid, α-tocopherol and β-carotene; phenolic compounds provide important sensory properties in food and are responsible for color, taste or texture; also, they are considered as adjuvants in reducing the risk of developing diseases such as atherosclerosis, hypertension, coronary diseases, degenerative neurological diseases and some cancers[5,6].

Previous studies have shown that roots and tubers provide a high amount of starch, so the development of composite products by mixing starch from different sources such as corn and cassava in combination with other raw materials has been an alternative for elaboration of foods with good physicochemical, sensory and nutritional characteristics[7]. On the other hand, the development of food products that satisfy the nutritional needs of the consumer has become a priority for the food industry. This has promoted the search for new ingredients as an alternative for the production of food; such as the elaboration of gluten-free bread from *Oxalis tuberosa* flour[8]. Therefore, the aim of this study was to evaluate the functional and physicochemical properties of flours composed of corn grits and *Oxalis tuberosa* flour, for future applications in the elaboration of foods of better nutritional quality and good functional properties.

MATERIALS AND METHODS

Chemicals: Concentrated sulfuric acid, sodium sulfate, cupric sulfate pentahydrate, sodium hydroxide, boric acid, concentrated hydrochloric acid, red indicator of methyl, petroleum ether, Folin-Ciocalteu reagent, gallic acid, sodium carbonate, ethanol, DPPH 2,2-diphenyl-1-picrylhydrazyl, methanol, were purchased from Sigma-Aldrich México (Toluca, México). All solvents and chemicals were analytical quality.

Raw materials: Fresh tubers of *Oxalis tuberosa* and corn grits (*Zea mays*), were purchased in the city of Tulancingo de Bravo, Hidalgo, Mexico (20°05 09"N and 98°21 48"O). The elaboration of *Oxalis tuberosa* flour was performed as follows: the tuber was washed and cut into approximately 2-3 mm slices to dehydrate it in a drying oven (Muebles Inoxidables Luckie S.A., CDMX, México) with temperature intervals between 50-60°C. It was then ground and passed through a sieve (Tyler brand, No. 40-425 µm) to homogenize the particle size.

Preparation of mixtures: Mixed grits of corn/*Oxalis tuberosa* flour were prepared with the following proportions: 90/10, 80/20, 70/30, 60/40, 50/50% respectively, which were named as treatments T1, T2, T3, T4 and T5.

Chemical composition: Both *Oxalis tuberosa* flour and corn grits were evaluated by means of a proximal chemical analysis to determine their moisture content, ash, total fiber and lipids using methods 925.10, 923.03, 985.29 and 920.39, respectively. Protein was calculated from the nitrogen content using a conversion factor of 6.25 by the method 920.87[9]. Carbohydrates were calculated by difference.

Evaluation of physical properties and antioxidant capacity of flours

Particle size analysis: Particle size was determined by light microscopy, flour samples were dispersed in one drop of isopropyl alcohol and dried at room temperature (25±1°C); subsequently were observed under an optical microscope (Nikon, Eclipse 50i, Japan) coupled to a digital camera (Nikon Digital Sight DS-2Mv, Tv lentex 0.55, Japan) for the acquisition of RGB images (NIS-Elements F2.30 software). The images were analyzed with ImageJ v.1.42q software (Bethesda, USA), obtaining parameters of circularity (form factor) and aspect ratio[10].

Color analysis: The color parameters (L*, a* and b*) were determined with a colorimeter (MicrOptix S560 i-LAB, USA), where the luminance coefficient L* has a range from black to white. The chromaticity spectra are represented by the values of a* (+redness and -greens) and b* (+yellowing and -blues). The colorimeter was calibrated with a standard plate with values of L* = 99.50, a* = -0.32 and b* = 0.48[11].

Total phenols content: The aqueous extracts were obtained weighing between 0.025 and 0.2 g of dry sample, which was diluted in 10 ml of distilled water[12], followed by vortexing for 1 min; it was finally centrifuged at 4000 rpm for 10 min. The total content of polyphenols was determined by the colorimetric technique of Folin Ciocalteu as described by Ondo and Ryu[13], with the following modifications: Aliquots of 1.58 mL extract, Folin-Ciocalteu reagent and of 20% sodium carbonate (Na_2CO_3) were mixed. It was then incubated for 15 min at 50°C, to finally measure the absorbance at 765 nm against a blank and the results were expressed as GA mg g^{-1} dry matter (DM).

Antioxidant activity: The extracts used in this test were obtained by diluting 0.1 g of sample in 1.5 mL of distilled water, then shaken for 1 min and finally centrifuged at 3000 rpm for 10 min. The antioxidant capacity was determined using the free radical scavenging activity of DPPH (2,2-diphenyl-1-picrylhydrazyl), according to the technique described by Ondo and Ryu[13], with some modifications: 50 µL of extract was added to 1.95 mL of DPPH methanol solution (0.1 mM). The mixtures were shaken and the absorbance was monitored every 10 min for one hour at 517 against a blank. All tests were carried out in triplicate and the results were expressed as percentage inhibition.

The mean effective concentration (EC_{50}) also was determined, which represents the sample concentration required to sequester 50% of the DPPH radicals (expressed in g sample g^{-1} DPPH). The EC_{50} was obtained through the percentage DPPH reduced versus concentration graph, as well as the time required (TEC_{50}) to reach EC_{50}[14].

Mechanical properties of doughs: An analysis of the texture profile (TPA) and the adhesiveness of the doughs were carried out. So that 100 g of dough of each of the treatments was prepared; the kneading process consisted in mixing flour with specific amounts of water (from 30-60 mL, this amount varied according to the treatment), during 15 or 20 min, then the dough was divided into portions corresponding to the amount required for each test.

Texture profile analysis: Texture profile analyses of doughs was performed using a texture analyzer (CT3 Texture Analyzer-Brookfield, Germany); 25 g of sphere-shaped sample was placed in an acrylic cylinder and compressed with a 3.50 cm diameter stainless steel probe for 15 min, then two cycles of compression were applied at a test speed of 0.5 mm sec^{-1} up to 20% deformation. Obtaining results of hardness, cohesiveness, adhesiveness and springiness[15].

Hoseney's adhesiveness: In this analysis the SMS/Chen-Hoseney dough-adhesion additive was used, where 10 g of dough was placed and pressed to obtain small filaments (approx. 4 mm diameter) and allowed to sit for 1 min. Subsequently, the insert was placed in the texture analyzer to compress the sample with an acrylic probe (2.54 cm in diameter) at a test speed of 2 mm sec^{-1}, obtaining the values of the study necessary to overcome the force of attraction between the filaments of the douhgs and the probe[15, 16].

Statistical analysis: The effect of replace corn grits with *Oxalis tuberosa* flour was determined by analysis of variance (ANOVA) and the results were expressed as mean±SD (standard deviation). TPA, Hoseney's adhesiveness, color analysis and total phenols the significant difference between treatments was determined through the Duncan's means comparison test using the Statistical Package (NCSS 10 Data Analysis, USA). A level of significance of $p<0.05$ was used. In addition, a Pearson linear correlation analysis was performed using the XLSTAT software (2009.3.02), to study the relationship of variables between doughs and flours. All experiments were performed in triplicate.

RESULTS AND DISCUSSION

Proximate composition of flours: Characterize raw material in this study is important to determine treatments, for this purpose a proximate chemical analysis was developed. *Oxalis tuberosa* flour has higher moisture, ash and fiber content (7.51±0.01, 5.11±0.01 and 5.30±0.29 g/100 g, respectively) compared with corn grits; since it presented values of moisture of 6.99±0.03, ash of 1.25±0.10 and fiber of 1.35±0.20 g/100 g. On the other hand, the protein and fat content was lower in *Oxalis tuberosa* flour (6.60±0.16 and 0.99±0.01 g/100 g, respectively), while in corn grits it was 8.71±0.17 g/100 g of protein and 8.03±0.50 g/100 g of lipids. According to Mexican Official Standard NOM-247-SSA1-2008, both *Oxalis tuberosa* flour and corn grits had lower moisture values than the maximum value allowed for this type of (15 tubers as yam (*Dioscorea alata* L.), taro (*Xanthosoma sagittifolium* L. Schott) and mapuey (*Dioscorea trifida* L.), since the protein content was found between 4.84 and 6.77 g/100 g[17]. This may be due to the fact that tubers and rhizomes, including several types of potato, cassava and malanga, are relatively low in protein. Also, the fat content is very low in several tubers crops, which is composed mainly of the lipids of the cell membrane that is variable between the cultivars[7]. The carbohydrate content for corn grits was 73.67±1.03 g/100 g, while in *Oxalis tuberosa* flour of 74.49±1.03 g/100 g was found, the high carbohydrate values may be directly related to the starch content mainly. Since, Juneja *et al.*[18] reported that the content of starch in corn grain was estimated at 86.5% on dry basis. In general, the results obtained are consistent with a study carried out on corn flour and taro flour (*Colocasia esculenta*), where taro flour was found to have a higher ash and carbohydrates content (3.78 and 82.42 g/100 g) compared to corn flour (1.34 and 71.27 g/100 g). While corn flour (4.47 and 9.42 g/100 g) than taro flour (0.74 and 5.37 g/100 g), since cereals normally contain more of these compounds than the tubers[7].

Physical properties and antioxidant capacity of flours

Morphology and particle size distribution: The characteristics of the granule in each of the flours were determined by a particle size analysis. According to this analysis, several diameter sizes were observed in corn grits, which were classified into three main fractions corresponding to sizes between 2-10, 10-20 and 20-40 µm (Fig. 1a); while in *Oxalis tuberosa* flour the diameters found were 5-30 µm in fraction one and 30-42 µm for fraction two (Fig. 1b). The treatments T1, T2 and T3 presented diameters similar to corn grits, while for T4 and T5 found granules identical to those present in *Oxalis tuberosa* flour (2-28 and 28-40 µm for both samples). Stasiak *et al.*[19] found that cereal and potato starches differ markedly in morphology indicating that potato starch granules were two fold larger and were more oblong with a coefficient of shape approximately twice larger.

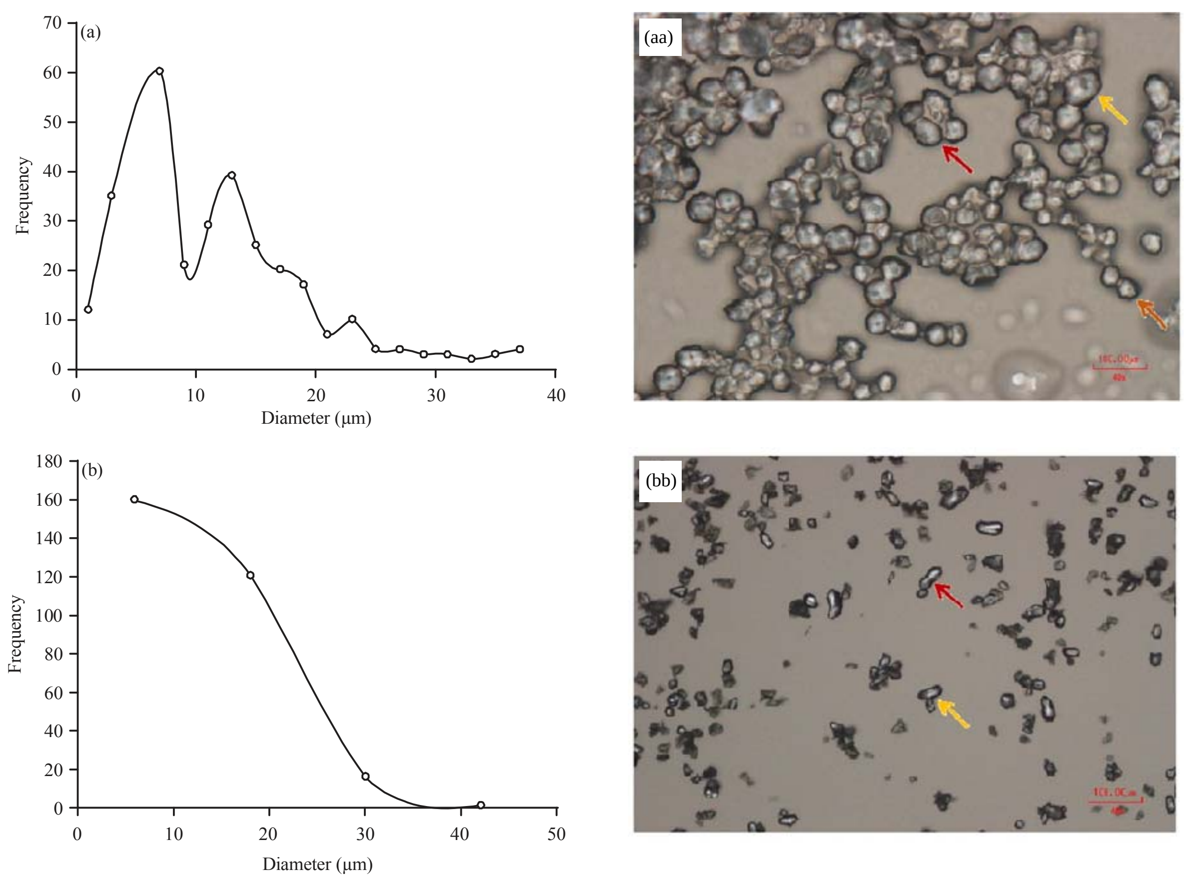

Fig. 1(a-b): Relationship between the particle size and micrographs obtained by optical microscopy. (a) Corn grits, (aa) Orange arrow corresponding diameters between 2-10 µm, red arrow 10-20 µm and yellow arrow 20-40 µm and (b) *Oxalis tuberosa* flour, (bb) Yellow arrow diameters of 10-30 µm and red arrow >30 µm

A study conducted by Lan *et al.*[20] where they analyzed different starches, they reported that taro starch contains individual granules that typically ranged from 1-2 μm, chestnut starch had an average size of 15 μm in various forms, chinese yam starch showed two types of granules with different sizes (15 and 30 μm). Canna and potato starch showed significant variations in size, ranging from 20-40 μm and 10-20 μm respectively, while larger granules showed intervals between 40-70 μm for canna and 20-55 μm for potato. In other research Perez *et al.*[21] reported that the granule diameter ranged from 24.5-60.0 μm for white yam starches, whereas purple yam showed mainly fractions of large granules (>40 μm), followed by granules with diameters between 20 and 40 μm and a smaller fraction <20 μm. These results indicate that the difference in the size of the granule can be directly related to the source of obtaining, which is an important factor since these characteristics are used as taxonomic criterion to identify the vegetal source of this polysaccharide. On the other hand, the size of the granule suggests some possible applications, since those of less than 60 μm are used as encapsulating agents of flavors, dyes and essences, due to their high water absorption capacity. Therefore, flours with these sizes could be considered as useful and interesting polymers in the food industry[22].

In this study also parameters related to the morphology of the granule as the form factor (FF), which was obtained from the image analysis, were analyzed. This parameter numerically describes the shape of a particle regardless of its size. In context, a perfectly round object will have a value equal to 1 and elongated or straight objects will have values close to zero. The aspect ratio (AR) was also obtained, which reveals the relation between the minimum and maximum diameter; values close to 1 correspond to equidimensional objects, whereas values tend to infinity for extended objects. Table 1 shows the results of FF and AR, it is observed that corn grits presented values of 0.80±0.07 (FF) and 1.23±0.17 for AR, indicating that corn grits granules are round or polyhedral shape. The values obtained in *Oxalis tuberosa* flour were 0.72±0.08 indicates that the granules present in this flour have an elongated shape (ellipticals). In a study carried out by Valcarcel-Yamani *et al.*[23] in different tubers, reported that oca starch granules have a cylindrical, elliptical or oval morphology, olluco granules showed asymmetric and irregular shapes with elliptic, oval, conic or prismatic forms and starch granules of mashua were oval or spherical in form, smaller in size compared to other tubers.

The morphological characteristics found for corn grits were similar to those reported in a study where they analyzed the morphology of four native starches, including corn starch, which presented polyhedral shape and cassava is spherical with some shortened granules; whereas potato starch presented both spherical and oval forms. Wheat starch showed two types of granules, one in lenticular form (large granules) and spherical shape for small granules[24]. These variations in the morphology of the starch granule are attributed to the biological origin, which depends on the biochemistry of chloroplasts or amyloplasts and plant physiology. But there are other factors that can affect the characteristics of the granule such as environmental factors (temperature and storage), since they influence the physico-chemical and thermal properties of the granule[23].

Color analysis: As for the effects of color by the addition of *Oxalis tuberosa* flour, significant differences ($p<0.05$) were found between treatments with respect to the control; observing the decrease in luminosity (L*) and yellowing (b*), as well as the increase in redness a* were observed (Table 1). The T5 treatment presented the lowest values of L* and b* (84.50±0.51 and 12.64±0.79, respectively) with respect to the control (94.86±0.58, 22.62±0.89, respectively). Also this treatment presented the highest value of a* (1.01±0.13) compared to the control (-1.54±0.24); the results indicate that flours composed of corn grits and *Oxalis tuberosa* flour present colors that tend towards the purple space, whereas for the control the yellow color predominates, showing greater luminosity compared to the composite flours. These color

Table 1: Effect of inclusion of *Oxalis tuberosa* flour on the form factor, aspect ratio, color and content of total phenols in composed flours

	Control	T1	T2	T3	T4	T5	OTF
Form factor	0.80±0.07	0.82±0.05	0.83±0.05	0.86±0.04	0.86±0.03	0.83±0.05	0.72±0.08
Aspect ratio	1.23±0.17	1.22±0.17	1.22±0.17	1.22±0.18	1.23±0.19	1.43±0.31	1.69±0.39
L*	94.86±0.58^{a}	93.05±1.33^{b}	90.42±1.48^{c}	89.02±1.93^{d}	87.92±1.43^{d}	84.50±0.51^{e}	83.03±0.81^{e}
a*	-1.54±0.24^{a}	-1.21±0.35^{b}	-0.79±0.35^{c}	0.62±0.18^{d}	0.66±0.31^{d}	1.01±0.13^{d}	0.80±0.27^{d}
b*	22.62±0.89^{a}	19.92±1.15^{b}	18.03±1.12^{c}	14.67±0.68^{d}	13.33±1.10^{e}	12.64±0.79^{e}	10.81±0.80^{f}
Total polyphenols(mg GA g^{-1} of DS)	0.69±0.02^{a}	0.75±0.001^{a}	0.93±0.05^{b}	1.16±0.07^{c}	1.35±0.02^{d}	1.47±0.02^{e}	2.54±0.03^{f}

[abcdef]Different literals indicate significant differences (Duncan's method p<0.05). Control; CG: Corn grits, T1: (90:10;CG:OTF) T2: 80/20;CG:OTF, T3: 70/30;CG:OTF, T4: 60/40;CG:OTF, T5: 50/50;CG:OTF, OTF: *Oxalis tuberosa* fluor

changes can be attributed to the degree of substitution for flour of red potato, as well as the presence of pigments and polyphenols mainly in the peel of this tuber.

Recent studies analyzing the color of biscuits added with sesame peel flour observed that incorporating up to 50% of this flour, decreased L^* values from 64.07±0.66-36.23±0.27 and b* values from 38.7±0.54-11.42±0.07, whereas there was an increase for a* values (4.27±0.03-10.79±0.62). The authors reported that this behavior could be due to the different levels of substitution of wheat flour for sesame peel flour, as well as the presence of natural pigments in sesame and polyphenols, since there is a greater content of these in the layer of sesame[25]. Similar results were found in products substituted with a corn flour, where the highest L* value was obtained for the control sample, i.e. the addition of this flour significantly decreased the values of L* in proportionally to the percentage of substitution. The control also presented negative values of a* but when adding flour of corn changed to positive values and in all cases the value that presented b* was positive[26].

Total phenols: The content of total polyphenols was initially determined in *Oxalis tuberosa* flour which presented a concentration of 2.54±0.03 mg GA g^{-1} DM (Table 1). Similar results were reported by Nems *et al.*[5], in an analysis of different potato varieties, since they had a total polyphenol content between 2.47 and 4.27 mg GA g^{-1} DM, the tubers of blue variety being the ones with the highest content of these compounds. Also, Kita *et al.*[27] found that violet potato cultivars presented higher content of polyphenols than red potato varieties, being the purple variety Vitelotte that presented high values of gallic acid equivalents (1.35 mg g^{-1} DM); followed by Blaue Galler, Blue Congo and Blaue Elise (1.01, 0.95 and 0.84 mg g^{-1} DM respectively). Whereas among red potato varieties, Highland Burgundy Red and Herbie 26 contained high levels of total polyphenols (0.60 and 0.57 mg g^{-1} DM) compared with Rosalinde and Rote Emma (0.55 and 0.52 mg g^{-1} DM). The difference in total polyphenol content may depend on the variety, harvest year, climatic conditions and factors affecting the potato plant during its growth and maturation, such as mechanical damage, the action of sun rays, diseases or pests which directly affect the tubers[2].

The content of total phenols in corn grits was 0.69±0.02 mg GA g^{-1} DM, however when incorporating *Oxalis tuberosa* flour the amount of phenolic compounds increased proportionally (Table 1). A similar behavior was found in ginger flour, where the content of phenolic compounds increased proportionally with increasing the concentration of this flour. It was observed that, at levels of 4.5% ginger flour, the phenolic content was higher (0.427±0.071 mg GA g^{-1} DM) than the control 0.143±0.002 mg GA g^{-1} DM[28].

Antioxidant activity and determination of EC_{50} by DPPH radical: For evaluating antioxidant activity, sample concentrations of 0.1-0.30 g were used in order to inhibit 50% of the initial DPPH radical, the best results were obtained with 0.30 g of sample, being *Oxalis tuberosa* flour and T5, the treatments that inhibited 50% of the DPPH radical, showing percentages of inhibition of 57 and 51.14%, respectively. The increase of the antioxidant activity is directly proportional to the concentration of *Oxalis tuberosa* flour (Fig. 2). This could be attributed to the antioxidative properties of tubers of the genus *Oxalis tuberosa*, due to the presence of phenolic acids, flavones and anthocyanins; the latter being found both in the shell and pulp. Likewise, are responsible for the coloration and contribute to the antioxidant capacity[4].

EC_{50} and TEC_{50} were also determined, the results obtained indicated that to inhibit 50% of the initial DPPH radical, 131 g of *Oxalis tuberosa* flour sample and 225.78 g of the T5 sample are required. Based on a previous study, it can be said that *Oxalis tuberosa* flour presents higher antioxidant activity compared to T5, since there is an inversely proportional relationship, i.e., the higher the value of EC_{50}, the lower the antioxidant activity[29]. When expressing this activity in TEC_{50}, it is observed that *Oxalis tuberosa* flour achieves 50% inhibition in a shorter time (min 10), whereas for T5 it was between 50 and 60 min; according to Stajcic *et al.*[30], the behavior of phenolic compounds with respect to the time of action is classified in: fast (<5 min), intermediate (5-30 min) and slow (>30 min). This could indicate that *Oxalis tuberosa* flour has

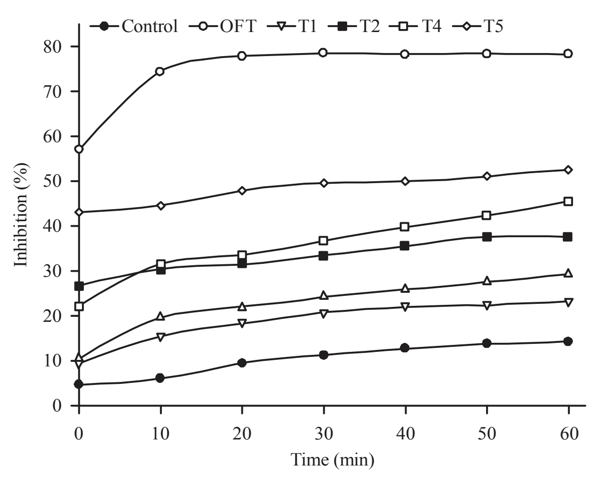

Fig. 2: Comparison of the antioxidant activity of flours composed by corn grits and *Oxalis tuberosa* flour

antioxidant compounds with a mean action time but when mixing *Oxalis tuberosa* flour with corn grains in different proportions, the action time increases, which it could be due to the fact that corn grits could contain slow-acting antioxidants. It is important to mention that both the high antioxidant activity (EC_{50}) and the reaction time can also be due to the joint action of antioxidants of very varied reactivity, since each polyphenolic component contributes in a different way to the antioxidant capacity[31].

Mechanical properties of doughs

Texture profile analysis: The effect of mixing *Oxalis tuberosa* flour with grits corn is shown in Table 2. The results of hardness indicates that treatments T5 (3.53±0.01 N) and *Oxalis tuberosa* flour (5.09±0.01 N) presented significant differences (p<0.05) with respect to the control dough but there was an increase in the value of this parameter was observed when the concentration of *Oxalis tuberosa* flour increased. Such behavior is consistent with a TPA performed on biscuit doughs, where a significant increase in hardness was observed by incorporating sesame peel flour in different proportions. Adding 40% of this flour resulted in the highest hardness, while also increasing resistance to the breakage of the dough[32]. The increase in hardness could be due to the substitution of the flour by fibers from different sources, because these significantly change the capacity of manipulation and the behavior of the viscoelastic parameters of the dough, affecting the mechanical properties. This depends strongly on the nature of the fiber in the mixture or the degree of substitution of flour[33].

With regards to the adhesiveness results (Table 2), in some treatments were found significant differences (p<0.05) with respect to the control (0.54±0.37 mJ) and the data obtained indicate that the adhesiveness increases proportionally to the concentration of *Oxalis tuberosa* flour, which could be attributed to the increase in water absorption[23]. In a study carried out on doughs added with flaxseed flour, in proportions of 0-15%, was observed that the stickiness of the dough increased proportionally with the addition of this flour which could be due mainly to the increase of the water absorption[34]. The increase of the adhesiveness can also be caused by the increase of starch, derived from the substitution by *Oxalis tuberosa* flour, since the adhesion is a property strongly related to the structural characteristics of the starch fraction, in particular by the state of aggregation of amylose[35].

For the results of cohesiveness (Table 2), it was found that the treatments T4 (0.23±0.01), T5 (0.25±0.01) and *Oxalis tuberosa* flour (0.33±0.02) showed significant differences (p<0.05) with respect to the control (0.19±0.01). As reported by Kaur *et al.*[36], this can be attributed to a higher degree of polymerization in amylose, as well as a greater leaching of the granules (amylose fraction), type of starch. Another factor that affects the adhesiveness is the increase of water absorption, obtaining doughs more cohesive, with internal structure resistant to the high forces of stress[33]. Table 2 also shows results for springiness; where no significant differences (p<0.05) were found with respect to the control (0.28±0.03), although the springiness increases as a function of *Oxalis tuberosa* flour concentration. This may be due to increasing the hydration capacity of the material due to the higher concentration of starch. According to Witczak *et al.*[37], hydration capacity is the most important factor for the increase in springiness and depends on the particle size, amount of damaged starch that may exist as result of the crushing, protein content. As well as changes in binding of the water, which lead to structural changes in dough due to the hydration of the starch.

Hoseney's adhesiveness: The addition of *Oxalis tuberosa* flour also modified other physical properties (Table 2), observing significant differences (p<0.05) between treatments with respect to the control for cohesiveness force, whereas in adhesiveness no significant differences were found with respect to the control (0.110±0.07 mJ). However, a decrease in both parameters can be observed by increasing the

Table 2: Effect of the substitution of corn grits with *Oxalis tuberosa* flour in texture profile analysis and adhesiveness of doughs

	Control	T1	T2	T3	T4	T5	OTF
Texture profile analysis							
Hardness (N)	2.84±0.02^{a}	3.04±0.02^{ab}	3.23±0.01^{ab}	3.23±0.03^{ab}	3.33±0.02^{ab}	3.53±0.01^{b}	5.09±0.01^{c}
Adhesiveness (mJ)	0.54±0.37^{a}	1.47±0.6^{abc}	1.67±0.24^{abc}	2.19±1.14^{bc}	2.45±0.27^{bc}	2.88±0.17^{c}	1.07±0.78^{ab}
Cohesiveness (-)	0.19±0.01^{a}	0.18±0.01^{a}	0.21±0.01^{ab}	0.21±0.02^{ab}	0.23±0.01^{bc}	0.25±0.01^{c}	0.33±0.02^{d}
Springiness (-)	0.28±0.03^{a}	0.27±0.03^{a}	0.28±0.02^{a}	0.34±0.08^{a}	0.35±0.01^{a}	0.36±0.08^{a}	0.34±0.04^{a}
Adhesiveness of hoseney							
Cohesiveness force (g)	22.80±3.28^{a}	10.30±2.92^{b}	7.93±2.72^{b}	5.55±0.50^{b}	4.55±0.87^{b}	4.05±0.29^{b}	8.68±0.85^{b}
Adhesiveness (mJ)	0.08±0.02^{a}	0.06±0.03^{a}	0.04±0.01^{a}	0.03±0.02^{a}	0.04±0.01^{a}	0.03±0.01^{a}	0.10±0.04^{a}

^{abc}Different literals indicate significant differences (Duncan's method p<0.05). Control; CG: Corn grits, T1: 90:10;CG:OTF, T2: 80/20;CG:OTF, T3: 70/30;CG:OTF, T4: 60/40;CG:OTF, T5: 50/50;CG:OTF, OTF: *Oxalis tuberosa* flour

Table 3: Relationship between hardness, color, total polyphenols and antioxidant activity of composite flours and doughs

	Doughs						Flours			
Variables	Hardness	Adhesiveness	Cohesiveness	Springiness	Cohesiveness force	Adhesiveness	L	a*	b*	Total polyphenols
Hardness										
Adhesiveness	-0.093									
Cohesiveness	0.971	0.040								
Springiness	0.474	0.674	0.622							
Cohesiveness forcé	-0.315	-0.794	-0.333	-0.564						
Adhesiveness	0.333	-0.895	0.273	-0.331	0.772					
L	-0.812	-0.484	-0.890	-0.833	0.658	0.177				
a*	0.581	0.687	0.692	0.969	-0.711	-0.395	-0.910			
b*	-0.742	-0.573	-0.817	-0.892	0.743	0.292	0.967	-0.965		
Total polyphenols	0.974	0.079	0.989	0.659	-0.395	0.221	-0.898	0.736	-0.855	
Antioxidant activity	0.928	0.268	0.963	0.748	-0.547	0.037	-0.962	0.832	-0.932	0.981

Bold values are different from 0 with a significance level alpha: 0.05

concentration of *Oxalis tuberosa* flour, this implies lower adhesion of the dough on the surface of the equipment, facilitating its malleability, a desirable aspect as it helps to reduce production costs in addition to not affecting the caramelization reactions during the process and consequently the color properties[16].

Relationship between hardness, color, total phenols and antioxidant activity of doughs and flours composed: The correlation coefficients found between physical and chemical analyses are presented in Table 3, showing a high correlation between hardness, total phenols and antioxidant activity ® = 0.974 and r = 0.928 respectively), i.e. there is a direct relationship between these parameters. When analyzing two sorghum genotypes, Luthria and Liu[38] reported that the concentration and type of phenolic compounds extracted from the husks were significantly higher than those found in edible parts of the grain. Also, indicated that phenolic acids have the ability to influence certain organoleptic properties such as taste, astringency and hardness[39]. In this regard Rytel *et al.*[2], mention that phenolic compounds are not uniformly distributed in fruits, vegetables and grains and the greater amount are found in the skin and just below its surface. They also indicated that polyphenols present in plants not only participate in their reproduction and growth but also influence sensory qualities such as texture. However, a negative correlation was found between luminosity (L*), total polyphenols and antioxidant activity ® = -0.898 and r = -0.962, respectively), indicating an inversely proportional relation, i.e. higher content of total polyphenols the L* is lower.

In this study it could be said that the antioxidant capacity of flours composed of corn grits and *Oxalis tuberosa* flour is highly correlated with total phenolic content ® = 0.981), which could be due to the presence of phenolic compounds in the tuber of *Oxalis tuberosa*[4]. These results are consistent with a study realized by Kita *et al.*[39], where they reported a high antioxidant activity in purple and red potatoes; while, varieties with lower concentration of polyphenols showed low antioxidant potential.

CONCLUSION

When corn grits were replaced by *Oxalis tuberosa* flour, flours with high antioxidant activity were obtained, which could be used for the development of products that, in addition to nourish, provide functional properties.

SIGNIFICANCE STATEMENT

This study discover the possible interaction that exist between functional properties and physicochemical characteristics of flours composed of *Oxalis tuberosa* and corn grits that can be beneficial for diabetes, metabolic sindrome and obesity. This study will help the researchers to uncover the critical areas of chronic degenerative diseases that many researchers were not able to explore. Thus a new theory on these composed combination and possibly other combinations, may be arrived at.

ACKNOWLEDGMENTS

The authors are grateful to the National Council of Science and Technology (CONACyT) for the scholarship awarded for the financing of this project. To the Autonomous University of the State of Hidalgo (Hidalgo, Mexico) for the support provided to carry out the project.

REFERENCES

1. Mosso, A.L., M.O. Lobo and N.C. Samman, 2016. Development of a potentially probiotic food through fermentation of *Andean tubers*. LWT-Food Sci. Technol., 71: 184-189.
2. Rytel, E., A. Tajner-Czopek, A. Kita, M. Aniolowska, A.Z. Kucharska, A. Sokol-Letowska and K. Hamouz, 2014. Content of polyphenols in coloured and yellow fleshed potatoes during dices processing. Food Chem., 161: 224-229.
3. Condori, B., P. Mamani, R. Botello, F. Patino, A. Devaux and J.F. Ledent, 2008. Agrophysiological characterisation and parametrisation of Andean tubers: Potato (*Solanum* sp.), oca (*Oxalis tuberose*), isaño (*Tropaeolum tuberosum*) and papalisa (*Ullucus tuberosus*). Eur. J. Agron., 28: 526-540.
4. Chirinos, R., I. Betalleluz-Pallardel, A. Huaman, C. Arbizu, R. Pedreschi and D. Campos, 2009. HPLC-DAD characterisation of phenolic compounds from Andean oca (*Oxalis tuberosa* Mol.) tubers and their contribution to the antioxidant capacity. Food Chem., 113: 1243-1251.
5. Nems, A., A. Peksa, A.Z. Kucharska, A. Sokol-Letowska, A. Kita, W. Drozdz and K. Hamouz, 2015. Anthocyanin and antioxidant activity of snacks with coloured potato. Food Chem., 172: 175-182.
6. Santos, M.A.I., A.A. Simao, T.R. Marques, A.A. Sackz and A.D. Correa, 2016. Efeito de diferentes metodos de extracao sobre a atividade antioxidante e o perfil de compostos fenolicos da folha de mandioca. Braz. J. Food Technol., 19: 6715-6723.
7. Rodriguez-Miranda, J., I.I. Ruiz-Lopez, E. Herman-Lara, C.E. Martinez-Sanchez, E. Delgado-Licon and M.A. Vivar-Vera, 2011. Development of extruded snacks using taro (*Colocasia esculenta*) and nixtamalized maize (*Zea mays*) flour blends. Food Sci. Technol., 44: 673-680.
8. Vera, N.G., S.O.E. Manzano and H.M.H. Hernandez, 2018. Use of *Oxalis tuberose* in gluten-free baked goods manufacture. Alternat. Replacement Foods, 10.1016/B978-0-12-811446-9.00006-X
9. AOAC., 2002. Official Methods of Analysis of the Association of Official Analytical Chemists. 17th Edn., Association of Official Analytical Chemists Inc., USA.
10. Protonotariou, S., A. Drakos, V. Evageliou, C. Ritzoulis and I. Mandala, 2014. Sieving fractionation and jet mill micronization affect the functional properties of wheat flour. J. Food Eng., 134: 24-29.
11. Kim, M.K., J.M. Lee, J.S. Do and W.S. Bang, 2015. Antioxidant activities and quality characteristics of Omija (*Schizandra chinesis* Baillon) cookies. Food Sci. Biotechnol., 24: 931-937.
12. Guntero, V.A., M.B. Longo, S.A. Ciparicci, R.E. Martini and A.E. Andreatta, 2015. Comparacion de metodos de extraccion de polifenoles a partir de residuos de la industria vitivinicola. Proceedings of the 8th Congreso Argentino de Ingenieria Quimica, Centro de Seguridad Para Los Procesos Quimicos, August 2-5, 2015, Asociacion Argentina de Ingenieros Quimicos, Palais Rouge, Buenos Aires, Buenos Aires.
13. Ondo, S.E. and G.H. Ryu, 2013. Physicochemical and antioxidant properties of extruded cornmeal with natural cocoa powder. Food Sci. Biotechnol., 22: 167-175.
14. Palomino Garcia, L.R. and V.L. Del Bianchi, 2015. Capacidade antioxidante em residuos da industria cafeeira. [Antioxidant capacity in coffee industry residues]. Braz. J. Food Technol., 18: 307-313.
15. Guemes-Vera, N., L. Gonzalez-Victoriano, S. Soto-Simental, J.F. Hernandez-Chavez and M.I. Reyes-Santamaria, 2014. Mechanical properties of cottage cheese-fortified wheat dough and loaf bread. J. Food Sci. Technol., 51: 2797-2802.
16. Guemes, V.N., A. Totosaus, J.F. Hernandez, S. Soto and E.N. Aquino Bolanos, 2009. Texture properties of dough and sweet bread "Concha" type fortified with milk whey protein. Cienc. Tecnol. Aliment., 29: 70-75.
17. Garcia, A., E. Perez and R. Davila, 2012. Caracteristicas fisicas, quimicas y funcionales de las harinas obtenidas por secado del name, ocumo y mapuey. Agronomia Trop., 62: 51-67.
18. Juneja, A., D. Kumar and V. Singh, 2017. Germ soak water as nutrient source to improve fermentation of corn grits from modified corn dry grind process. Bioresour. Bioproces., Vol. 4. 10.1186/s40643-017-0170-8
19. Stasiak, M., M. Molenda, I. Opalinski and W. Blaszczak, 2013. Mechanical properties of native maize, wheat and potato starches. Czech J. Food Sci., 31: 347-354.

20. Lan, X., Y. Li, S. Xie and Z. Wang, 2015. Ultrastructure of underutilized tuber starches and its relation to physicochemical properties. Food Chem., 188: 632-640.
21. Perez, E., A. Rolland-Sabate, D. Dufour, R. Guzman and M. Tapia *et al*., 2013. Isolated starches from yams (*Dioscorea* sp.) grown at the Venezuelan Amazons: Structure and functional properties. Carbohydrate Polym., 98: 650-658.
22. Jimenez-Hernandez, J., J.A. Salazar-Montoya and E.G. Ramos-Ramirez, 2007. Physical, chemical and microscopic characterization of a new starch from chayote (*Sechium edule*) tuber and its comparison with potato and maize starches. Carbohydrate Polym., 68: 679-686.
23. Valcarcel-Yamani, B., G.G. Rondan-Sanabria and F. Finardi-Filho, 2013. The physical, chemical and functional characterization of starches from Andean tubers: oca (*Oxalis tuberose* Molina), olluco (*Ullucus tuberosus* Caldas) and mashua (*Tropaeolum tuberosum* Ruiz and Pavon). Braz. J. Pharm. Sci., 49: 453-464.
24. Munoz, L.A., F. Pedreschi, A. Leiva and J.M. Aguilera, 2015. Loss of birefringence and swelling behavior in native starch granules: Microstructural and thermal properties. J. Food Eng., 152: 65-71.
25. Drisya, C.R., B.G. Swetha, V. Velu, D. Indrani and R.P. Singh, 2015. Effect of dried *Murraya koenigii* leaves on nutritional, textural and organoleptic characeteristics of cookie. J. Food Sci. Technol., 52: 500-506.
26. Korus, J., M. Witczak, R. Ziobro and L. Juszczak, 2015. The influence of acorn flour on rheological properties of gluten-free dough and physical characteristics of the bread. Eur. Food Res. Technol., 240: 1135-1143.
27. Kita, A., A. Bakowska-Barczak, G. Lisinska, K. Hamouz and K. Kulakowska, 2015. Antioxidant activity and quality of red and purple flesh potato chips. LWT-Food Sci. Technol., 62: 525-531.
28. Balestra, F., E. Cocci, G. Pinnavaia and S. Romani, 2011. Evaluation of antioxidant, rheological and sensorial properties of wheat flour dough and bread containing ginger powder. LWT-Food Sci. Technol., 44: 700-705.
29. Padilla, F.C., A.M. Rincon and L. Bou-Rached, 2008. Contenido de polifenoles y actividad antioxidante de varias semillas y nueces. Arch. Latinoam. Nutr., 58: 303-308.
30. Stajcic, S.M., G.S. Cetkovic, S.M. Dilas and J.M. Canadanovic-Brunet, 2013. Kinetic study of the DPPH antiradical activity of lipophilic tomato waste extracts. Acta Periodica Technol., 44: 301-312.
31. Vergara-Valencia, N., E. Granados-Perez, E. Agama-Acevedo, J. Tovar, J. Raules and L.A. Bello-Perez, 2007. Fibre concentrate from mango fruit: Characterization, associated antioxidant capacity and application as a bakery product ingredient. LWT-Food Sci. Technol., 40: 722-729.
32. Zouari, R., S. Besbes, S. Ellouze-Chaabouni and D. Ghribi-Aydi, 2016. Cookies from composite wheat-sesame peels flours: Dough quality and effect of *Bacillus subtilis* SPB1 biosurfactant addition. Food Chem., 194: 758-769.
33. Collar, C., E. Santos and C.M. Rosell, 2007. Assessment of the rheological profile of fibre-enriched bread doughs by response surface methodology. J. Food Eng., 78: 820-826.
34. Marpalle, P., S.K. Sonawane and S.S. Arya, 2014. Effect of flaxseed flour addition on physicochemical and sensory properties of functional bread. LWT-Food Sci. Technol., 58: 614-619.
35. Brunnschweiler, J., D. Mang, Z. Farah, F. Escher and B. Conde-Petit, 2006. Structure-texture relationships of fresh pastes prepared from different yam (*Dioscorea* spp.) varieties. LWT-Food Sci. Technol., 39: 762-769.
36. Kaur, L., J. Singh and N. Singh, 2005. Effect of glycerol monostearate on the physico-chemical, thermal, rheological and noodle making properties of corn and potato starches. Food Hydrocolloids, 19: 839-849.
37. Witczak, M., L. Juszczak, R. Ziobro and J. Korus, 2012. Influence of modified starches on properties of gluten-free dough and bread. Part I: Rheological and thermal properties of gluten-free dough. Food Hydrocolloids, 28: 353-360.
38. Luthria, D.L. and K. Liu, 2013. Localization of phenolic acids and antioxidant activity in sorghum kernels. J. Funct. Foods, 5: 1751-1760.
39. Kita, A., A. Bakowska-Barczak, K. Hamouz, K. Kulakowska and G. Lisinska, 2013. The effect of frying on anthocyanin stability and antioxidant activity of crisps from red-and purple-fleshed potatoes (*Solanum tuberosum* L.). J. Food Compos. Anal., 32: 169-175.