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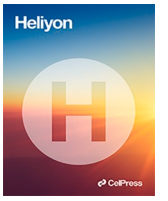

Techno-functional properties of gluten-free pasta from hyperprotein quinoa flour

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ABSTRACT

Many consumers who are aware of the importance of good nutrition demand quality food alternatives. In particular, many of them are looking for quality, plant-based protein sources such as quinoa. The objective of this work was to evaluate the techno-functional properties of gluten-free pasta from hyperprotein quinoa flour. Pasta mixes were made from gluten-free flours, corn, rice, cassava starch, hyperprotein quinoa flour and defatted high protein quinoa flour, which were subsequently extruded. The flow rheological properties of aqueous dispersions of flour mixtures were analyzed before and after the pasting test. In addition, thermal properties were analyzed by differential scanning calorimetry and structural properties by Fourier transform infrared spectroscopy. The results showed a change of flow from dilatant ($n > 1$) to pseudoplastic ($n < 1$) after the pasting test. In addition, a positive correlation was observed between hyperprotein defatted quinoa flour and viscosity, and a negative correlation with hyperprotein quinoa flour. Regarding thermal properties, it was found that all blends showed low gelatinization enthalpy values, attributed to the high proportions of HQF and HDQF. Spectroscopic analysis showed that the extrusion did not significantly affect the native structure of the protein, by monitoring the intensities of the 1648 cm^{-1}, 1656 cm^{-1} and 1667 cm^{-1} bands associated with the Random coil, α-helix, β-turns secondary structures, respectively. It was possible to conclude that both hyperprotein quinoa flour and defatted hyperprotein quinoa flours have a differential influence on the techno-functional properties of pasta. The first one, tends to reduce viscosity and consistency while the second one tends to increase it. Finally, moderate temperatures during extrusion did not cause significant changes in starch and protein structures as determined by spectroscopic study.

1. Introduction

More and more consumers around the world are becoming aware of the importance of good nutrition for good health and well-

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being and are demanding healthier food alternatives. On the other hand, the increase of some digestive disorders among the population, such as gluten intolerance, has created the need to produce differentiated foods to cover this growing market segment [1]. Celiac disease is a genetic enteropathy characterized by the inability to digest gluten proteins that are present in certain grains such as wheat, barley and rye [2]. It is estimated that 1% of the population suffers from celiac disease and 6% suffers from non-celiac gluten sensitivity [3]. In this respect, the use of grains such as quinoa, amaranth, millet and corn have become a good alternative for the production of different gluten-free products, but also to attract another market segment that demands products produced from good quality vegetable proteins.

Quinoa is a small, round-shaped grain categorized as a pseudocereal native to the Andean region of Bolivia and Peru, which has been cultivated for the past 4000–6000 years by ancient civilizations in the Americas [4]. The nutritional content of quinoa has been termed high quality and contains nutrients such as starch (58.1–64.2%), crude fiber (1.29–10.5%), protein (12.5–16.7%), fat (5.5–8.5%), vitamins (thiamine, folic acid, vitamin C, α-carotene and niacin) and minerals (calcium, magnesium, iron, copper and zinc). Likewise, a protein containing the nine essential amino acids has been highlighted [5]. In order to meet the demand for foods rich in vegetable proteins, a flour called hyperprotein quinoa flour (HQF) had previously been developed through an abrasive milling process, which polished the external part of the quinoa grain (the embryo or protein part), separating it from the starchy fraction of the perisperm or internal part [6]. This previous development allowed the flour obtained to have protein percentages between (15.62 ± 0.23) and (34.85 ± 0.17) g/100 g (wb), depending on the abrasion time. On the other hand, it had been found that the flour obtained had an important lipid content (18% d.b), so it was suggested that by removing them, the HQF protein could be more concentrated.

Pasta is a popular food among the population and is a highly appreciated dish among families. Its traditional elaboration is made with wheat semolina [1] and its multiple forms of presentation such as spaghetti, bigoli, macaroni, fettuccine, bombardoni, capunti, giglo, lasagna, fusilli, and others, make it a field of great interest in the development of food with nutritional functionality. The development of products such as pasta represents a great challenge for food developers since, as in bread, the lack of gluten can cause different textural and rheological characteristics [7]. Therefore, the study of ingredients and processing methods can help to establish conditions to obtain products similar to commercial ones.

Extensive rheological information on the effect of temperature, shear rate and time, and other studies on starch suspensions from different sources can be found in the literature. However, studies evaluating the rheological, thermal and structural properties of flour blends for the production of gluten-free pastas including quinoa germ are still insufficient. The aim of this study was to evaluate the techno-functional properties of gluten-free pasta from hyperprotein quinoa flour.

2. Material and methods

2.1. Flours

Corn flour, rice flour, cassava starch, were supplied by SEGALCO S.A.S. (Popayan, Cauca, Colombia). In addition, hyperprotein quinoa flours were used and produced as follows:

2.1.1. Hyperprotein quinoa flour

For this work quinoa grain of the Tunkahuan variety grown in the region of Los Milagros, Bolivar Cauca, Colombia and provided by the company SEGALCO S.A.S, was used.

The production of hyperprotein quinoa flour (HQF) was carried out by the abrasive milling process with a continuous flow mill (MAVIMAR, Popayán, Colombia) with a capacity of 30 kg/h. This process made it possible to obtain a protein-rich fraction (HQF) and a starch-rich fraction from the grain perisperm [6].

2.1.2. Hyperprotein defatted quinoa flour

In order to concentrate the protein of the HQF, a mechanical defatting process was carried out. For this, the flour was pressed in an automatic pressing machine (Cgoldenwall, K28, Shanghai China). The process was carried out with heating at 120 °C during compression and shearing of the flour.

Table 1
Established formulations for the production of gluten-free pasta rich in vegetable proteins.

Mixture	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Corn flour	24.21	34.63	0.00	30.75	37.04	13.81	27.61	21.38	28.24	41.28
Rice flour	10.65	0.00	33.34	14.00	16.86	5.97	12.09	9.47	12.36	18.74
Cassava starch	4.79	4.80	4.76	4.73	4.68	15.96	15.61	15.77	0.00	0.00
HQF	60.35	60.56	61.90	30.79	0.00	64.26	0.00	34.64	59.40	0.00
HDQF	0.00	0.00	0.00	19.72	41.43	0.00	44.70	18.74	0.00	39.98
Protein*	21.58	21.82	21.48	21.47	21.72	21.53	21.85	21.11	21.76	21.64
Lipids*	12.37	12.63	12.11	8.99	5.45	12.67	5.34	9.23	12.36	5.50
Fiber*	8.17	8.14	8.28	9.08	10.17	7.53	9.69	8.37	8.46	10.36

Percentages of each ingredient are shown on a dry basis. M1 to M10 are the mixtures for pasta. HQF means hyperprotein quinoa flour and HDQF means hyperprotein defatted quinoa flour. *Values are expressed as g/100 g dry basis (taken from Ref. [8]).

2.2. Production of gluten-free pasta

2.2.1. Formulation of mixtures

In order to produce a gluten-free, vegetable protein-rich dough, different blends of corn flour, rice flour, cassava starch, HQF and HDQF were established to achieve a minimum protein percentage of 21%. Table 1 shows the formulations made. Preliminary trials were conducted to establish flour and moisture ranges for the extrusion process (data not shown).

2.2.2. Pasta extrusion

The formulations were homogenized at 30% moisture (w/w) prior to extrusion in a 4.8 l mixer (KitchenAid Artisan Model KSM 1520, St. Joseph, MI, USA). Extrusion was performed in a Haake Rheomex OS extruder, Thermo Scientific, (USA), equipped with twin screws. An average temperature profile of 80.9 °C (75, 81, 90, 80, 95, 70, 75 °C) and a screw speed of 160 rpm were programmed. A nozzle with a 2.5 mm outlet diameter was used. The pastes were dried at room temperature for three days under controlled conditions at 20 °C and 78% relative humidity [8].

2.3. Rheological characterization

Rheological analysis of the paste mixtures before and after the extrusion process was performed using an AR 1500 Rheometer, TA Instruments, New Castel, USA, equipped with a pasting cell for starch analysis (SPC). With each mixture, aqueous dispersions were prepared at a concentration of 12 g/100 mL. dispersions were analyzed by means of a sequential rheological assay, starting with a flow test at a constant temperature, followed by a pasting test and finally another flow test at constant temperature, with the objective of verifying the rheological changes in flow before and after heating the dispersions [9]. For paste analysis, the product was ground in an IKA A11 blade mill and sieved to obtain particle sizes of less than 150 μm. With the powder obtained, dispersions were prepared and analyzed as mentioned above.

2.3.1. Flow tests

Flow analysis was performed at a constant temperature of 30 °C in a shear rate range between 0.01 and 200 s^{-1} [10]. The experimentally obtained data were fitted to the power law equation, Ostwald model

$\tau = k\,\dot{\gamma}^{\,n}$

where τ represents the shear stress, k the consistency index, $\dot{\gamma}$ the shear velocity, and n is the flow index. Values of: $n = 1$ represent Newtonian type flow, $n < 1$ pseudoplastic type flow and $n > 1$ dilatant type flows.

2.3.2. Pasting test

For this test, the dispersions were subjected to a temperature gradient. The initial temperature was 30 °C for 40 s, then heated at a rate of 10 °C/min to 90 °C, this temperature was maintained for 4 min, then cooled at a rate of 10 °C/min to 30 °C and finally this temperature was maintained for 2 min. The values of Pasting temperature [°C], Viscosity peak [Pa.s], Peak time [s], Trough viscosity [Pa.s], Final viscosity [Pa.s], Setback viscosity [Pa.s] were recorded [9]. Pasting temperature is the temperature at the initial increase of viscosity, Peak viscosity, is the maximum viscosity during the heating and holding cycle, Peak time is the time of the maximum viscosity peak after the heating cycle, trough viscosity, is the minimum viscosity after peak viscosity is reached, final viscosity is the viscosity reached after the cooling and stabilization period at 30 °C, and setback viscosity is the difference between final and trough viscosity [11].

2.4. Differential scanning calorimetry

Enthalpy changes on different samples were determined by differential scanning calorimetry (DSC; ΔH values). A DSC Polyma 214 equipment (NETZSCH-Gerätebau, Germany) was employed. The instrument was calibrated with indium (156.6 °C), lead (327.5 °C), zinc (419.6 °C) and water (0 °C). The measurements were performed using hermetically sealed 40 μL aluminum pans with sample: water radio of 3mg/7 μL after storage for 24 h at 4 ± 1 °C. The materials were heated from 25 to 110 °C at 10 °C/min. The onset temperature (To) was determined at the beginning of the change in the baseline thermogram, while the peak temperature (Tp) was determined at the maximum point of the peak.

2.5. Attenuated total reflectance-Fourier transform-infrared spectroscopy

The flours and dough mixtures were analyzed by infrared spectroscopy using an IRAFFINITY-1S spectrometer (Shimadzu, Inc., Shelton CT, Japan) and the single reflection diamond crystal attenuated total reflectance (ATR) accessory at an angle of incidence of 45°. The spectra obtained were the average of 45 sweeps at 4 cm^{-1}. Happ-Genzel apodization was used, with a magnitude phase correction. The spectra were recorded between 500 and 4000 cm^{-1}. Each measurement was performed at least in duplicate. For the analysis of the spectra, the baseline was normalized between 0 and 1. Additionally, an analysis was performed by deconvolution of the peaks in the region from 800 cm^{-1} to 1200 cm^{-1} and between 1600 cm^{-1} to 1710 cm^{-1} to identify differences in the samples in the β-sheet, β-turns α-helix and Random Coil secondary structures [6]. The analysis of the spectra was performed with OriginPro 2016.

2.6. Statistical analysis

The results obtained in the evaluation of each of the properties of the pasta mixes were compared by means of a One-way ANOVA, followed by a Tukey's test for multiple comparisons. In addition, a Pearson correlation analysis was performed between the ingredients used and the response variables obtained. The correlation coefficient (r) and p-value are reported where the correlation was significant ($p < 0.05$). GraphPad Prism 7 software, San Diego CA, was used for all analyses.

3. Results and discussion

3.1. Rheological properties

In complementary studies [8] carried out on the pastes obtained with these formulations, a protein content (dry basis) between 21.11 and 21.85 g/100 g, a lipid content between 5.45 and 12.67 g/100 g and a crude fiber content between 7.53 and 10.36 g/100 g of sample were reported.

3.1.1. Pasting properties

As for the results of the pasting test, Fig. 1 and Table 2 summarize the results found. Fig. 1, panel A, shows the viscosity profiles of the mixtures before extrusion (BE), and panel B after extrusion (AE). It was observed that the mixing of different types of flour, in different percentages, produced dispersions with different pasting properties. BE, the mixtures 9, 6 and 7 showed the highest viscosity profiles, while mixtures 5 and 3 showed the lowest. Also AE, the highest and lowest viscosity profiles respectively were M6 and M8 (Fig. 1, Panel B).

The pasting temperature (PT) for BE dispersions was found to be between 69.45 and 91.4 °C and for AE dispersions between 64.3 and 71.85 °C (Table 2). In BE dispersions, no significant correlation was found among the types of flour used and PT. In contrast, in AE dispersions, a negative correlation ($r = -0.8286$; $p = 0.0031$) was found between HDQF and PT, and a positive correlation ($r = 0.7949$; $p = 0.0060$) between HQF and PT. This means that the higher the addition of HDQF, the lower the PT and the higher the HQF, the higher the PT. These correlations are evidently associated with the defatting process of the hyperprotein flour, since molecules such as

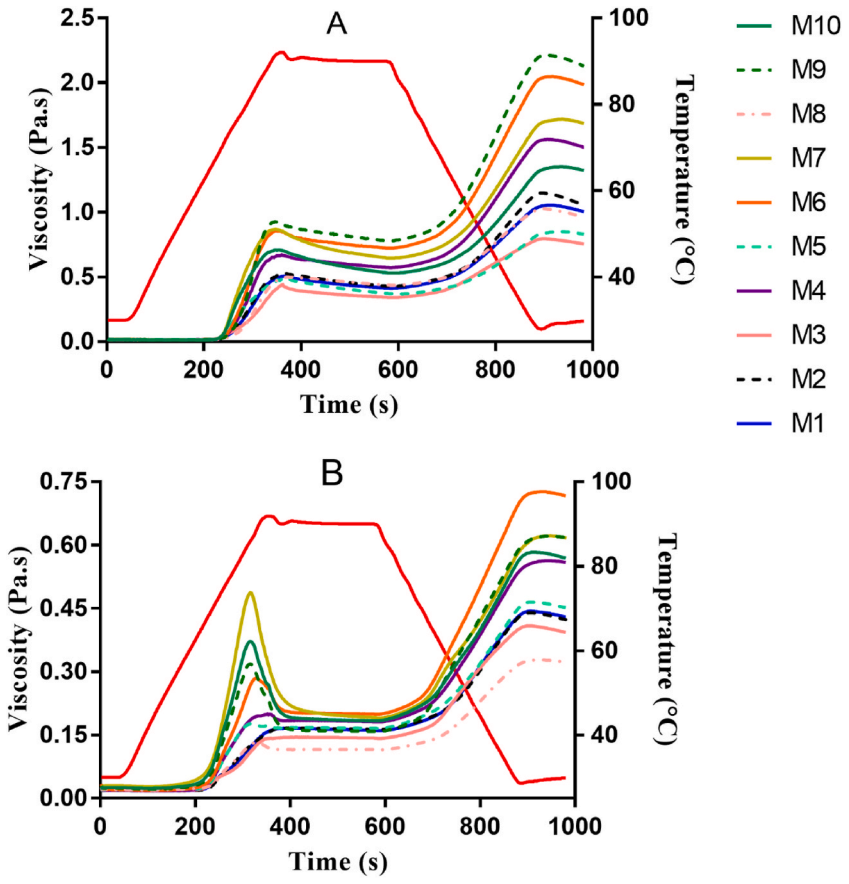

Fig. 1. Viscosity profile of the paste mixtures; (A: before extrusion, B: after extrusion).

Table 2
Pasting test results before and after extrusion of the mixtures.

Before extrusion						
Mixture	Pasting temperature [°C]	Viscosity peak [Pa.s]	Peak time [s]	Trough [Pa.s]	Final viscosity [Pa.s]	Setback [Pa.s]
1	86.15 ± 0.07^{b}	0.490 ± 0.001^{c}	$350.0 \pm 0.1^{b,c,d}$	0.4166 ± 0.0003^{e}	$1.05 \pm 0.01^{f,g}$	0.6299 ± 0.01^{g}
2	84.75 ± 0.07^{c}	0.52 ± 0.02^{c}	$351 \pm 1^{b,c}$	0.443 ± 0.009^{e}	1.16 ± 0.03^{f}	0.71 ± 0.02^{f}
3	91.4 ± 0.1^{a}	0.421 ± 0.004^{d}	$354 \pm 1^{a,b,c}$	0.349 ± 0.002^{f}	0.7883 ± 0.0005^{i}	0.439 ± 0.001^{j}
4	71.2 ± 0.1^{f}	0.647 ± 0.009^{b}	$340 \pm 1^{c,d,e,f}$	0.57685 ± 0.006^{d}	1.53 ± 0.02^{d}	0.95365 ± 0.02^{d}
5	70.25 ± 0.07^{h}	0.52 ± 0.06^{c}	$348 \pm 3^{c,d,e}$	0.40 ± 0.04^{e}	0.9 ± 0.1^{h}	$0.51 \pm 0.06^{h,i}$
6	70.75 ± 0.07^{g}	0.823 ± 0.002^{a}	$335 \pm 1^{e,f}$	0.731 ± 0.002^{b}	2.032 ± 0.006^{b}	1.301 ± 0.006^{b}
7	69.55 ± 0.07^{i}	0.854 ± 0.004^{a}	$332 \pm 1^{f,g}$	0.653 ± 0.005^{c}	1.712 ± 0.009^{c}	1.059 ± 0.004^{c}
8	73.55 ± 0.07^{d}	0.489 ± 0.005^{c}	$356 \pm 1^{a,b,c}$	0.442 ± 0.002^{e}	$1.024 \pm 0.005^{g,h}$	$0.581 \pm 0.003^{g,h}$
9	71.45 ± 0.07^{f}	0.89815 ± 0.009^{a}	$333 \pm 1^{f,g}$	0.792 ± 0.004^{a}	2.21 ± 0.01^{a}	1.414 ± 0.008^{a}
10	69.45 ± 0.07^{i}	0.697 ± 0.003^{b}	$336 \pm 1^{d,e,f}$	0.537 ± 0.004^{d}	1.35 ± 0.01^{e}	0.812 ± 0.006^{e}
After extrusion						
1	70.65 ± 0.07^{g}	$0.158 \pm 0.004^{g,h}$	$359 \pm 1^{a,b}$	$0.161 \pm 0.004^{g,h}$	$0.43 \pm 0.02^{m,n}$	$0.27 \pm 0.01^{k,l}$
2	71.85 ± 0.07^{e}	$0.157 \pm 0.008^{g,h}$	362 ± 3^{a}	$0.162 \pm 0.003^{g,h}$	$0.434 \pm 0.007^{m,n}$	$0.268.004^{k,l}$
3	70.25 ± 0.07^{h}	$0.15 \pm 0.01^{g,h}$	$346 \pm 6^{c,d,e}$	0.141 ± 0.004^{h}	$0.39 \pm 0.02^{m,n}$	$0.25 \pm 0.02^{k,l}$
4	69.55 ± 0.07^{i}	0.194 ± 0.003^{g}	$324 \pm 1^{f,g,h}$	0.186 ± 0.002^{g}	0.57 ± 0.02^{k}	0.39 ± 0.02^{j}
5	69.95 ± 0.07^{h}	$0.171 \pm 0.001^{g,h}$	306 ± 2^{j}	$0.1671 \pm 0.0003^{g,h}$	$0.460 \pm 0.006^{l,m}$	0.288 ± 0.003^{k}
6	68.35 ± 0.07^{f}	0.272 ± 0.002^{f}	$318 \pm 1^{h,i}$	0.201 ± 0.001^{g}	$0.7262 \pm 0.0001^{i,j}$	$0.5249 \pm 0.0001^{h,i}$
7	64.3 ± 0.2^{i}	$0.473 \pm 0.004^{c,d}$	$309 \pm 1^{i,j}$	0.199 ± 0.003^{g}	$0.624 \pm 0.005^{j,k}$	0.426 ± 0.002^{j}
8	$71.5 \pm 0.1^{e,f}$	0.128 ± 0.001^{h}	$318 \pm 2^{h,i}$	0.116 ± 0.001^{h}	0.330 ± 0.003^{n}	0.214 ± 0.003^{l}
9	67.4 ± 0.1^{g}	$0.306 \pm 0.003^{e,f}$	$309 \pm 1^{i,j}$	$0.159 \pm 0.001^{g,h}$	$0.613 \pm 0.007^{j,k}$	$0.453 \pm 0.007^{i,j}$
10	66.55 ± 0.07^{h}	0.35 ± 0.01^{e}	$313 \pm 7^{h,i,j}$	$0.183 \pm 0.004^{g,h}$	$0.57 \pm 0.02^{k,l}$	0.39 ± 0.01^{j}

Different lower case letters in the same column means significantly different ($p < 0.05$).

lipids have been found to influence the pasting temperature, as for example, Nierle & El Bayâ [12], found that fatty acids such as oleic acid increased the PT in wheat starch dispersions added with different types of fatty acids, up to 85 °C. PT represents the initial gelatinization temperature when the viscosity starts to increase. When comparing the PT between the BE and AE mixtures, it was found that in general AE had significantly lower values ($p < 0.05$) than BE (Table 2), showing that the extrusion process significantly reduces the onset of gelatinization. High PT may also be associated with the presence of non-starch components such as proteins, oligosaccharides and polysaccharides, which compete with starch for water and increase the pasting temperature [13]. On the other hand, the high PT in mixture 3 could be related to a higher content of rice flour. In some studies, rice starch has been associated with a higher amylose content than products such as corn or cassava [14]. The interaction of the amylose chains could increase the stability of the granules to rupture under mechanical agitation [13]. Moreover, amylose content has been positively correlated to peak time and negatively correlated to peak viscosity in tests on different types of starch [15]. In this work, sample 3 was found to have a high peak time and low peak viscosity, which is in agreement with the above mentioned.

The viscosity peak (VP), BE, was found between 332 and 356s, reaching viscosity values between 0.421 and 0.854 Pa s. AE, the VP was found between 306 and 362s, obtaining viscosity values between 0.128 and 0.473 Pa s, which were significantly lower ($p < 0.05$) than those obtained BE (Table 2). The VP is associated with the swelling of the starch granules during the heating stage, prior to their physical breakdown. This process is also influenced by the presence of other molecules such as lipids [16]. In the analyses of the mixtures carried out prior to extrusion, a strong positive correlation was found between HDQF and VP ($r = 0.9739$; $p = 0.0000$) and between Corn flour and VP ($r = 0.6439$; 0.0445). Likewise, a strong negative correlation between HQF and VP ($r = -0.9747$; $p = 0.0000$) was found, which means that the addition of a defatted product such as corn flour or HDQF increases VP and the addition of HQF, tends to decrease VP values, which is in accordance with the above mentioned. The higher PV values could be explained by the starch content, which increases in HDQF due to the defatting process. In the after extrusion experiments, equivalent correlations were obtained between the hyperprotein flours and VP. In the BE analysis, a strong negative correlation ($r = -0.9326$; $p = 0.0001$) was also found between HDQF addition and peak time and a positive correlation (0.9237; $p = 0.0001$) between HQF addition and peak time. This correlation shows that defatting the flours causes the viscosity peak to appear in a shorter time than when using hyperprotein flour without defatting.

The trough viscosity, or lowest viscosity after peak viscosity at 90 °C, were found between 0.349 and 0.792 Pa s before extrusion and between 0.116 and 0.201 Pa s after extrusion. The trough values found were in the order of those reported by Xiaojuan Guo et al. [17], who found values between 0.387 and 1.027 Pa s in purple corn flour suspensions, and those reported by Burcu Havva Tiga et al. [18], who reported values between 0.185 and 1.595 Pa s, in blends of wheat and quinoa flours. Additionally, a strong positive correlation ($r = 0.9453$; $p = 0.000$) was found between trough and HDQF and a strong negative correlation ($r = -0.9634$; $p = 0.000$) between trough and HQF.

The final viscosity (FV) values BE were found to be between 0.9 and 2.21 Pa s and AE between 0.330 and 0.7262 Pa s. A positive correlation was found between FV and corn flour ($r = 0.7674$; $p = 0.0097$) and between HDQF and FV ($r = 0.9308$; $p = 0.0001$). Moreover, the addition of HQF was found to correlate negatively with FV ($r = -0.9520$; $p = 0.0000$). AE, the same correlation trend was found between ingredients and FV. This shows that both corn flour and HDQF tend to increase FV, while HQF tends to reduce its value. The final viscosity is related to phenomena of association or retrogradation of the starch molecules after the cooling period. In

this way, inferences could be made about the behavior of food materials after being subjected to heating-cooling processes such as cooking or pasteurization. As the temperature decreases from 90 °C, the starch molecules reassociate and aggregate to form a gel network, which increases the final viscosity [19]. The increase in viscosity of the dispersions during cooling can denote a short-term retrogradation of the starch, which can be reflected in the setback value. As for the setback (SB), values between 1.414 and 0.439 Pa s BE and AE between 0.214 and 0.5249 Pa s were found. BE, SB presented positive correlations with corn flour ($r = 0.7753$; $p = 0.0084$) and with HDQF ($r = 0.9442$; $p = 0.0000$) and a negative correlation with HQF ($r = -0.9442$; $p = 0.0000$). AE, similar correlations were found. During paste cooling, a re-association between starch molecules, especially amylose, will produce a gel structure, increasing the viscosity until the final viscosity values are reached. This phase is commonly described as the setback region which is associated with retrogradation and rearrangement of starch molecules [20]. In different studies the setback value has been related to the starch retrogradation of the cooked starch dispersion [15,21,22]. In this study the mixtures 1, 3, 5 were those with the lowest setback values ($p < 0.05$), which determines a lower tendency to retrograde [23].

As could be verified in Fig. 1 and Tables 2 and in general, the extrusion process produced a significant reduction ($p < 0.05$) in the viscosity profile of the dispersions analyzed. It has been reported that the extrusion process produces changes in the starch structure, modifying its pasting profile. This fact has been explained by the loss of starch granule integrity during extrusion [24]. In this respect, it has been shown that dispersions of extruded products have a lower viscosity profile than non-extruded products [20]. In addition, studies on sweet potato [25], amaranth [26], and long grain rice [26–28] starches also have shown a reduction in viscosity and pasting temperature after extrusion, which is in agreement with the findings of this study.

3.1.2. Flow properties

Table 3 summarizes the results found for the flow analysis. All the results obtained in the flow test fit the power model, obtaining R^2 values between 0.91 and 0.999. It was found that BE and before pasting test (BPT), all the dispersions of the ten mixtures had a value for the flow index n, greater than 1, denoting a dilatant type flow behavior. Dilatant behavior means that the flow of dispersions shows an increase in viscosity with increasing shear rate [29]. Furthermore, there were no significant differences ($p < 0.05$) in the n-values or the consistency index k.

In contrast, BE and after pasting test (APT), the flow behavior was reanalyzed and it was found that the dispersions of the mixtures presented a significant reduction ($p < 0.05$) in the values of n, and furthermore, that it presented a change in the type of flow, going from a dilatant to a pseudoplastic behavior ($n < 1$). Contrary to the dilatant behavior, the pseudoplastic type flow implies a reduction in viscosity with increasing shear rate [30]. It was also found that among the dispersions analyzed there were no significant differences ($p < 0.05$) in the n values. As for the k values, significant differences ($p < 0.05$) were found between the dispersions, obtaining values between 0.35 and 18.6 Pa. s^n. The consistency index was found to correlate positively with corn flour ($r = 0.6559$; $p = 0.0394$) and HDQF ($r = 0.8935$; $p = 0.0005$), and negatively with HQF ($r = -0.9080$; $p = 0.0003$), showing that the addition of corn flour and HDQF tends to increase the consistency index of the dispersions, while the addition of HQF tends to reduce it.

Table 3
Flow test results before and after extrusion and before and after the pasting test.

Before extrusion				
	Before pasting test		After pasting test	
Mixture	K	n	K	n
1	0.0040 ± 0.0002^{o}	1.61 ± 0.01^{a}	6.18 ± 0.03^{g}	$0.354 \pm 0.001^{b,c,d,e}$
2	0.00414 ± 0.00002^{o}	1.605 ± 0.002^{a}	7.2 ± 0.4^{f}	$0.322 \pm 0.009^{b,c,d,e}$
3	0.00396 ± 0.00001^{o}	1.615 ± 0.001^{a}	3.49 ± 0.05^{i}	$0.454 \pm 0.003^{b,c,d,e}$
4	0.0042 ± 0.0004^{o}	1.60 ± 0.02^{a}	11.1 ± 0.2^{d}	$0.290 \pm 0.002^{c,d,e}$
5	0.0038 ± 0.0004^{o}	1.63 ± 0.02^{a}	5 ± 1^{h}	$0.41 \pm 0.04^{b,c,d,e}$
6	0.0043 ± 0.0001^{o}	1.599 ± 0.008^{a}	16.40 ± 0.04^{b}	$0.258 \pm 0.001^{d,e}$
7	0.0043 ± 0.0001^{o}	1.597 ± 0.006^{a}	12.4 ± 0.1^{c}	$0.304 \pm 0.002^{c,d,e}$
8	0.00427 ± 0.00001^{o}	1.600 ± 0.001^{a}	$0.35 \pm 0.04^{n,o}$	$0.345 \pm 0.001^{b,c,d,e}$
9	0.0044 ± 0.0001^{o}	1.598 ± 0.006^{a}	18.6 ± 0.1^{a}	0.236 ± 0.001^{e}
10	0.0040 ± 0.0001^{o}	1.614 ± 0.006^{a}	8.9 ± 0.1^{e}	$0.333 \pm 0.002^{b,c,d,e}$
After extrusion				
	Before pasting test		**After pasting test**	
Mixture	**K**	**n**	**K**	**n**
1	$0{,}00481 \pm 0{,}00006^{o}$	$1588 \pm 0{,}002^{a}$	$0{,}91 \pm 0{,}08^{m,n}$	$0{,}69 \pm 0{,}02^{b,c,d,e}$
2	$0{,}00462 \pm 0{,}00006^{o}$	$1596 \pm 0{,}004^{a}$	$0{,}909 \pm 0{,}040^{m,n}$	$0{,}685 \pm 0{,}008^{b,c,d,e}$
3	$0{,}0049 \pm 0{,}00005^{o}$	$1588 \pm 0{,}001^{a}$	$0{,}73 \pm 0{,}08^{m,n,o}$	$0{,}73 \pm 0{,}02^{b,c}$
4	$0{,}0051 \pm 0{,}0003^{o}$	$1{,}57 \pm 0{,}01^{a}$	$1.804 \pm 0.001^{j,k}$	$0.579 \pm 0.004^{b,c,d,e}$
5	0.0051 ± 0.0001^{o}	1.581 ± 0.004^{a}	$0.94 \pm 0.01^{l,m,n}$	$0.708 \pm 0.001^{b,c,d,e}$
6	0.00512 ± 0.00004^{o}	1.580 ± 0.002^{a}	2.603 ± 0.001^{j}	$0.5427 \pm 0.0005^{b,c,d,e}$
7	0.00816 ± 0.00006^{o}	1.506 ± 0.001^{a}	$1.76 \pm 0.09^{k,l}$	$0.630 \pm 0.001^{b,c,d,e}$
8	0.00559 ± 0.00020^{o}	1.560 ± 0.008^{a}	$0.527 \pm 0.001^{n,o}$	0.782 ± 0.001^{b}
9	0.00576 ± 0.00002^{o}	1.565 ± 0.001^{a}	$2.053 \pm 0.007^{j,k}$	$0.569 \pm 0.002^{b,c,d,e}$
10	0.00609 ± 0.00007^{o}	1.558 ± 0.003^{a}	$1.50 \pm 0.08^{k,l,m}$	$0.64 \pm 0.01^{b,c,d,e}$

Different lower case letters in the same column means significantly different ($p < 0.05$).

Likewise, AE process and before pasting test (BPT) the values of k and n were not significantly different ($p < 0.05$). This means that the extrusion process at the operating conditions analyzed in this work, produces pastes with characteristics analogous to those of raw flour mixtures (BE), for example, a dilatant type of flow, a dependence of viscosity on shear rate, which tends to increase with increasing shear rate.

Finally, AE and after the pasting test, the values of n, in general, were statistically equal ($p < 0.05$). In general, it was possible to verify that the extrusion process produced a reduction in the k values after the pasting test (for statistically equal n values). On the other hand, significant differences could be observed in the K values of the different mixtures. In this respect, a positive correlation ($r = 0.9105$; $p = 0.0394$) in the addition of HDQF and k and a negative correlation ($r = -0.9194$; $p = 0.002$) between HQF and k were also found. These correlations were similar to those found before extrusion. After analyzing the correlation analyses, it is observed that, in both the pasting and flow analyses, HDQF had a positive effect on viscosity or consistency and HQF had a negative effect.

Both before and after extrusion, it could be observed that the flour dispersions changed their flow form after being heated in the pasting test, changing from a dilatant behavior to a pseudoplastic one. Dilatant flow behavior has been related to the increase in size of the structural units as a result of shearing. In addition, in starch-water systems, shear thickening behavior has been associated with the rigidity of starch granules to resist shear, and the high solids concentration resulting in particle crowding [31]. The transition from dilatant to pseudoplastic flow is caused by heating of the dispersion and shearing during the gelatinization process [32]. Thus, it can be verified that the gelatinization of starch during the cooking process transforms the rheological behavior from dilatant to pseudoplastic flow.

3.2. Differential scanning calorimetry

Table 4 shows the thermal characteristics of rice flour (RF), maize flour (CF), quinoa hyperprotein flour (HQF), hyperprotein defatted quinoa flour (HDQF), cassava starch (CS) and mixtures elaborated, where To and Tf correspond to onset and final temperature the starch gelatinization, Tp peak temperature and ΔH enthalpy change.

Corn flour showed higher onset gelatinization temperature ($p < 0.05$) than both cassava starch and rice flour. Quinoa defatted hyperprotein flour presented a transition above 85 °C, which may be related to the process realized to increase the protein content of the flour. Other authors reported that two transitions were observed in quinoa thermograms, where the second endothermic peak observed between 85 and 100 °C, is related to amylose-lipid complex and/or protein denaturation [33]. In addition, quinoa milling reduces the size of the starch granule, which could make it more resistant to heating and delay the onset of gelatinization [34].

Gelatinization is an endothermic process, and the gelatinization enthalpy (ΔH) gives an overall measure of degree of crystallinity, indicating the loss of molecular order within the granule, and reflects the amount of energy needed to disintegrate the structure ordinate of the starch granule [34]. The ΔH value of gelatinization of cassava starch was higher than employed flours in pasta formulations.

Furthermore, it is important to note that all mixtures showed small ΔH values, attributed to high proportions of HQF and HDQF. Although some formulations have high contents of corn flour and cassava starch, the mixtures would be expected to have high ΔH. However, during the extrusion process, the high temperatures generate total or partial gelatinization of the starch, obtaining small ΔH values.

Other authors reported onset temperature values around 60 °C for quinoa flour and defatted quinoa flour. However, these researchers indicated that extruded flour did not show this transition [35]. The differences in gelatinization temperatures could be attributed to the abrasive milling process, by which the germ is separated from the starchy perisperm. This germ fraction is the so-called hyperprotein quinoa flour HQF, which, because of its low starch content, did not allow visualization of the gelatinization

Table 4
Thermal properties of raw materials and formulated mixtures.

Sample	To (°C)	Tp (°C)	Tf (°C)	ΔH (J/g)
RF	67.7 ± 0.6^{h}	70.6 ± 0.2^{g}	74.6 ± 0.4^{h}	5.0 ± 0.3^{b}
CF	$68.6 \pm 0.7^{g,h}$	$74.3 \pm 0.4^{d,e}$	$78 \pm 1^{e,f}$	2.8 ± 0.2^{c}
CS	65.2 ± 0.6^{i}	69.7 ± 0.4^{g}	$77.2 \pm 0.1^{f,g}$	10.1 ± 0.4^{a}
HQF	n.a	n.a	n.a	n.a
HDQF	87.4 ± 0.8^{b}	90.3 ± 0.9^{b}	93.0 ± 0.3^{b}	$2.1 \pm 0.2^{c,d}$
M1	81.1 ± 0.8^{c}	82.1 ± 0.9^{c}	82.5 ± 0.4^{c}	0.03 ± 0.07^{e}
M2	$68.6 \pm 0.7^{g,h}$	$74.3 \pm 0.6^{d,e,f}$	$76.0 \pm 0.6^{g,h}$	$0.7 \pm 0.4^{d,e}$
M3	$70.2 \pm 0.5^{e,f,g}$	72.5 ± 0.4^{f}	74.4 ± 0.8^{h}	$0.5 \pm 0.2^{d,e}$
M4	72.1 ± 0.6^{d}	$74.7 \pm 0.5^{d,e}$	$77.3 \pm 0.4^{f,g}$	$0.9 \pm 0.5^{d,e}$
M5	$71.5 \pm 0.6^{d,e,f}$	$75.1 \pm 0.6^{d,e}$	$77.8 \pm 0.3^{f,g}$	$1.2 \pm 0.6^{c,d,e}$
M6	$71.5 \pm 0,6^{d,e,f}$	$73.9 \pm 0.1^{e,f}$	74.6 ± 0.4^{h}	$0.37 \pm 0.03^{d,e}$
M7	$71.1 \pm 0.9^{d,e,f}$	$75.4 \pm 0.3^{d,e}$	$80.0 \pm 0.5^{d,e}$	$0.46 \pm 0.08^{d,e}$
M8	$72.0 \pm 0.4^{d,e}$	$73.7 \pm 0.5^{e,f}$	$80.7 \pm 0.4^{c,d}$	$0.54 \pm 0.09^{d,e}$
M9	$71.3 \pm 0.4^{d,e,f}$	$75.5 \pm 0.5^{d,e}$	76.5 ± 0.2^{g}	$0.5 \pm 0.1^{d,e}$
M10	$69.8 \pm 0.8^{f,g}$	76.0 ± 0.6^{d}	$77.7 \pm 0.5^{f,g}$	$0.72 \pm 0.01^{d,e}$

n.a not applicable. M1 to M10 are the mixtures for pasta, RF means rice flour, QF means quinoa flour, CS means cassava starch, HQF means hyperprotein quinoa flour and HDQF means hyperprotein defatted quinoaflour. Different lower case letters in the same column means significantly different ($p < 0.05$).

temperatures [36].

On the other hand, the correlation of the results of the thermal properties (Table 4) with those of FTIR infrared spectroscopy (Table 5) was analyzed. It was found that Tp was positively correlated with the starch band 1077 cm^{-1} ($r = 0.9151$; $p = 0.0002$) and negatively correlated with the protein band 1645 cm^{-1} ($r = -0.6770$; $p = 0.0315$). These two results imply that the higher the protein in the mixtures (lower transmittance) or the lower the starch (higher transmittance), the higher the Tp values. In addition, the effect of other molecules such as lipids and proteins on gelatinization is corroborated, as discussed in the section on the pasting test. Additionally, a negative correlation ($r = -0.7220$; $p = 0.0172$) was also found between the 1077 cm^{-1} band and ΔH. This shows that the higher the starch content in the mixture (lower transmittance), the higher the ΔH. Finally, it is worth noting that this band (1077 cm^{-1}) is related to the structural organization of starch, which is lost during heating and affects enthalpy changes.

3.3. FTIR spectroscopic analysis

Table 5 shows the transmittance of the bands at 1077 cm^{-1}, 1645 cm^{-1}, 2925 cm^{-1} associated with C–O–C, N–H and C═C bonds, respectively. Cassava flour showed a low transmittance at 1077 cm^{-1} associated with high starch content. While that, high intensities were observed at 1645 cm^{-1} and 2925 cm^{-1} associated with low protein and lipid content, respectively. On the other hand, both HQF and HDQF flours showed low transmittance at 1645 cm^{-1}, this band was associated with the N–H bond of protein. Intermediate transmittance values were observed at 1077 cm^{-1}, 1645 cm^{-1}, 2925 cm^{-1} for all flour mixtures. The above results show that the extrusion process does not significantly affect the conformation of functional groups related to starch, protein and fats.

Roa Acosta et al. [6] studied the changes in the structural organization of the starch granule using the function of the Fourier transform to obtain modified spectra. Which related the intensities with the amorphous/crystalline structures. This same methodology was used by García et al. [37] to study the change of secondary protein structures in various quinoa cultivars subjected to different agroecological conditions. In this work, similar changes were observed which can be seen in Table 6.

On the other hand, several Pearson correlations were found between the lipid (2925 cm^{-1}), protein (1645 cm^{-1}) and starch (1077 cm^{-1}) bands and the parameters obtained from the pasting and flow tests. For example, BE, a negative correlation was found between PT and the 2925cm-1 band ($r = -0.7896$; $p = 0.0066$), which means that the lower the transmittance in this band (less lipids), the higher the PT. This effect could also be explained in terms of the addition of HQF and HDQF flours as discussed above. Likewise, it was found that this lipids band had several correlations with viscosity parameters, for example with VP after extrusion (AE), where a correlation coefficient of $r = 0.8384$; $p = 0.0024$ was found, which means that the higher the transmittance (less lipids), the higher the VP, this correlation also implies that the higher the addition of HDQF allows higher viscosity peaks, as mentioned above. Moreover, as for the final viscosity (FV) after extrusion, correlations were found with the lipid band ($r = 0.8106$; $p = 0.0044$) and with the protein band, 1645 cm^{-1}, ($r = 0.6807$; $p = 0.0303$). As can be seen, both are positive, showing that the higher the transmittance (less lipids or proteins), the higher the viscosity values in the mixtures. On the other hand, it was also possible to determine a correlation between the 2925 cm^{-1} band and the consistency index (K) of the flow analysis ($r = 0.7992$; $p = 0.0055$). This analysis implies that having less lipids (higher transmittance) results in higher K values.

The stress applied to the flour mixtures during pasta formation did not significantly affect the native structure of the protein. This could be inferred from the low variability of the intensities in the bands at 1648 cm^{-1}, 1656 cm^{-1} and 1667 cm^{-1} which are associated with the secondary structures Random coil, a-helix, b-turns, respectively [38]. However, the β-sheet structures at 1635 cm^{-1} showed changes in intensity due to the instability of these structures against the applied stress. This result is appropriate to avoid generating a change in the native structure of the protein and preserve its bioavailability. On the other hand, the most affected bands were 1014 cm^{-1} and 1041 cm^{-1}, which were associated with the crystallinity of the starch granule [39]. The band ratio is sometimes effective in determining minimal differences, in this case, it was useful to employ the ratio 1041 cm^{-1}/1014 cm^{-1}. Significant differences were

Table 5
Band intensities distinctive to lipids, proteins and starch.

Sample	1077 cm^{-1}	1645 cm^{-1}	2925 cm^{-1}
RF	$0.42 \pm 0.03^{b,c}$	0.724 ± 0.008^{b}	$0.823 \pm 0.001^{a,b}$
CF	0.35 ± 0.1^{d}	$0.69 \pm 0.02^{b,c}$	$0.74 \pm 0.02^{b,c}$
CS	0.28 ± 0.05^{e}	0.86 ± 0.04^{a}	0.89 ± 0.04^{a}
HQF	0.50 ± 0.03^{b}	0.34 ± 0.04^{f}	0.54 ± 0.05^{g}
HDQF	0.38 ± 0.01^{d}	0.29 ± 0.02^{f}	$0.59 \pm 0.02^{f,g}$
M1	0.5635 ± 0.002^{a}	0.350 ± 0.006^{f}	0.565 ± 0.006^{g}
M2	$0.3496 \pm 0.0002^{c,d}$	0.441 ± 0.008^{e}	$0.60 \pm 0.04^{f,g}$
M3	$0.355 \pm 0.008^{c,d}$	$0.485 \pm 0.005^{d,e}$	$0.655 \pm 0.001^{d,e,f}$
M4	$0.368 \pm 0.007^{c,d}$	$0.507 \pm 0.004^{d,e}$	$0.653 \pm 0.009^{d,e,f}$
M5	$0.346 \pm 0.008^{c,d}$	0.45 ± 0.02^{e}	$0.62 \pm 0.01^{e,f,g}$
M6	$0.384 \pm 0.002^{b,c,d}$	0.540 ± 0.005^{d}	$0.695 \pm 0.003^{c,d,e}$
M7	$0.375 \pm 0.005^{c,d}$	0.537 ± 0.005^{d}	$0.70 \pm 0.01^{c,d,e}$
M8	$0.358 \pm 0.002^{c,d}$	$0.469 \pm 0.002^{d,e}$	$0.5919 \pm 0.0006^{f,g}$
M9	$0.3815 \pm 0.0003^{b,c,d}$	0.532 ± 0.003^{d}	$0.710 \pm 0.002^{c,d}$
M10	$0.3587 \pm 0.0002^{c,d}$	$0.4974 \pm 0.0003^{d,e}$	$0.66 \pm 0.02^{c,d,e,f}$

M1 to M10 are the mixtures for pasta, RF means rice flour, QF means quinoa flour, CS means cassava starch, HQF means hyperprotein quinoa flour and HDQF means hyperprotein defatted quinoa flour. Different lower case letters in the same column means significantly different ($p < 0.05$).

Table 6
Secondary protein and starch structures in the formulations.

Sample	β-sheet-3 (1635 cm^{-1})	Random coil (1648 cm^{-1})	α-Helix (1656 cm^{-1})	β-Turns-1 (1667 cm^{-1})	1041 cm^{-1}	996/1014 cm^{-1}	1041/1014 cm^{-1}	996 cm^{-1}
RF	$2.552 \pm 0.001^{a,b,c}$	$9.4 \pm 0.2^{a,b}$	11.7 ± 0.5^{a}	6.4 ± 0.8^{a}	$15.1 \pm 0.3^{a,b}$	$2.4 \pm 0.2^{a,b}$	$2.974 \pm 0.008^{a,b}$	12.2 ± 1.2^{b}
CF	$2.2 \pm 1.6^{a,b,c}$	$8.8 \pm 1.4^{a,b}$	9.2 ± 3.7^{a}	5.0 ± 0.7^{a}	$13.9 \pm 0.2^{b,c}$	$2.3914 \pm 0.0009^{a,b}$	$2.71 \pm 0.05b,^{c}$	12.30 ± 0.03^{b}
CS	$5.0 \pm 1.2^{a,b}$	$12.2 \pm 5.8^{a,b}$	14.2 ± 8.7^{a}	6.2 ± 2.0^{a}	16.8 ± 1.4^{a}	2.4 ± 0.6^{a}	3.6 ± 0.6^{a}	11.4 ± 0.2^{b}
HQF	5.4 ± 0.4^{a}	$15.1 \pm 2.4^{a,b}$	18.5 ± 1.1^{a}	8.1 ± 1.5^{a}	$12.2 \pm 0.1^{d,e}$	$2.1 \pm 0.7^{a,b}$	$1.7 \pm 0.2^{d,e}$	$14.7 \pm 3.1^{a,b}$
HDF	$3.6 \pm 0.4^{a,b,c}$	16.8 ± 1.0^{a}	19.7 ± 0.4^{a}	9.1 ± 0.2^{a}	11.2 ± 0.4^{e}	2.45 ± 0.08^{a}	1.63 ± 0.05^{e}	16.8 ± 0.7^{a}
M1	$1.9 \pm 0.1^{b,c}$	$8.6 \pm 0.1^{a,b}$	10.6 ± 0.2^{a}	5.6 ± 0.2^{a}	$12.11 \pm 0.05^{d,e}$	$1.76 \pm 0.04^{a,b}$	$1.73 \pm 0.01^{d,e}$	11.98 ± 0.02^{b}
M2	$2.6 \pm 0.5^{a,b,c}$	$8.0 \pm 1.3^{a,b}$	9.6 ± 1.7^{a}	4.7 ± 0.7^{a}	$12.7 \pm 0.1^{c,d,e}$	1.70 ± 0.02^{b}	1.625 ± 0.005^{e}	13.3 ± 0.2^{b}
M3	$2.4 \pm 0.3^{a,b,c}$	$9.8 \pm 0.4^{a,b}$	13.169 ± 0.003^{a}	6.95 ± 0.09^{a}	$12.8 \pm 0.2^{c,d}$	$1.77 \pm 0.02^{a,b}$	$1.777 \pm 0.007^{d,e}$	12.8 ± 0.4^{b}
M4	$1.9 \pm 0.3^{b,c}$	$9.7 \pm 0.6^{a,b}$	11.0 ± 0.4^{a}	6.67 ± 0.21^{a}	$12.8 \pm 0.1^{c,d,e}$	1.701 ± 0.005^{b}	$1.71 \pm 0.02^{d,e}$	12.76 ± 0.02^{b}
M5	1.2 ± 0.4^{c}	$9.5 \pm 0.5^{a,b}$	12.0 ± 0.2^{a}	6.78 ± 0.05^{a}	$12.681 \pm 0.004^{c,d,e}$	$1.72 \pm 0.01^{a,b}$	1.66 ± 0.02^{e}	13.2 ± 0.2^{b}
M6	1.39 ± 0.08^{c}	$12.0 \pm 4.5^{a,b}$	15.4 ± 5.8^{a}	8.5 ± 2.4^{a}	$13.1 \pm 0.5^{c,d}$	$1.73 \pm 0.06^{a,b}$	$1.74 \pm 0.07^{d,e}$	13.0 ± 0.5^{b}
M7	0.6 ± 0.7^{c}	$8.7 \pm 0.8^{a,b}$	10.5 ± 1.4^{a}	6.3 ± 1.0^{a}	$12.73 \pm 0.08^{c,d,e}$	$1.74\ 0.02^{a,b}$	$1.70 \pm 0.03^{d,e}$	12.99 ± 0.03^{b}
M8	$1.8 \pm 0.4^{b,c}$	7.8 ± 1.5^{b}	9.1 ± 2.2^{a}	5.6 ± 2.4^{a}	$12.2 \pm 0.4^{d,e}$	1.69 ± 0.08^{b}	1.53 ± 0.02^{e}	$13.5 \pm 0.4^{a,b}$
M9	$1.8 \pm 2.0^{b,c}$	$8.5 \pm 1.9^{a,b}$	10.4 ± 2.5^{a}	5.6 ± 2.7^{a}	$12.37 \pm 0.02c,^{d,e}$	$1.75 \pm 0.05^{a,b}$	$1.67 \pm 0.06^{d,e}$	12.93 ± 0.08^{b}
M10	$3.0 \pm 0.9^{a,b,c}$	$10.4 \pm 0.4^{a,b}$	12.3 ± 0.3^{a}	6.3 ± 0.9^{a}	$12.6 \pm 0.2^{c,d,e}$	$1.74 \pm 0.02^{a,b}$	$1.670 \pm 0.005^{d,e}$	13.11 ± 0.01^{b}

M1 to M10 are the mixtures for pasta, RF means rice flour, QF means quinoa flour, CS means cassava starch, HQF means hyperprotein quinoa flour and HDQF means hyperprotein defatted quinoa flour. Different lower case letters in the same column means significantly different ($p < 0.05$).

observed at 1041 cm^{-1}/1014 cm^{-1} ratio, mainly in the flours used in the formulations. This is due to the crystalline nature of the starch granule. It was observed that the crystallinity of cassava starch was higher than quinoa starch. Therefore, the mixtures between these flours affect the final behavior in the formulation of the pastes, mainly their rheological properties, which were explained above.

4. Conclusions

The evaluation of techno-functional characteristics of pasta formulated with gluten free raw materials and high protein content, constitute an alternative to market diversification with relevant nutritional intake and low costs in order to give a response to the current consumption request. The laboratory-scale results constitute a starting point for process understanding and possible industrial scale-up for the commercial development of new gluten-free food products. The rheological study of the mixtures before and after extrusion showed positive correlations between the hyperprotein defatted quinoa flour and the viscosity of the dispersions, and negative correlations with the hyperprotein quinoa flour. Furthermore, the extrusion process allows lower viscosity values in the dispersions than in the non-extruded mixtures. The differences in transmittance intensities are due to the addition of flours and not to the effect of the extrusion process. The low temperature profile used in extrusion did not cause major changes in starch and protein structures determined by FTIR.

Author contribution statement

Deiny Maryeli Córdoba-Cerón, Lina Marcela Agudelo-Laverde: Performed the experiments; Analyzed and interpreted the data.
Jesús Eduardo Bravo-Gómez: Contributed reagents, materials, analysis tools or data.
Diego Fernando Roa-Acosta: Analyzed and interpreted the data; Wrote the paper.
Jhon Edinson, Nieto-Calvache: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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