Chemical, rheological and mechanical evaluation of maize dough and tortillas in blends with cassava and malanga flour

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Abstract Masa or dough from nixtamalized maize with cassava (Cf) and malanga flour (Mf) addition at 20, 30 and 40 % (w/w) were prepared making seven treatments. The produced masas or doughs were subjected to chemical analysis, rheological and mechanical tests. Tortillas were manufactured from these doughs and mechanical tests were undertaken. Doughs from tubers had less protein and lipid content but higher nitrogen free extract than the control. All doughs presented weak viscoelastic gel-like behavior, with those of Mf behaving mainly as viscous systems. Doughs with Cf showed lower decrease in both the elastic (G') and viscous (G'') moduli than those with Mf. The adhesiveness and cohesiveness of doughs with Mf showed a higher reduction of maximum force than those with Cf. Tortillas with Cf were more elastic with higher tensile strength than those with Mf. Using Cf as partial substitution of maize might lower production costs, but Mf is not particularly suitable as maize substitute in tortilla production. Tortillas with 40 % (w/w) cassava flour, presented the highest preference on a sensory test.

Keywords Maize dough · Tuber flours · Dynamic rheology · Tortillas · Mechanical properties

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Introduction

Maize tortillas are one of the most widely consumed food items in Mexico and are a fundamental food in the national diet. They are mainly made from a dough named as “masa”, processed by heating maize grains in an alkaline medium, an ancient method known as nixtamalization. Some industrialized processes also use flour from nixtamalized maize grain. Tortilla demand has increased steadily as does that for flour from nixtamalized maize. This flour offers various advantages (e.g., financial, management) over ground whole grain maize, such as the ability to be mixed with preservatives and dough improvers, to lengthen tortilla shelf life (Cornejo-Villegas et al. 2010). Maize production in Mexico, however, has been unable to meet domestic demand for the last 20 years, leading to increasing imports of maize for human consumption (Vaca-García et al. 2011).

Tortillas are formed by partially gelatinized starch granules, mixed with intact granules, endosperm fragments and lipids, which form a heterogeneous complex matrix within a continuous aqueous phase (Gómez et al. 1987; Ruiz-Gutierrez et al. 2010). Heating maize dough affects tortilla quality. For example, an excess of heating causes starch granules to lose their structure and integrity, leading to formation of gelatinized paste with a higher water absorption index, and resulting in dough with higher adhesiveness, which complicates the manufacturing process.

Certain non-traditional crops have been grown more widely, while the sowing of traditional crops such as maize, has changed little or even decreased. Thus, studies are needed on the feasibility of partial substitution of food raw materials with alternative ingredients, to control costs and maintain the supply of foods, particularly staples like tortillas. In this sense, tubers (e.g. potato, malanga, yam, macal, cassava, etc.) offer the advantages of high yield and calorie content, and form a vital part of the energy and nutritional requirements of

millions of people in developing countries (Scott et al. 2000). For instance, the partial substitution of wheat flour with cassava (*Manihot esculenta*) flour in some foods, has the advantage of being a relatively low cost procedure, and working properly at substitution levels as high as 50 to 100 %. Functional advantages over other flours (e.g. wheat) include its greater water absorption capacity and a crunchier consistency in products made with cassava flour (Wheatley et al. 1997). Malanga (*Xanthosoma saggitifolium*) is one of the most important food tubers in the tropical Americas. It is perennial and, if not harvested, it will form a short main subterranean stem (corm), rather than an aerial stem, and from this sprout, secondary, lateral thickened cormels (Anonymous 2011; Valerio 1988). The cormels are edible and are used in various foods, either for feeding or industrial applications.

Measurement of food consistency using rheology, is increasingly common in industrial and academic applications. Rheology has been ordinarily used in quality control, process engineering, product development and formulae optimization (Steffe 1992). Dynamic rheology is commonly used to measure food viscoelasticity, where basic sample descriptive components are the storage modulus (G'), an indicator of materials elastic component; the loss modulus (G''), an indicator of materials viscous component; and the $\tan \delta$ (G''/G'); the ratio of a sample's viscous and elastic moduli (Ferry 1980; Macosko 1994).

The objective of the present study was to evaluate the chemical composition, physicochemical and rheological characteristics of doughs and mechanical properties of tortillas made from nixtamalized maize in blends with different inclusion levels of cassava (*Manihot esculenta*) and malanga (*Xanthosoma saggitifolium* Schott) flour.

Materials and methods

Commercial maize was purchased at the local market in Tenosique, province of Tabasco, Mexico. Cassava and malanga roots were harvested in the same area.

Flour production Cassava (Cf) and malanga (Mf) flours were produced following the modified method of Wheatley et al. (1997). The tubers were first brushed and washed with running water to eliminate surface impurities. Both species were then peeled and cut into pieces (approx. 1 cm²). Cassava pieces were then dried in a forced air oven at 60 °C for 24 h. Malanga pieces were soaked in a potassium bisulphate solution with 25 ppm SO₂ at a 1:3 ratio, drained and then dried under the same conditions as above. After drying, the cassava and malanga pieces were milled separately (Ciclotec 1093, TECATOR), screened through a US#60 mesh and stored in closed containers at room temperature until use.

Dough production and chemical composition evaluation Three types of dough were produced from different flours: maize; maize-cassava; and maize-malanga. The maize flour base was produced by first nixtamalizing the maize. At a 1:3 ratio, 1 Kg maize grain was mixed into boiling water containing 1 % (w/w) (10 g) lime, cooked for 20 min and allowed to rest for 12 h. The resulting liquid (known as *nejayote*) was discarded and the cooked maize (known as *nixtamal*), was manually washed until removing all detached pericarps. This washed and cooked maize was ground twice in a manual mill (Estrella, Mexico), until producing a fine dough. The cassava and malanga flours were mixed with the maize dough at 20, 30 or 40 % (w/w) (dry basis) to produce seven treatments: Cf20, Cf30 and Cf40, containing cassava; Mf20, Mf30 and Mf40, containing malanga; and Ctl, a control with 100 % maize flour. Each treatment was kneaded manually for 5 min, adding 10 % (w/w) water. After kneading, the treatments were allowed to rest for 15 min and then a rheological (viscoelastic) profile measured for each one. Chemical composition was calculated on dry basis, using maize dough content and the cassava or malanga substitution levels in each treatment. Total dietary fiber was evaluated as well. Numerical evaluations were done with the demonstration version of the calculation software Nutritionist Pro, ver. 2.090. First Data Bank (2004).

Dough viscoelastic characterization Dough viscoelastic measurements were done with a controlled stress rheometer, working in its strain mode (model AR2000, TA Instruments) at 25 °C using a parallel plate geometry with 40 mm diameter and a gap of 2 mm. A dough sample (2 g) was molded into a disc shape, matching exactly the diameter and thickness of the space between the fixed and mobile plates. Dough samples were left to rest for 15 min before each test. Linear strain (deformation) interval, or linear viscoelastic region (LVR), was measured with a strain sweep from 4 to 12 % at a frequency of 6.2 rad/s. A frequency sweep was then done from 4 to 12 rad/s with 8 % strain, this last value derived from the LVR. All rheological tests were done in triplicate for each of the six treatments and the control.

Dough cohesion and adhesion Cohesion and adhesion for the control and treated samples was measured as maximum necessary compression and tension force using a texturometer (Instron 4411) with a 5 Kgf load cell. Samples were molded into a 36 mm diameter×5 mm thick plastic ring. Using a compression yoke (accessory 2830–011), a 5 Kgf maximum load was applied at a rate of 5 mm/min and a 6 mm initial distance. Measurement of cohesion and adhesion was done following the modified method of Ramírez-Wong et al. (1993). Two programs were run: in the first compression one, force was applied to 4 mm thickness to measure cohesion; after 1 min, the second one was run to evaluate adhesion.

Tortilla production Of the prepared maize dough, one portion was used to make control tortillas and the remainder, mixed with cassava or malanga flour in different proportions for the treatments. Tortillas (12.5 cm diameter) were produced from the doughs using a manual tortilla machine with rollers calibrated to 2 mm thickness. As they were rolled out, each tortilla was placed on a circular polyethylene mold and covered with polyethylene to evaluate weight loss. They were then cooked on a griddle preheated to 250–300 °C for 30 s on one side and 25 s on the other side. They were flipped once and allowed to rest until inflating. After cooking, they were cooled down to room temperature, stored for 30 min in paper napkins and packed in polyethylene bags until analyzed. The prepared dough mixtures (Cf20, Cf30, Cf40, Mf20, Mf30 and Mf40) plus the control (Ctl), were taken to a commercial tortilla factory and processed with the conditions described above. The main difference is that they were not cooked on a griddle, but over a gas flame, an integral part of the preparation process when using a commercial tortilla machine. Mechanical properties were evaluated for the control and treated tortillas.

Weight loss Weight loss was measured by difference between the raw and cooked tortillas. Raw tortillas (12.5 cm diameter, 2 mm thick) were weighed while still in polyethylene bags to prevent moisture loss. Cooked tortillas were weighed after cooling down to room temperature. All measurements were done in triplicate.

Tensile strength and elasticity The tensile strength and elasticity test simulates the breakage force and displacement of the tortilla in the hands. Three tortillas were taken from each treatment and an “I”-shaped strip cut from the center, avoiding the edges. Strip dimensions were 8 cm long by 2 cm wide, not including the upper and lower portions of the “I” shape. Each tortilla strip was placed in a 5 Kgf load cell and fixed with two tension clips. Tension at break (tensile strength) was measured with a texturometer (Instron, model 4411) at a 1 Kgf/mm² maximum load, 2 mm/s rate and a 15 mm maximum displacement deformation distance, the elasticity was considered as the maximum distance (mm) a tortilla strip reached at the breaking point i.e., the elongation at break (Arámbula et al. 2001).

Sensory analysis A sensory evaluation was undertaken to the tortillas made from the various nixtamalized doughs, that showed similar viscoelastic, cohesive and adhesive characteristics to that of the control dough. This test was done with 80 non-trained subjects selected among the students of the university campus. Three samples of tortillas coded with three digits were supplied to each subject, along with a questionnaire based on a 7 point-Hedonic scale (Lawless and Heymann 2010), where number 1 corresponded to the qualification “dislike very much” and 7 to “like very much”. The sample

size was half of a tortilla, using a small piece of a local soft cheese as a sample supplement.

Experimental design and statistical analysis A random block design with three replicates was applied to evaluate dough adhesion and cohesion, as well as tortilla weight loss, elasticity and tension force. Blocks were the different replacement proportions (20, 30 and 40 % (w/w)) for the cassava and malanga flours, resulting in a total of seven treatments. An analysis of variance (ANOVA) was applied to identify differences between treatments and a Duncan multiple comparison test, was used to compare the treatments to the control (nixtamalized maize dough). The significance level (α) was 0.05 in all cases (Montgomery 2004), and all data analyses were run with the Statgraphics Plus, ver. 5.1 package.

Result and discussion

Dough chemical composition Both the cassava and malanga doughs exhibited decreased protein content, with the Cf treatments having the largest reductions versus the control (Table 1). This was due in both cases, a consequence of the low protein content of these tubers. The fat content had a similar behaviour to the protein (lower values), for both Cf and Mf treatments when compared to the control, with different values between the treatments. Ash content was highest in the Mf treatments, while those of the Cf and control did not differ appreciably. Nitrogen-free extract (NFE) was the highest in the Cf treatment, while Mf and Ctl presented similar content, this was due probably because carbohydrates (e.g., starch) are the main components in Cassava flour (Whistler et al. 1984). The crude fiber content was highest in malanga doughs and its blends with maize, while Ctl and Mf treatments had similar contents. However, for the total dietary fiber, Ctl showed the highest content, while malanga treatments showed higher values than those of cassava at the same substitution level.

Dough viscoelasticity With the exception of the Cf30 and Mf30 treatments, dough storage modulus (G') profiles were usually linear, beginning at values greater than approximately 6 % strain or deformation (Fig. 1). No pronounced distortion or inflection point was visible in these plots, which might indicate disruption of sample structure. The control predominated in the 6 to 12 % deformation interval, followed by Cf30 and Cf20 (up to approx. 7.5 % deformation), and then, in descending order Cf40>Mf20>Mf40>Mf30. Respect to the viscous modulus (G''), the control and Cf treatments, exhibited an almost linear behavior from 6 % deformation to the end of the test (Fig. 2). Except for the control and Cf30, the trend in this modulus was similar to that of G' , as manifested by linear plots, lacking the accentuated inflection points that

Table 1 The computed chemical composition (%) of maize and maize-tuber doughs (d.b.)

Component	Ctl	Cf	Mf	Cf20	Cf30	Cf40	Mf20	Mf30	Mf40
Protein	9.78	2.67	6.30	8.27	7.53	6.81	9.25	8.95	8.64
Crude fat	2.04	1.07	0.79	1.84	1.73	1.64	1.85	1.74	1.63
Crude fiber	2.96	2.67	3.15	2.90	2.87	2.84	2.99	3.00	3.03
Ash	2.04	1.60	4.72	1.95	1.90	1.86	2.46	2.68	2.92
N.F.E.	83.18	91.99	85.04	85.04	85.97	86.85	83.45	83.63	83.78
TDF	10.35	3.50	5.57	8.98	8.30	7.61	9.39	8.92	8.44

20, 30 and 40 are the tuber substitution percentages

Ctl control, Cf cassava flour, Mf malanga flour, N.F.E. nitrogen free extract, TDF total dietary fiber

could indicate breakage of sample structure. Absolute G'' values were higher than the G' values, and the descending order of treatments differed: Ctl>Cf20>Cf 30>Cf 40≈Mf20>Mf40>Mf30. However, the overall order was consistent with the tendency for the Cf treatments to have higher values than the Mf treatments, in both (viscous and elastic) moduli. Except for the Ctl, this tendency does not agree with previous reports, that found a high correlation between the dough protein and total dietary fiber content and its consistency (Arámbula et al. 2002), since malanga flours presented higher protein and fiber contents, but lower moduli (G' , G'') values. Thus, the higher values in the Cf than in the Mf treatments, may be due to modification of starch during drying, which might lead to the formation of a greater viscoelastic gel network when cassava was mixed with maize flour, because of a higher enhancing effect of cassava-maize flour structure, than that produced when malanga and maize flour interacted; as well as to granule physical characteristics. This is supported by the different granule shapes and sizes of cassava (8 to 22 μm) and malanga (2.8 to 50 μm) starches reported previously (Hernández-Medina et al. 2008). It is also consistent with the higher gelatinization temperature range of malanga starch (69 to 85 °C) as compared to the range of cassava starch (58 to 78 °C); suggesting that the malanga starch probably might not have reached the gelatinization temperature during the drying process, as the temperature used was about 60 °C and thus, the optimum viscoelastic properties might not have been developed yet, suggesting the convenience of using a higher temperature for drying cassava. This effect rose as Mf concentration increased. On the above basis, an intermediate deformation value of 8 %, within the linear region, was used for all frequency sweeps under the previously described conditions.

Rheological profiles were generated based on the frequency of the control and treated samples for the elastic (G' , Fig. 3) and viscous (G'' , Fig. 4) moduli. At 5 rad/s, all dough samples had similar profiles (Fig. 3). The control had highly predominant values, followed by the Cf treatments (no significant differences among them) and Mf treatments, which did differ one respect to the other. Overall, the tendency for this modulus

was Ctl>Cf20≈Cf30≈Cf40>Mf20>Mf30>Mf40. Viscous modulus values were also lower for the treated samples than for the control (Fig. 4). Again, the Cf treatments had higher values than the Mf treatments, but were somewhat frequency dependent from 5 rad/s onwards. In contrast, the Mf profiles were linear over the entire frequency interval. The tendency in this modulus (G'') was Ctl>Cf40>Cf 20>Cf30>Mf20>Mf30>Mf40, with an overall substitution level dependence, but showing a reverse trend the two species. Tuber flour type and substitution level resulted in lower viscous modulus values in the treated samples, in other words, both the Cf and Mf treatments had lower dough viscous character than the control. Overall, similar tendencies were found for the moduli (G' , G'') plots in both frequency and strain sweeps, with no apparent relationship with the dough protein and dietary fiber contents. So, the fact that reductions in the Cf treatments were not as drastic as in the Mf treatments, may be due to modification of the cassava starch during drying. Its minimum gelatinization temperature is approximately 58 °C (González and Pérez 2003), slightly lower than the drying temperature (60 °C). The notably lower viscous behavior in the Mf treatments was probably due to the higher gelatinization temperature (average value of 77 °C) of malanga starch (Sefa-Dedeh and Kofi-Agyir 2002), suggesting that it would not have been modified appreciably (i.e. gelatinized) during drying.

Frequency sweeps for both moduli (G' and G'') were run for the Ctl, Cf and Mf treatments, and measurements were taken at the initial (4 rad/s), middle (8 rad/s) and final (12 rad/s) phases of every profile (Table 2). In all cases, the viscous modulus predominated ($G''>G'$) in the three phases. The descendent order of both moduli (G' and G'') values were control>Cf>Mf samples. The frequency sweeps suggest that overall, the moduli values of all samples showed the same trend, over the entire frequency range (Table 2).

All $\tan \delta$ (G''/G') values of the dough samples, decreased as frequency increased with all values greater than unity (Table 3), indicating that as is common in such systems (Ferry 1980), G' increased with frequency more than G'' . As expected, the control had the lowest values at all three phases, while

Fig. 1 Storage modulus (G') profiles during the deformation sweep of maize dough and tuber-maize dough mixtures. *Ctl* control, *Cf* Cassava, *Mf* malanga. 20, 30 and 40=tuber substitution percentages

Mf treatments had higher values than Cf treatments. This is consistent with the greater difference between the G'' and G' moduli for Mf treatments when compared to Cf treatments and Ctl (Tables 2 and 3), as well as with the profiles for both moduli (Figs. 3 and 4). As Mf inclusion levels increased, the $\tan \delta$ values increased as well, leading to mainly viscous systems ($G'' > G'$). These changes in the viscoelastic and elastic character may be due to flour source material (cassava and malanga) and thus, to the physical characteristics of their starches during heating. Starch granule size can determine differences in moduli and any modifications in starch characteristics (e.g. changes in Cf starch during drying by heating) may affect the moduli values (González-Reyes et al. 2003). The fact that the Cf treatments had an elastic profile similar to that of the control, suggests that these substitution levels could be used in tortilla dough without it sticking or breaking during processing, which is most important for the final quality of tortillas.

The Ctl, Cf and Mf treatments, all had $\tan \delta$ values indicating that they are variant systems (Table 3), with lower values as frequency increased (Ferry 1980). In the initial

phase, all doughs had $\tan \delta$ values greater than 3, meaning they were more viscous than elastic systems, and that both water and flour contributed to the viscous component (G'') (Ferry 1980; Macosko 1994). Overall, except for Mf40, the $\tan \delta$ values tended to decrease in the middle and final steps of the frequency range for all treatments, with a more notorious decrease in treated samples. This is consistent with the fact that especially the Mf treatments, produced notably weaker gels than the other samples, which in turn, affected their malleability and made tortilla preparation more difficult; which was apparent during dough kneading.

Cohesion and adhesion Cohesion is the interactive force between the internal bonds the shape material structure (also known as “body”) during compression. The texture of doughs is crucial during the production of tortillas. The dough should be readily cohesive to allow the formation of a sheet and thus, favor its cutting and shaping as round disks or another shape. The doughs generally differed ($P < 0.05$) in terms of this parameter. Molecular interaction forces in the Cf treatments were lower than those in the Mf treatments. Two factors may

Fig. 2 Loss modulus (G'') profiles during the deformation sweep of maize dough and tuber-maize dough mixtures. *Ctl* control, *Cf* cassava, *Mf* malanga. 20, 30 and 40=tuber substitution percentages

Fig. 3 Storage modulus (G') profiles during the frequency sweep of maize dough and tuber-maize dough mixtures. *Ctl* control, *Cf* cassava, *Mf* malanga. 20, 30 and 40=tuber substitution percentages

have influenced this behavior; cassava flour has a higher hydration capacity, which would allow greater interaction between water and dough components; and possible modification of the cassava starch during drying. Maximum compression force in the control was 2.9 Kgf, while in the *Cf* treatments, it ranged from 2.06 to 2.40 Kgf. It was even lower in the *Mf*20 and *Mf*40 treatments, and overall, lowest in *Mf*30 (Table 4).

Adhesiveness is the force of attraction between the surface of a food and other surfaces it comes into contact with. The *Ctl* had the highest value, followed by the *Cf* and the *Mf* treatments (Table 4). All the *Cf* values did not differ significantly ($P>0.05$), and also, *Mf*20 and *Mf*40 were not different ($P>0.05$), but the *Cf* values were lower ($P<0.05$) than the control, while the *Mf* values were lower ($P<0.05$) than those of the *Cf* treatments.

Inclusion of cassava and malanga flour also lowered adhesiveness and cohesiveness, possibly due to starch granule

physical characteristics in the *Cf* and *Mf*. Cassava starch granules vary in shape from round to oval or spherical, and size can range from 4 to 42 μm . Malanga starch granules are round and measure from 2.8 to 50 μm diameter (Narayana 2002). Red malanga has been reported to have starch granule sizes ranging from 0.74 to 1.19 μm , while white malanga granules range varies from 0.75 to 1.19 μm (Sefa-Dedeh and Kofi-Agyir 2002). These differences in starch granule shape and size, may account for the different hydration capacities of the *Cf* and *Mf* when mixed with the nixtamalized maize. In addition, the malanga starch remained close to its native state, probably with just slight modifications caused by drying. It is therefore probable that, as with viscoelasticity, these discrepancies are responsible for the doughs' different behaviors.

Weight loss Weight loss in the control, as well as in *Cf* and *Mf* treatments, did not differ significantly ($P>0.05$), varying from 22.88 to 23.25 % (Table 5). This percentage is within the 16 to

Fig. 4 Loss modulus (G'') profiles during the frequency sweep of maize dough and tuber-maize dough mixtures. *Ctl* control, *Cf* cassava, *Mf* malanga. 20, 30 and 40=tuber substitution percentages

Table 2 Variation in the storage (G') and loss (G'') moduli during the frequency sweep of the maize, maize-cassava and maize-malanga doughs

Sample	G' (Pa)			G'' (Pa)		
	Initial	Middle	Final	Initial	Middle	Final
Ctl	2,350	5,374	6,727	6,042	9,765	10,690
Cf20	609	3,030	3,832	4,284	6,270	7,061
Cf30	338	2,969	3,604	1,610	5,650	6,215
Cf40	391	2,916	3,479	1,702	5,206	5,758
Mf20	131	197	276	777	1,023	1,280
Mf30	49	77	98	460	592	696
Mf40	33	43	45	290	363	422

Values are the average of three readings

20, 30 and 40=tuber substitution percentages. Initial=4 rad/s, middle=8 rad/s, final=12 rad/s

Ctl control, Cf cassava flour, Mf malanga flour

25 % reported previously for tortillas (Arámbula et al. 2001), and is only slightly lower than the 23.9 to 24.8 % reported for tortillas made from a mixture of nixtamalized maize and soy paste. Weight loss in maize tortillas is reflected in total yield, and optimum conditions for water to penetrate the grain and interact with other components, are a combined cooking and soaking period of 5 h (Arámbula et al. 2001). In the present study, the Cf and Mf treatments contained nixtamalized maize dough that had been cooked for 20 min and allowed to soak for 12 h. This was done to ensure greater interaction of water with the maize components and thus, prevent their rapid elimination during tortilla cooking. It is probable that these interactions occur during the nixtamalization process, when the hydroxyl bonds of the amylose and amylopectin in the starch granules are more exposed and therefore, interact strongly with water molecules (bound water). These granules retain more water, making it less available for biochemical reactions, leading to less tortilla weight loss during cooking, since unbound water is the first component to evaporate.

Table 3 Variation in delta tangent ($\tan \delta$) during frequency sweep of the maize, maize-cassava and maize-malanga doughs

Sample	Initial (4 rad/s)	Middle (8 rad/s)	Final (12 rad/s)
Ctl	2.57	1.82	1.54
Cf20	3.95	2.07	1.84
Cf30	4.77	1.90	1.73
Cf40	4.35	1.79	1.66
Mf20	5.95	5.19	4.65
Mf30	9.45	7.73	7.07
Mf40	8.83	8.34	9.43

Values are the average of three readings

20, 30 and 40=tuber substitution percentages

Ctl control flour, Cf cassava flour, Mf malanga flour

Table 4 Cohesion and adhesion force of the maize, maize-cassava and maize-malanga doughs

Sample	Cohesion (Kgf)	Adhesion (Kgf)
Ctl	2.89±0.21 ^a	1.03±0.072 ^a
Cf20	2.40±0.14 ^b	0.87±0.06 ^b
Cf30	2.28±0.11 ^c	0.87±0.052 ^b
Cf40	2.06±0.14 ^d	0.84±0.058 ^b
Mf20	1.20±0.07 ^e	0.48±0.03 ^c
Mf30	0.89±0.045 ^f	0.38±0.02 ^d
Mf40	1.22±0.08 ^e	0.49±0.04 ^c

Values are the average of 6 replicates ± standard deviation. 20, 30 and 40=tuber substitution percentages. Different letters in the same column indicate significant statistical difference ($P<0.05$)

Ctl control flour, Cf cassava flour, Mf malanga flour

Tensile strength and elasticity Maximum tensile strength (maximum force required to cause rupture) was lowest in the Mf40 treatment, followed by the Mf20, while the Mf20 and Ctl were not different. The Cf treatments did not differ from one another and all had values higher ($P<0.05$) than the Mf treatments and Ctl (Table 6). The elongation at break, which gives an idea of the elasticity of the material (tortillas), did not differ ($P>0.05$) between the control and the Mf treatments, but all tortillas coming from Cf treatments, had higher ($P<0.05$) values than the Mf treatments and the control. The differences in tortillas elasticity between the Cf and the Mf treatments and control, suggest that as Cf concentration increased, the cassava starch probably interacted with lipids, proteins and carbohydrate remaining in the maize structure. An aqueous medium favors these interactions as suggested in a previous work (Arámbula et al. 2001). It was the interaction between water, and the above mentioned components, which probably increased dough elongation ability in these treatments; for instance, cassava flour has a reported water

Table 5 Weight loss (%) in tortillas made from maize, maize-cassava and maize-malanga doughs

Tortillas	Weight loss
Ctl	23.00±1.38 ^a
Cf20	22.75±1.14 ^a
Cf30	23.00±1.4 ^a
Cf40	22.88±1.60 ^a
Mf20	22.88±1.37 ^a
Mf30	23.25±1.16 ^a
Mf40	22.63±1.58 ^a

Values are the average of three readings±standard deviation. 20, 30 and 40=tuber substitution percentages. The same letter in the same column indicates no significant statistical difference ($P<0.05$)

Ctl control flour, Cf cassava flour, Mf malanga flour

Table 6 Maximum tensile strength and elasticity of tortillas made from maize, maize-cassava and maize-malanga doughs

Tortilla sample	Tensile strength (gf/mm ²)	Elasticity (mm)
Ctl	6.7±0.40 ^b	5.86±0.35 ^c
Cf20	9.0±0.63 ^a	10.85±0.54 ^b
Cf30	8.9±0.45 ^a	13.02±0.91 ^a
Cf40	8.7±0.52 ^a	14.40±0.86 ^a
Mf20	6.6±0.46 ^b	7.22±0.36 ^c
Mf30	4.2±0.21 ^c	6.74±0.47 ^c
Mf40	3.4±0.20 ^d	6.07±0.36 ^c

Values are the average of three replicates ± standard deviation. 20, 30 and 40=tuber substitution percentages. Different letters in the same column indicate significant statistical difference ($P<0.05$)

Ctl control flour, Cf cassava flour, Mf malanga flour

absorbance index of 2.2 to 2.7 g/g and a water absorption capacity of 1.2 to 1.6 g/g (Niba et al. 2002).

All tortillas from Cf and Mf treatments, had elasticity values (6.07 to 14.4 mm) higher than those reported for nixtamalized maize tortillas with added preservatives (potassium sorbate and calcium propionate) and improvers (carboxymethylcellulose and stearyl-2-sodium lactilate) (Ordaz and Vázquez 1997). These additives improve tortilla texture by contributing to moisture preservation and impart cohesiveness to the structure formed by starch gelatinization and protein denaturation. Tortillas containing improvers had elongation at break values (4.17 to 5.26 mm) well below those of the Cf treatments, possibly due to high water absorption index and water absorption capacity of the cassava flour, which allowed the interaction with maize dough components (e.g. protein, lipids and carbohydrate remains) enhancing the structure between these components and water.

Sensory analysis

According to the evaluated parameters, and since the cassava flour affected on a less degree the mechanical characteristics of the masas than that of the control, its formulations were chosen to undertake the sensory evaluation of tortillas manufactured with such formulations. The preference (liking) tests of tortillas with 20, 30 and 40 % of cassava flour addition, showed significant differences among treatments ($p<0.05$). The Duncan multiple comparison test of means, showed that the treatments with 30 and 40 % of cassava flour were not statistically different, but both showed significant difference respect to 20 % cassava flour added tortilla (Fig. 5), with a liking degree higher than 5 (like moderately to like very much). It was observed that the 40 % cassava flour added tortilla, had the highest liking degree, followed by that with 30 % cassava flour addition. Based on the affective attributes,

Fig. 5 Degree of liking of tortillas with cassava flour addition. 20, 30 and 40=cassava flour percentages. Different letters indicate significant difference between samples

the subjects mentioned that the samples with 20 % cassava flour addition displayed hard texture, unpleasant and viscous taste; for tortillas with 30 % cassava flour they sensed a soft texture with sweet and pleasant tasting; for tortillas with 40 % cassava flour, the subjects found as main characteristics a sweet and pleasant tasting, best consistency and soft texture. This is consistent with the fact that 66.25 % of subjects graded higher than 5 on the mentioned Hedonic scale, the tortillas with 40 % of cassava flour addition, followed by 56.25 % that found the tortillas with 30 % of cassava flour addition as tasty, while 45.5 % of the subjects described the tortillas with 20 % of cassava flour addition as tasty (data not shown).

Conclusion

The tortilla dough containing either cassava or malanga flours, had lower protein content but more fat and nitrogen free extract contents than the control dough. Malanga dough showed the highest ash percentage. Crude and total dietary fiber content, was highest in malanga doughs and its blends with maize than cassava dough, but no notorious effect was observed on the characteristics of such doughs because of these components. All doughs exhibited weak viscoelastic gel-like behavior, with highest tendency in the malanga specimens to be mainly viscous systems. The viscoelastic behavior changed as a function of cassava and malanga flour incorporation level into the nixtamalized maize dough. Cassava flour treatments had lower decrements in the elastic (G') and viscous (G'') moduli than malanga flour treatments. Adhesiveness and cohesiveness were also affected by tuber flour inclusion, with greater reductions in maximum adhesion and cohesion in the malanga, than in the cassava flour treatments.

Neither the cassava nor the malanga flours affected tortilla weight loss, although tortillas made from doughs containing cassava flour, were more elastic and resistant than tortillas made from the control or malanga treatments. The use of cassava flour as an improver in nixtamalized maize dough for tortilla production, could lower overall tortilla production costs. The results suggest that the use of malanga flour at 20 % (w/w) in innovative blends with maize flour, might be the “threshold” for good tortilla production, further partial substitution with malanga flour (30–40 %), did not improve tortilla characteristics and is therefore, not a particularly promising levels of maize flour substitute. Its starch physical properties would have to be modified before inclusion in such systems. A sensory evaluation showed that the tortillas with cassava flour, presented a good preference by the involved subjects, being the blend with 40 % substitution, the one with the highest score. Further study would be needed to determine cassava and malanga dough possible functions in other food systems, but so far, valuable information was derived from this work.

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