


Original article

Native and modified chayotextle flour effect on functional property and cooking quality of spaghettiSara M. Chavarría-Fernández,¹ J. De J. Berrios,² James L. Pan,² Priscila L.S. Alves,² Heidi M. Palma-Rodríguez,¹ Juan P. Hernández Uribe,¹ Alejandro Aparicio-Saguilan³ & Apolonio Vargas-Torres^{1*} 

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Summary The objective of this research was to study the effect of partially substituting semolina flour by native (NCHF) and modified chayotextle (CHFMD) flours, on the physicochemical properties and cooking quality of spaghetti. Spaghetti was obtained by replacing semolina flour (control) with five different concentrations of NCHF and CHFMD flours (10%, 17.5%, 25%, 32.5% and 40%). The proximal composition of the flours showed that both NCHF and CHFMD flours lower content of protein and fat but higher content of ash and resistant starch (RS). Moreover, the RS content increased due to thermal modification (TM) and that RS remained high, even after the cooking process. Pasting properties such as peak viscosity, breakdown, setback and final viscosity were influenced by NCHF and CHFMD concentrations. Brightness (ΔL^*) was significantly reduced by inclusion of increasing CHFMD levels. True density and water absorption values increased with addition of NCHF and CHFMD, compared to the control spaghetti. The results obtained in this study demonstrated the possibility for producing spaghetti containing up to 40% CHFMD flour, with acceptable quality and functional properties.

Keywords Chayotextle flour, cooking quality, functional properties, spaghetti, thermal modification.

Introduction

In Mexico, the consumption of pasta-type products is very high since they are widely available in local markets, have a low cost and are easily prepared and stored (Union, 2019). Pasta is obtained by the mechanical kneading of semolina flours, or any combination of wheat, and water plus other optional ingredients, moulded or extruded and subjected or not to a thermal drying process (NOM-247-SSA1-2008, 2008). Pasta is made from durum wheat semolina (*Triticum durum*) due to the content of proteins (glutelins and gliadins) that form gluten, responsible for the viscoelastic and cohesive properties of the dough (Juárez *et al.*, 2014) and prevents the disaggregation of the pasta during cooking in water (Elizalde, 2010). Pasta contains essential proteins that play a primary role in human nutrition (Troccoli *et al.*, 2000), but deficient in the essential amino acids, such as lysine and threonine (Gallegos-Infante *et al.*, 2010). With the aim of

improving the nutritional deficiencies of pasta, nowadays flours from different sources are used to substitute durum wheat semolina, either totally or partially, in some products (Chillo *et al.*, 2010).

Studies on the use of chayotextle are limited. Chayotextle is a root that acts as a storage organ for water and nutrients. It is a rich source of carbohydrates, protein, calcium, phosphorus, iron, vitamin A, thiamine, riboflavin, niacin, ascorbic acid, water and starch (Hernandez-Urbe *et al.*, 2011). Their high content in starch polymer makes it ideal to produce food products as pasta and noodles (Hernandez-Urbe *et al.*, 2011; Cruz-Villegas *et al.*, 2016; Victoriano *et al.*, 2020). Flores-Silva *et al.* (2014) reported the use of chickpea, unripe plantain and maize flours in the preparation of gluten-free spaghetti. They found that the spaghetti showed good cooking quality, lower content of available starch and higher resistant starch content. Flores-Silva *et al.* (2015), using similar ingredient formulations, reported comparable values in textural properties of the formulated spaghetti, but significantly different ($P < 0.05$) compared to the control (100%

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semolina). However, the sensory test of the developed gluten-free spaghetti showed an acceptability score of up to 70%. In another study, it was reported that an increase in common bean flour concentration reduced the firmness values and increased the cooking loss (Gallegos-Infante *et al.*, 2010). The fortification with various sources such as legume flour, unripe fruit flour, soy proteins, gluten meal and modified starches has been attempted in several studies to enhance the nutritional and quality values of spaghetti (Zweifel *et al.*, 2000; Gallegos-Infante *et al.*, 2010; Petitot *et al.*, 2010; Flores-Silva *et al.*, 2015). Most studies have focused on the fortification of pasta and its effects on the final quality. Moreover, studies that report the thermal modification of flours and starches, used for the preparation of various food products, are focused on determining the effect of the modification on the digestibility properties of food components, such as resistant starch, available starch and slow digesting starch (Gou *et al.*, 2019; Cahyana *et al.*, 2020; Zou *et al.*, 2020). Only a few studies relate the effect of thermally modified flours on product quality (Kaur *et al.*, 2016; Cahyana *et al.*, 2019).

Unconventional flours, such as native and modified chayotextle flours, should be characterised in order to improve, colour, texture and cooking properties of traditional pasta products, such as spaghetti. These characteristics are considered as indicators of the quality and acceptability of the food. Hence, the aim of this study was to investigate the effect of native and modified chayotextle flours as unconventional ingredients to produce spaghetti, with up to 40% of semolina substitution, and evaluate the physicochemical and viscosity properties of the flours, raw and cooked spaghetti.

Materials and methods

Raw materials

Chayotextle (*Sechium edule* Sw.) was purchased from local producers in Acaxochitlan, Hidalgo, Mexico. Commercial durum wheat semolina was acquired at the Whole Foods Market in Albany, California, United States. The content of amylose and amylopectin of 26.3 and 73.7, respectively, were previously reported by (Hernandez-Urbe *et al.*, 2011). The study was carried out at the Western Regional Research Center, Albany, California, United States.

Chayotextle flour

The chayotextle was cut into 2-mm slices that were submerged in a citric acid solution (3 g L⁻¹). The slices were then placed on trays and dehydrated in a convection oven (1380FX, Shel Lab) at 45 °C for 24 h. Once dehydrated, the slices were ground in a

cyclone mill (3010-080, UDY) and sieved using a 100 (0.15 mm) screen. The flours obtained were stored in airtight Ziplock bags until use.

Thermal modification of Chayotextle flour

The thermal modification was carried out the methodology described by Hoover & Vasanathan (1994), with slight modifications. The moisture content of the flour was assessed, and 300-g batches were weighed. The moisture content was adjusted to 30% by adding distilled water in an airtight ziplock bag. The sample was mixed thoroughly as the water was added and shaken for 10 min until the mixture was homogeneous. The bag was sealed and kept at room temperature for 24 h. The sample was then transferred to a glass jar with lid. The sealed sample was heated in a convection oven (3489M-1, Barnstead International, Dubuque, Iowa, US) at 100 °C for 24 h and then refrigerated at 4 °C for 24 h; this cycle was completed 3 times. Once the jar was opened, the sample was mixed for 5 min, dried (6% moisture content) and stored in ziplock bags until use.

Spaghetti formulation and processing

Different formulations consisting of 100% semolina (control) and a mixtures of semolina and different concentrations of native and modified chayotextle flours (Table 1) were processed into spaghetti using a Batch Pasta Extruder (Standard Industries, Inc, Fargo, ND, USA) under conditions similar to those described by the American Association of Cereal Chemists (AACC), approved method 66-41.01 (AACC, 2003). The actual conditions for dough extrusion were screw speed, 26 rpm; mixer vacuum, 457 mmHg; and extrusion tube temperature, 50 °C. The temperature of the production room was approximately 20 °C. Strands (60 cm) of spaghetti were cut as they came out of the

Table 1 Formulated flours (%) used in the production of spaghetti

Sample ID	NCHF	CHFMD	SE
Control	0	0	100
F1	10	0	90
F2	17.5	0	82.5
F3	25	0	75
F4	32.5	0	67.5
F5	40	0	60
F6	0	10	90
F7	0	17.5	82.5
F8	0	25	75
F9	0	32.5	67.5
F10	0	40	60

CHFMD, Chayotextle flour modified by heat-moisture treatment; NCHF, Native Chayotextle Flour; SE, Semolina.

extruder and dried in a laboratory scale drier (Standard Industries, Inc, Fargo, ND, USA) using gradient temperature drying cycles as follows: The chamber drying temperature was raised from 35 to 50 °C in the first hour, held at 55 °C for 10 h, and then gradually lowered to 45 °C for a total drying time of 19 h. The relative humidity in the chamber varied from initial 95% to 40% at the end of the drying cycles.

Chemical composition and resistant starch

Moisture, protein, lipids and ash contents were determined according to the standard methods of the Association of Official Analytical Chemists (AOAC, 2012) methods 925.10, 920.87, 920.85 and 923.03, respectively. The resistant starch (RS) was determined by the method 32-40.01 (AACC, 2003), using a commercial assay kit purchased from Megazyme International (Wicklow, Ireland).

Particle size distribution

The particle size distribution of the flours was determined by laser diffraction using a Mastersizer 2000 (Malvern Instruments Ltd., Malvern, Worcestershire, UK). Powders samples were dispersed using a Scirocco dry dispersion unit (Malvern, Worcestershire, UK) at a feed pressure of 2 bars and a feed rate of 40%. The obscuration was in the interval of 0.5–5%. The Fraunhofer approximation was used for the calculation of particle size. The volume, particle size distribution and average values were determined from at least three experimental runs.

Pasting profile

The pasting properties of the flours were evaluated with a Rapid Visco Analyzer (RVA; RVA-4500, Per-ten Instruments). The flour (2.50 g, 6% moisture db) was weighed directly in an aluminium RVA sample canister, and distilled water was added to a total weight of 28 g. The slurry was previously homogenised using a plastic paddle to avoid lump. A programmed heating and cooling cycle was set for 23 min in which the samples were held at 30 °C for 1 min, heated to 95 °C in 7.5 min, held at 95 °C for 5 min, cooled to 50 °C within 7.5 min and held at 50 °C for 2 min. The parameters recorded were pasting temperature (PT), peak viscosity at 95 °C (PV), breakdown (BD), setback (SB) and final viscosity at 50 °C (FV). All the measurements were done by triplicate.

Colour

The colour of the raw extruded spaghetti was measured using a Minolta model CM-600D (Konica

Minolta Sensing, Inc, Osaka, Japan). Briefly, the spaghetti samples were milled (UDY Corporation, Fort Collins, CO, USA) and sieved through a 0.5-mm screen prior to colour evaluation. The measurements were made holding the milled sample in direct contact with the colorimeter reading surface. Twenty measurements were taken on each sample to obtain the average of the luminosity (L^*), a^* (red/green) and b^* (yellow/blue) values. Qualitative colour differences using lightness (L^*) and chroma [$C_{ab}^* = (a^2 + b^2)^{\frac{1}{2}}$] representations were calculated using Equations 1 and 2:

$$\Delta L^* = L_t^* - L_s^* \quad (1)$$

$$\Delta C^* = C_t^* - C_s^* \quad (2)$$

where t refers to trial and s to standard or control sample (Minolta, 1994).

Cooked weight and cooking loss

The cooking quality of spaghetti was determined using the AACC-approved method 66-50.01 (AACC, 2000). The cooked weight (g) was determined as the final weight of 10 g of spaghetti cooked for 6 min in 300 mL of boiling water and drained for 2 min. The remaining cooking water was collected from each sample and evaporated overnight in a forced-air drying oven at 105 °C, and then, the residue was weighed and reported as percentage, in order to determine the cooking loss (% total solid weight).

Firmness of cooked spaghetti

The firmness of the cooked spaghetti was measured using a texture analyser (TA-XT plus 100, Texture Technology Corp., Hamilton, MA, US) using a 50 kg load cell. The pre-test and post-test speed were set to 2.0 mm s⁻¹ and 10.0 mm s⁻¹, respectively, with 30 per cent compression of the original height. The maximum force required to shear the pasta was taken as firmness from the force–time graph.

Water absorption (WA)

Spaghetti samples (10 g) were cut into 5-cm strands and cooked in 300 mL of boiling distilled water for 6 min. The spaghetti was then drained and rinsed with 50 mL of distilled water at room temperature for 2 min. The samples were weighed after reaching room temperature. The water absorption was determined as:

$$\%WA = \frac{(\text{weight of cooked drained pasta} - \text{weight of raw pasta})}{\text{weight of raw pasta}} \times 100$$

True density

True density of spaghetti was measured with a pycnometer (AccuPyc II 1340, Micromeritics, Norcross, GA, USA) using 350 cm³ sample holder and helium as a volume displacement medium. To calculate sample volume and total pore volume, helium volume before and after density was measured. The analysis of each sample was carried out in triplicate.

Spaghetti diameter

The diameter of the dried and cooked spaghetti was determined based on a protocol (Patil *et al.*, 2007). The midpoint of 20 individual strands of spaghetti control and those formulated with Chayotextle flour were taken randomly, using a digital calliper (Model CD-6", Mitutoyo Corp., Kawasaki, Japan) and the results reported as average of those measurements.

Statistical analysis

The experimental values were submitted to a completely randomised design. Analysis of variance (ANOVA) was performed using Sigma-Stat version 11.0 and their mean comparisons were determined using Tukey's test ($\alpha = 0.05$).

Results and discussion

Proximate composition, particle size and resistant starch of raw materials

The proximate composition, particle size and RS of the flours used in the preparation of spaghetti are shown in Table 2. The semolina (SE) flour had higher protein values (15.46%) when compared to the native chayotextle flour (NCHF) and chayotextle flour modified by heat and humidity treatment (CHFMD), which protein values were 6.52% and 5.42%, respectively. A similar pattern was observed in their fat content.

Moreover, there was a marked decrease in protein and fat values due to the heat modification treatment. These observations agree with the results of Meera *et al.* (2011), who studied the effect of heat treatment on sorghum flour. They reported a decrease in the content of free fatty acids due to the heat treatment during processing. Since, heat treatment promotes hydrolytic and oxidative reactions (Stewart & Bewley, 1980). The product of those reactions may not be determined in the standard fat analysis test. An analogous observation may relate to the observed decreased in protein, possible due to some protein hydrolysis and denaturation reactions. The ash content was higher in the flours obtained from chayotextle tuber (native and modified), and there were no significant statistical differences ($\alpha \leq 0.05$) due to the effect of thermal modification. Previous studies carried out by Jiménez-Hernández *et al.* (2007), reported ash values of 3.65% in chayote tubers, similar to those determined in this study. The moisture content of the studied samples was similar, with no statistical difference ($\alpha \leq 0.05$), with values ~6%. The particle size was higher in the CHFMD sample, as was also reported by Gonzalez-Cervantes *et al.* (2020), in oca tuber flours obtained by heat-drying. Leewatchararongjaroen & Anuntagool (2016) explained that the increase in particle size is a result of the effect of heat drying on the protein, which act as an adhesive, causing the agglomeration of starch granules.

The RS content was higher in the native chayotextle flour (NCHF), due possible to the granule supramolecular arrangement and intact crystalline structure of RS (Sajilata *et al.*, 2006). After the cooking process, RS content decreased in the NCHF samples (See Table 2). This behaviour is attributed to gelatinisation of the starch granules that occur by heat processing, which influences RS susceptibility to enzymatic hydrolysis (Sajilata *et al.*, 2006). A similar behaviour was indicated by Aparicio-Saguilán *et al.* (2005), who reported RS percentages of 1.51% and 16.02% in native and modified starch, respectively. The content of RS of

Table 2 Proximate composition (g/100 g db), particle size and resistant starch of the flours used from the production of spaghetti^{a,†}

Sample ID	Protein (%)	Fat (%)	Moisture (%)	Ash (%)	Particle size Dv (0.5)	RS (%)	
						BC	AC
NCHF	6.52 ± 0.04 ^b	0.39 ± 0.08 ^b	6.28 ± 0.00 ^a	3.32 ± 0.19 ^a	22.92 ± 2.68 ^b	36.34 ± 0.82 ^a	1.3 ± 0.07 ^b
CHFMD	5.42 ± 0.03 ^c	0.18 ± 0.00 ^c	6.14 ± 0.22 ^a	3.25 ± 0.07 ^a	37.75 ± 1.43 ^a	31.82 ± 0.53 ^b	17.8 ± 0.87 ^a
SE	15.46 ± 0.40 ^a	0.63 ± 0.01 ^a	6.45 ± 0.01 ^a	0.98 ± 0.00 ^b	ND	ND	ND

AC, after cooking; BC, before cooking; RS, Resistant starch; ND, Not determined.

^aSee footer of Table 1, to identify sample.

[†]Data are average of three replicates ± standard error. Means in the same column followed by different superscripts are significantly different ($\alpha \leq 0.05$).

NCHF and CHFMD were 36.34% and 31.82% db, respectively (Table 2). Rachman *et al.* (2021) reported that semolina contains 6.2% RS, which is about 6 and 5.2 times less than those present in NCHF and CHFMD, respectively. Even after cooking, the content of RS in the CHFMD was 17.8, which makes chayotextle spaghetti made from CHFMD a good source of RS.

Pasting profile of the flour blends

The pasting characteristics of the native and modified chayotextle flours and the SE flour are shown in Table 3 and Figure 1. The pasting temperature (PT) of the NCHF, SE, F1, F3 and F5 flour samples showed values of ~69.9 °C without any significant differences ($\alpha \leq 0.05$) between them. The same values were observed in F2 and F4 (values not shown). This indicates that the starch contained in the chayotextle and SE flours has similar gelatinisation temperatures. However, when CHFMD was blended with SE flour, the pasting temperature values increased to 82.63 °C, 86.57 °C and 90.83 °C in blends containing 10%, 25% and 40% of CHFMD flour, respectively (see Table 1 to ID). All the samples showed an increase of 4 °C as the concentration of modified flour increased. Similar behaviour was observed by da Rosa Zavareze & Dias (2011), who reported that a high pasting temperature in starches undergoing different heat–moisture treatments indicated more paste strength due possible to crosslinks in the starch granules that required higher heating temperature for structural breakdown and paste formation.

The peak viscosity (PV) of NCHF was 8008 cP while that of CHFMD exhibited the lowest value of 9 cP (see Table 3). This result could be due to the heat treatment of CHFMD, which induced a gelatinisation of the starch. The SE flour showed PV values of 1996

cP, which increased when the NCHF concentration was higher in the blends. An inverse pattern was observed in samples F6, F8 and F10, containing CHFMD, that showed a reduction in PV values with increased concentration of the modified flour. A similar behaviour was observed in BD and FV properties with increased NCHF and CHFMD in the blends. Aprianita *et al.* (2009), reported that a low protein content and high concentrations of carbohydrates lead to a higher peak viscosity, as observed in this study on samples F1, F3 and F5. The decrease in BD and FV values in F6, F8 and F10 indicated that these flours are more resistant to shear thinning during cooking. Similar observation was made by Wani *et al.* (2017), in a study with sweet chestnut submitted to pan and microwave roasting. The SB values provide information on rates of starch retrogradation and syneresis (Ahmed & Al-Attar, 2015). The values of SB for NCHF and CHFMD (Table 3) shows that NCHF had a significantly higher ($\alpha \leq 0.05$) retrogradation rate than CHFMD. Both formulated group of samples with either NCHF (F1, F3 and F5) or CHFMD (F6, F8 and F10) showed reduced SB values, as the native and modified chayotextle flour was increased in the formulations, indicating their effect on slow starch retrogradation. Furthermore, a high PT in the flour reflects the resistance of starch against swelling and degradation, as observed in the F6, F8 and F10 samples. The pasting profiles of a flour is an effective method for relating starch functionality with its structural features and its potential industrial application in products depending on the viscosity and thickening behaviour of starch, as in the preparation of spaghetti.

Spaghetti colour

Colour parameters determined in the raw spaghetti are shown in Table 4 and Figure 2. The lightness (L^*)

Table 3 Pasting properties of flour formulations used in the production of spaghetti^{*,†}

Sample ID	Pasting temperature (°C)	Peak viscosity (cP)	Breakdown (cP)	Setback (cP)	Final Viscosity (cP)
NCHF	69.43 ± 0.24 ^d	8008 ± 19.00 ^a	3687.3 ± 27.80 ^a	2223.3 ± 69.90 ^g	5784.7 ± 52.80 ^a
CHFMD	ND	9 ± 1.00 ⁱ	8.33 ± 1.53 ⁱ	35.67 ± 1.16 ^f	44.67 ± 1.53 ⁱ
SE	69.98 ± 1.03 ^d	1996.43 ± 15.01 ^e	984.67 ± 10.02 ^e	1757.3 ± 17.21 ^b	2991.7 ± 20.60 ^e
F1	69.92 ± 0.42 ^d	2509.9 ± 20.19 ^d	1111.7 ± 21.20 ^d	1885 ± 58.60 ^a	3512.7 ± 36.30 ^d
F3	69.92 ± 0.20 ^d	2854.3 ± 29.00 ^c	1549.33 ± 17.04 ^c	1353 ± 45.30 ^c	4207.3 ± 29.00 ^c
F5	69.47 ± 0.20 ^d	3980 ± 55.40 ^b	1630.7 ± 30.80 ^b	448 ± 46.90 ^e	4428 ± 29.60 ^b
F6	82.63 ± 0.32 ^c	1282.67 ± 39.19 ^f	748.67 ± 15.01 ^f	1347 ± 9.64 ^c	2240.67 ± 7.23 ^f
F8	86.57 ± 0.38 ^b	470 ± 13.86 ^g	412 ± 9.64 ^g	705.3 ± 10.07 ^d	1175.3 ± 22.70 ^g
F10	90.83 ± 0.13 ^a	184.5 ± 0.50 ^h	159 ± 0.00 ^h	440 ± 2.00 ^e	624.5 ± 2.50 ^h

ND, Not determined.

^aSee footer of Table 1, to identify sample.

[†]Data are average of three replicates ± standard error. Means in the same column followed by different superscripts are significantly different ($\alpha \leq 0.05$).

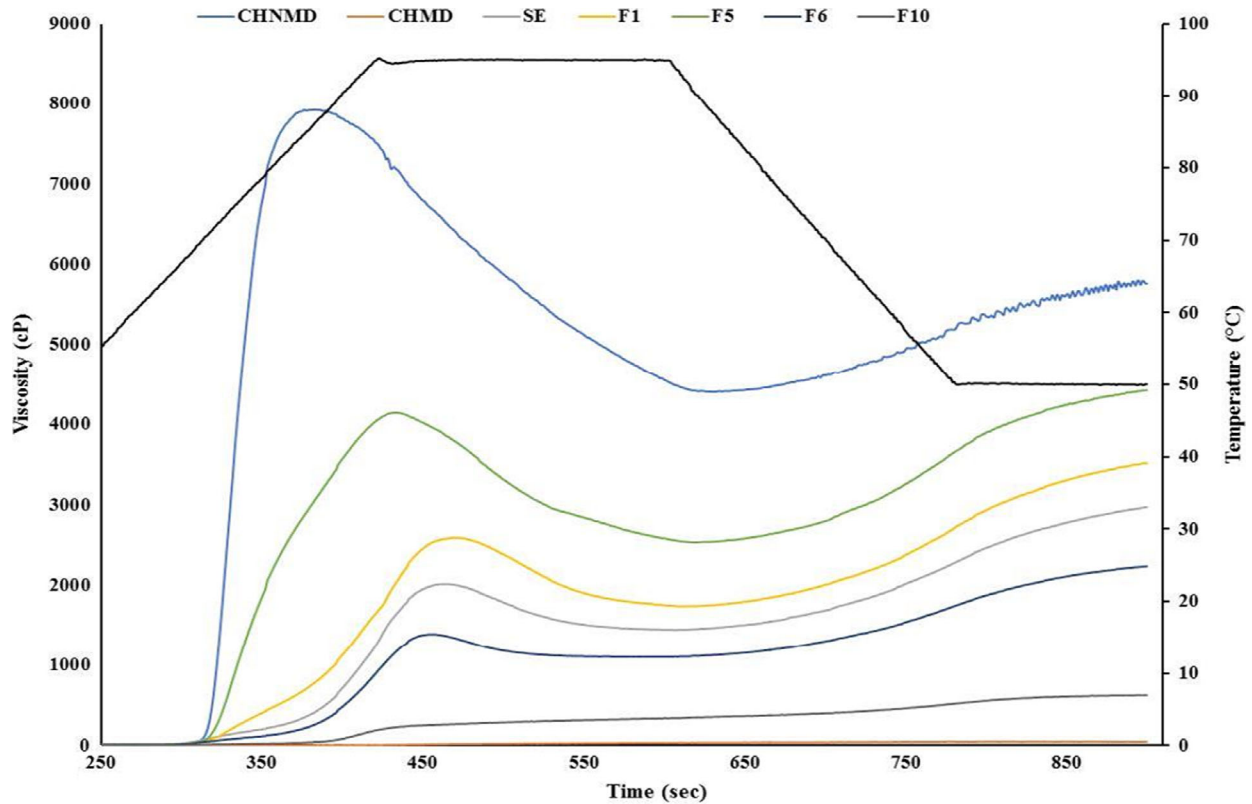


Figure 1 Viscosity profile of formulated flours used in the production spaghetti (For sample identification, see Table 1). NCHF, Native chayotextle flour, CHFMD, Chayotextle flour modified by heat–moisture treatment, SE, Semolina. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.com)]

Table 4 Colour parameters determined in raw spaghetti made from semolina (control) and those made with different levels of NCHF and CHFMD in substitution of semolina^{a,†}

Sample ID	L^*	Chroma	ΔL^*	ΔC^*
Control ^a	93.76 ± 0.30 ^b	13.51 ± 0.37 ^f		
S1	92.42 ± 0.37 ^c	17.13 ± 0.51 ^d	-0.41 ± 0.03	-0.32 ± 0.04
S2	92.20 ± 0.39 ^c	16.75 ± 0.59 ^d	-0.73 ± 0.04	-0.73 ± 0.03
S3	94.61 ± 0.37 ^{a,b}	14.66 ± 0.59 ^e	-0.62 ± 0.02	-2.44 ± 0.01
S4	93.39 ± 1.12 ^b	12.84 ± 0.34 ^g	-0.80 ± 0.01	-3.81 ± 0.11
S5	95.02 ± 0.37 ^a	13.12 ± 0.25 ^{f,g}	-0.70 ± 0.03	-3.11 ± 0.23
S6	82.06 ± 0.63 ^d	18.03 ± 0.67 ^c	-2.10 ± 0.31	-2.55 ± 0.09
S7	78.04 ± 0.76 ^e	17.76 ± 0.83 ^c	-2.62 ± 0.37	-4.40 ± 0.22
S8	75.94 ± 0.70 ^{f,g}	20.34 ± 0.37 ^a	-2.78 ± 0.09	-3.72 ± 0.17
S9	76.17 ± 0.44 ^f	19.69 ± 0.42 ^b	-5.64 ± 0.51	-5.09 ± 0.44
S10	75.51 ± 0.52 ^g	20.62 ± 0.42 ^a	-6.63 ± 0.54	-5.14 ± 0.38

^aSee Table 1 for sample ID; here F-flour was changed to S-spaghetti.

[†]Data are average of three replicates ± standard error. Means in the same column followed by different superscripts are significantly different ($\alpha \leq 0.05$).

values of the control spaghetti and samples S1 to S5 (added with NCHF) did not show a large discrepancy, ranged from 92.42 to 95.02. However, samples

containing CHFMD showed a drastic reduction in L^* values. The reduction in L^* values was more pronounced as the amount of modified flour was increased in the formulations. As previously indicated, CHFMD was obtained by cycles of heating and cooling of chayotextle flour. The heating process promoted a darkening colour on this flour, with a $L^* = 43.03$. The colour change in samples that contain starch is caused by Maillard reactions and caramelisation of sugars, being dependent on the distribution of water and the presence of reducing sugars and amino acids, as lysine (Purlis, 2010). This explain the reduction of L^* values in samples with increased concentration of CHFMD in their formulations. Chroma (C^*) showed a reverse pattern with those of L^* values. As the concentration of NCHF increased in the spaghetti, C^* saturation levels decreased from 17.13 to 13.12, while as the concentration of CHFMD increased in the spaghetti, C^* saturation levels increased from 18.03 to 20.62 (Table 4). In the case of ΔL^* and ΔC^* , the increase in the negative values as the concentration of CHFMD increased in the formulations indicated that the colour of the spaghetti was darker and less saturated, respectively, as observed in Figure 2. A similar behaviour



Figure 2 Photographs of raw spaghetti made from semolina (control) and those made with different levels of NCHF and CHFMD in substitution of semolina. See Table 1 for sample identification; here F-flour was changed to S-spaghetti. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.com)]

Table 5 Spaghetti weight gain and loss during cooking and their firmness values at the optimum cooking time of 7 min^{*,†}

Sample ID	Cooking weight gain (g)	Cooking loss (%)	Firmness (N)
Control	66.37 ± 1.72 ^{b,c}	4.62 ± 0.25 ^f	0.18 ± 0.00 ^a
S1	67.30 ± 2.93 ^b	4.70 ± 0.30 ^f	0.16 ± 0.00 ^b
S2	66.00 ± 1.87 ^{b,c}	5.10 ± 0.25 ^e	0.15 ± 0.00 ^b
S3	67.49 ± 0.00 ^b	5.61 ± 0.18 ^{d,e}	0.13 ± 0.00 ^c
S4	74.03 ± 2.00 ^a	6.20 ± 0.31 ^{c,d}	0.12 ± 0.00 ^{d,e}
S5	72.71 ± 1.11 ^a	6.52 ± 0.27 ^{b,c}	0.11 ± 0.00 ^e
S6	63.91 ± 2.30 ^{b,c}	4.80 ± 0.23 ^f	0.15 ± 0.01 ^b
S7	62.14 ± 1.11 ^c	5.39 ± 0.31 ^e	0.15 ± 0.00 ^b
S8	65.14 ± 1.57 ^{b,c}	6.51 ± 0.47 ^{b,c}	0.13 ± 0.00 ^{c,d}
S9	64.63 ± 0.57 ^{b,c}	7.21 ± 0.07 ^{a,b}	0.12 ± 0.00 ^{d,e}
S10	66.54 ± 1.66 ^{b,c}	7.69 ± 0.03 ^a	0.12 ± 0.00 ^{d,e}

^{*}See Table 1 for sample ID; here F-flour was changed to S-spaghetti.

[†]Data are average of three replicates ± standard error. Means in the same column followed by different superscripts are significantly different ($\alpha \leq 0.05$).

was reported by Hernández-Nava *et al.* (2009), in the preparation of spaghetti added with different concentrations of banana starch. This shows that the partial substitution of SE has an important effect on this colour parameter.

Pasta cooking quality

Table 5 shows the effect of NCHF and CHFMD addition on the cooking quality of spaghetti. The cooking

weight gain (CWG) of spaghetti containing NCHF in their formulation (S1 to S5) was higher than those containing CHFMD, and their CWG increased with a higher concentration of NCHF in the spaghetti. These results could be explained by the increasing values of PV, previously observed with in the same samples (Table 3), as PV is a parameter related with the WA capacity of starch. Therefore, higher values of PV are related to increase in CWG, as determined in this study. Spaghetti containing CHFMD showed CWG in the range of 62.14 g to 66.54 g, which are lower CWG values than spaghetti containing NCHF in their formulations. In general, no statistically significant differences ($\alpha \leq 0.05$) were observed within all samples from containing CHFMD (S6 to S10), which also showed low PV values. This suggests that the WA in the spaghetti was directly affected by the increase in starch concentration and the thermal modification of the flours.

The cooking loss (CL) of the control sample (semolina spaghetti) was 4.62% (Table 5). Similar values were observed in spaghetti with low content of native or modified flour (S1 and S6), with no significant statistical difference between them ($\alpha \leq 0.05$). Nevertheless, when the concentration of NCHF and CHFMD increased in the spaghetti, the CL were between 5.10% and 7.69% higher than the control. These results are related to the extent of solubilisation of the amylose in the spaghetti during cooking (Hernández-Nava *et al.*, 2009). Furthermore, the addition of non-gluten flour in the spaghetti weakens the chemical bonds of gluten,

Table 6 Physical properties of spaghetti made from semolina (control) and those made with different levels of NCHF and CHFMD in substitution of semolina^{*†}

Sample ID	True density (g cm ⁻³)	Diameter in raw spaghetti (mm)*	Diameter in cooked spaghetti (mm)*	Diameter increase due to cooking (mm)	Water absorption (%)
Control	1.462 ± 0.00 ^e	1.59 ± 0.03 ^a	2.18 ± 0.08 ^a	0.59 ± 0.02 ^c	161.13 ± 0.24 ^c
S1	1.467 ± 0.00 ^d	1.57 ± 0.05 ^a	2.15 ± 0.06 ^a	0.61 ± 0.04 ^{a,b}	162.35 ± 1.88 ^c
S3	1.472 ± 0.00 ^c	1.54 ± 0.04 ^b	2.16 ± 0.03 ^a	0.62 ± 0.01 ^a	169.82 ± 0.16 ^b
S5	1.477 ± 0.00 ^b	1.56 ± 0.02 ^a	2.18 ± 0.05 ^a	0.62 ± 0.02 ^a	193.01 ± 0.34 ^a
S6	1.468 ± 0.00 ^d	1.57 ± 0.05 ^a	2.17 ± 0.04 ^a	0.60 ± 0.02 ^b	149.96 ± 1.94 ^d
S8	1.470 ± 0.00 ^c	1.58 ± 0.02 ^a	2.18 ± 0.06 ^a	0.60 ± 0.02 ^b	156.85 ± 2.03 ^d
S10	1.483 ± 0.00 ^a	1.58 ± 0.12 ^a	2.18 ± 0.04 ^a	0.60 ± 0.02 ^b	154.34 ± 3.25 ^d

^{*}See Table 1 for sample ID; here F-flour was changed to S-spaghetti.

[†]Data are average of three replicates ± standard error. Means in the same column followed by different lowercase are significantly different ($\alpha \leq 0.05$).

resulting in a dough with low strength that affected the structural integrity of the spaghetti (Rayas-Duarte *et al.*, 1996) and promoted the solubilisation of solids. Conversely to the results induced by the addition of NCHF and CHFMD on CL, the firmness values decreased, which agrees with the report of Rayas-Duarte *et al.* (1996) who found that dough with low strength have a negative effect in the integrity of the spaghetti structure. They observed a decrease in firmness when the concentration of non-gluten flours increased.

True density, diameter and water absorption of extruded spaghetti

The density property is a very important parameter in the production of expanded and formed food products. The true density (TD) values of spaghetti are shown in Table 6. The TD values among all spaghetti varied relatively close in the range of 1.462–1.483 g cm⁻³. In general, the TD values in the spaghetti steadily increased in spaghetti containing higher concentrations of NCHF and CHFMD in the blends. Previous studies have indicated that spaghetti made with high starch contents in the dough led to greater gelatinisation of the starch during the extrusion process at high temperatures (Hernández-Nava *et al.*, 2011). Additionally, as the gelatinisation increased, the volume of the extruded products also increased and the density decreased (Case *et al.*, 1992). Such phenomenon was not observed in this study since the extrusion process of the spaghetti was carried out at a low temperature of 50 °C, which was well below the gelatinisation temperature of wheat and chayotextle starch of 64 °C and 63 °C, respectively (Ghiasi *et al.*, 1982).

The diameter of the spaghetti range between 1.54 and 1.59 mm (Table 6). In general, it was observed that the increase in the concentration of native or

modified chayotextle flour did not largely affect the diameter of extruded spaghetti. This result could be due to the low extrusion temperatures used, which did not provide the conditions to reach the gelatinisation point of the starch (Case *et al.*, 1992) and therefore did not promoted a notable expansion in the spaghetti. On the other hand, when the diameter of the cooked spaghetti was compared to raw spaghetti, their values were significantly different ($\alpha \leq 0.05$). Since the diameter values in the cooked spaghetti range from 2.15 to 2.18 mm and those of the raw spaghetti ranged from 1.54 to 1.59 mm. The greater diameter values in the cooked spaghetti correspond with the observed values in WA, as shown in Table 6. The increase in the native or modified chayotextle flour, within the cooked or raw spaghetti groups, did not have an effect on the diameter of the spaghetti, as the diameter of those samples were not significantly different ($\alpha \leq 0.05$). Flores-Silva *et al.* (2015) reported similar results in diameter data in raw and cooked gluten-free spaghetti made from unripe banana, chickpea and maize flours also extruded under processing temperature condition of 50 °C.

Conclusions

The addition of different concentrations of NCHF and CHFMD flours in the blends used to make spaghetti, affected their pasting properties. Increasing concentration of CHFMD in the formulated flours significantly increased their pasting temperatures and the decreased peak viscosity, breakdown, setback and final viscosity, compared to their native counterpart and the control semolina flour. Also, the colour of samples containing CHFMD was darker than their native counterpart and the control semolina flour, due to the thermal pre-treatment applied to the CHFMD samples. The cooking weight and cooking loss increased with an increase in NCHF or CHFMD in the spaghetti. Conversely,

their firmness values decreased as the concentration of chayotextle flour increased in the spaghetti. The true density and diameter values in the raw and cooked spaghetti containing NCHF or CHFMD were slightly greater to those of the control spaghetti. Water absorption was influenced by the concentration and the modification of the chayotextle flour in the spaghetti. Chayotextle is an underutilised commodity that could be used in fabrication of value-added foods, as spaghetti. The results obtained in this study indicate that the chayotextle flour modified by heat and humidity could provide suitable alternative for the production of spaghetti with up to 40% substitution of semolina, with acceptable cooking quality and functional properties.

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Ethical guidelines

Ethics approval was not required for this research.

Conflicts of interest

The authors declare that no conflict of interest exists related with this publication.

Author contribution

Sara M Chavarría-Fernández: Data curation (supporting); **Jose De J. Berrios:** Investigation (supporting); Writing-review & editing (supporting). **James Pan:** Data curation (supporting); Supervision (supporting). **Priscilia L. S Alves:** Data curation (supporting); Formal analysis (supporting). **Heidi M Palma-Rodríguez:** Investigation (supporting); Methodology (equal). **Juan P Hernández Uribe:** Methodology (supporting); Supervision (supporting). **Alejandro Aparicio-Saguilan:** Resources (equal); Supervision (supporting). **Apolonio Vargas Torres:** Conceptualization (equal); Investigation (equal).

Peer review

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Data availability statement

Research data are not shared.

References

- This article was cited because it shows the use of heat-treated flours and their potential application in food products, studying the effect of these heat-treated flours on the physicochemical properties of the final product.
- This article was considered in this research because the physicochemical characterization of pastes is reported and some techniques were taken for the characterization in this study.
- The results of this article show that this tuber could have potential use in the elaboration of food products since it contains high contents of carbohydrates (starch).
- This article was considered because it reports the adequate substitution conditions of semolina for chayotextle flour in the preparation of noodles. Concluding that adequate amounts of chayotextle flour could maintain the technological quality of food.
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