Research Article

Received: 14 November 2019 Revised: 7 February 2020 Accepted article published: 24 April 2020 Published online in Wiley Online Library: 10 May 2020

(wileyonlinelibrary.com) DOI 10.1002/jsfa.10436

Influence of partial pork meat replacement by pulse flour on physicochemical and sensory characteristics of low-fat burgers

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Abstract

BACKGROUND: Numerous non-meat ingredients, such as hydrocolloids, starches, and fibers, have been studied to improve texture characteristics and increase the ability to bind water in low-fat meat products. In this sense, pulses flours (lentil, chickpea, pea, and bean) were studied at two levels and various water:flour ratios to replace 10–44% pork meat in low-fat burgers and determine the effect on their sensory and technological properties (cooking yield, expressible liquid, diameter reduction, and color and texture profile).

RESULTS: All pork-meat burgers that included pulse flour showed higher cooking yields, lower diameter reductions, and expressible liquids than all-meat burgers, which displayed better oil and water retention. Higher water additions resulted in burgers with less hardness. Burgers with 80 g kg^{-1} lentil flour in all water/flour ratios presented the lowest total color difference (ΔE) compared with the commercial control. Burgers with the higher level of all pulse flour tested and medium water levels showed acceptable sensory scores.

CONCLUSIONS: Partial pork meat replacement by different legume flour (lentil, chickpea, pea, and bean), at levels of 80 and 150 g kg^{-1} and water/flour ratios of 1250, 1600, and 2000 g kg^{-1} resulted in low-fat burgers with adequate physicochemical characteristics. Moreover, the sensorial evaluation of the formulations with the maximum flour addition and intermediate water/flour ratio showed that they had good sensorial acceptability with no effect of flour type.

Keywords: pulse flours; pork burgers; meat replacement; low-fat meat products

INTRODUCTION

In recent years, consumers have become aware of the relationship between food and health. Meat and meat products consumption have long been regarded as an essential part of a healthy diet, since they are important sources of a wide range of nutrients that are essential for optimal growth and development.[1] However, high consumption of processed meat has been related to colon cancer[2] or cardiovascular disease.[3] The development of modified meat products was encouraged by the current shift in consumers' mainstream eating habits to highly nutritious and healthy ones. Moreover, a reduction in the consumption of animal-protein-rich foods or the proportion of animal proteins in processed meat products would be efficient ways to reduce the negative impact of the human behavior on the environment and ultimately to improve human health in a sustainable manner.[4]

The main strategies followed in the reformulation process of meat products involved reducing the fat content and modifying the fatty acid profile. With regard to fat reduction, this is usually attained by adding water simultaneously with other non-meat ingredients, such as macromolecular hydrocolloids, starches, and fibers, that have been studied to improve texture characteristics and increase the ability to bind water in low-fat meat products.[5–9] The substitution of animal fat by lipids of vegetable or marine origin improved the fatty acid profile of meat products by increasing their unsaturated fatty acid content.[10,11] However, a direct substitution is quite difficult due to the intrinsic and unique characteristics of animal fats, such as texture, mouthfeel, and juiciness.[12] Oil pre-emulsion technology with a non-meat protein improves the ability of the system since the oils can be stabilized or immobilized in a protein matrix. Oil-in-water emulsions may be easier to disperse into water-based foods (such as muscle foods) than bulk oil and may reduce the chances of bulk oil physically separating from the structure of the meat product so that it remains stable throughout processing, storage, and consumption.[13]

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Furthermore, there is strong evidence that high consumption of legumes and other plant foods has beneficial health effects and is associated with lower cardiometabolic disease risk.[14–16] Consistently, growing consumer demand for healthier products is stimulating new product development that is more sustainable by incorporation of these vegetal sources into what are known as 'hybrid products'.[17]

In this sense, pulses flours or fractions have been satisfactorily used as ingredients in meat products[18–21] in different proportions that could be up to 150 g kg^{-1}. The pulse type to be used in meat products must be carefully chosen to obtain a stable matrix that reduces water and fat losses and increases interactions between meat proteins.[22]

Pulses contain considerable proportions of starch, fiber, and protein. Starch leads to the formation of stronger heat-induced structures through swelling of granules embedded in the protein gel matrix, increasing its water-binding capacity.[23] Fiber also contributes to an increase in water and fat binding capacities. From a functionality perspective, proteins play a crucial role in the manufacture of food products. Proteins contribute to solubility, emulsification, foaming ability, gelling characteristics, and oil absorption, influencing functional properties. In the presence of meat proteins as in a meat system, pulse macromolecules can form a complex three-dimensional gel network involving various forces (van der Waals, electrostatics, and hydrogen bonding) trapping fine particles of emulsified meat or the meat matrix, with the starch and non-meat proteins as fillers. Additionally, flour components could increase the cooking yield through their water and oil retention capacities.[24]

Therefore, the purpose of this study was to evaluate the effect of partial pork meat replacement by different pulse flours (pea, chickpea, lentil, and bean), flourlevels, and water/flour ratios on technological and sensory characteristics of low-fat burgers made with high oleic acid (HO) sunflower oil.

MATERIALS AND METHODS

Materials

Pork lean muscles (top round cut including *adductor femoris* and *semimembranosus* muscles) were obtained from the local retail market. Meat (two batches, each one with three cuts from different carcasses, pH 5.61 ± 0.01) without visible fat and connective tissue was passed through a grinder (80 mm diameter and 8 mm thickness plate with 21 holes of 95 mm diameter) (Meifa 32, Cimbra; Buenos Aires, Argentina). Meat packages of 500 g were vacuum packed in Cryovac BB4L bags (PO_2: 0.35 $cm^3\ m^{-2}\ day^{-1}\ kPa^{-1}$ at 23 °C; Sealed Air Co., Buenos Aires, Argentina), frozen, and stored at −20 °C until used, after no more than 3 weeks.[25]

Refined HO sunflower oil (82.6 g C18:1/100 g; Granix S.A., Buenos Aires, Argentina) was used as lipid source.

Commercial green pea (*Pisum sativum*) (Yin Yang; Dietética Científica, Buenos Aires, Argentina), chickpea (*Cicer arietinum* L., var. Kabuli) (Dietética Científica), lentil (*Lens culinaris* Medik) (Condiment S.A., Buenos Aires, Argentina), and bean flours (*Phaseolus vulgaris*, var. Alubia) (Fincas Andinas S.R.L., Buenos Aires, Argentina) were obtained. Analytical-grade sodium chloride (NaCl) and sodium tripolyphosphate (TPP) (Anedra, Research GA, Argentina) were used. Cold distilled water (4 °C) was used.

Pulse flours characterization

Proximate composition and color

Moisture, ash, crude fat, and protein contents were determined in duplicate using AOAC[26] procedures. A nitrogen to protein conversion factor of 5.40 was used to calculate total protein.[27] Megazyme (Megazyme International Ltd, Wicklow, Ireland) was used for determining total dietary fiber content. Carbohydrate content was calculated by the difference.

Flour color was measured (quadruplicate) using a portable colorimeter (Chroma Meter CR-400; Minolta Co., Ramsey, NJ, USA). The CIE $L^*a^*b^*$ scale was used; lightness L^* and chromaticity parameters a^* (red–green) and b^* (yellow–blue) were measured. Before each series of measurements, the instrument was adjusted using a white ceramic tile ($L^* = 98.45$, $a^* = -0.10$, $b^* = -0.13$; Minolta calibration plate).

Functional properties

The water absorption capacity (WAC; grams of water per gram of sample) and oil absorption capacity (OAC; grams of oil bound per gram of sample) were measured (quadruplicate) according to the methods described by Ferreira *et al.*,[28] with some modifications. Flour (1 g samples) was weighed into 25 mL pre-weighed centrifuge tubes. For each sample, distilled water or refined sunflower oil, for WAC and OAC respectively, was added in small increments and mixed until the sample was saturated with water or oil. The samples were allowed to stand for 30 min at 20 °C and then centrifuged (20 min, 3000×*g*). The water or oil released by centrifugation was drained.

Emulsifying activity (EA) was measured according to Yasumatsu *et al.*[29] with modifications. Briefly, pulse flour (1 g) was suspended in 15 mL of water and homogenized (Ultra-Turrax T25; IKA-Werke GmbH & Co. KG, Germany) at 20000 rpm for 30 s; then HO sunflower oil (15 mL) was added, emulsified for 1.5 min and centrifuged (750×*g*, 5 min). EA (%) was calculated as the height of the emulsified layer divided by that of the whole tube content multiplied by 100. To measure emulsion stability (ES) each emulsion was prepared in the same way and heated (30 min, 80 °C), cooled in tap water (12 °C, 15 min) and centrifuged (750×*g*, 5 min). ES (%) was then calculated as the height of the remaining emulsifying layer divided by that of the whole tube content multiplied by 100.

Flour pasting properties were studied by using a controlled stress rheometer (HaakeRS600, ThermoGap, Karlsruhe, Germany) with a temperature control unit (K-15 Haake, Thermoelectron, Karlsruhe, Germany). Pasting analysis was performed as described by Byars and Singh[30] with modifications. Viscosity profiles of flour suspensions (100 g kg^{-1} water) were recorded after being positioned on the sensor system (serrated parallel plate, 35 mm diameter with 1 mm gap) and equilibrated at 50 °C for 1 min. Samples, stirred at 293.2 s^{-1} during the entire test, were heated to 95 °C at 6 °C min^{-1} and then kept at 95 °C for 5 min. Afterward, suspensions were cooled to 50 °C at 6 °C min^{-1}. To minimize dehydration, samples were covered with a thin layer of silicone oil, and a solvent trap was employed. Each sample was analyzed in triplicate.

Experimental design and burger production

All the ingredients to produce 1 kg of all raw burger formulations are described in Table 1. The experimental design consisted of four pulse flours (pea, chickpea, lentil, and bean), two pulse flour levels (80 and 150 g kg^{-1}), and three water/flour ratios (1250, 1600, and 2000 g kg^{-1}); all formulations contained an equal amount of meat + flour + water (885 g kg^{-1}; Table 1). The other ingredients (sunflower oil, NaCl, TPP) were kept constant for all burgers (115 g kg^{-1}). Two controls were additionally included: an available commercial pork burger (COTO C.I.C.S.A, Buenos

Table 1. Formulations to prepare 1 kg of raw pork meat burgers that included pulse flour (1–6) and 100% pork control burgers

	Ingredients (g)					
Formulation	Pork meat	Pulse flour[a]	Water	Oil	Sodium chloride	TPP
1	705	80	100	100	10	5
2	677	80	128	100	10	5
3	645	80	160	100	10	5
4	547.5	150	187.5	100	10	5
5	495	150	240	100	10	5
6	435	150	300	100	10	5
Control	785	—	100	100	10	5

[a] Pulse flour varied among pea, chickpea, lentil, and bean in the proportion indicated (1–6). TPP: sodium tripolyphosphate.

Aires, Argentina), and one laboratory-prepared 100% pork burger (control).

To obtain similar emulsions for each burger formulation, flour was stirred with cold distilled water at the same ratio (1 g flour/2 mL water) with a hand-held food processor (Braun, Buenos Aires, Argentina) for 30 s, rested 10 min for better hydration, and then emulsified with oil for 1.5 min. Then, the emulsion obtained, salts, and the rest of the water or flour according to formulation were added to the thawed meat (18 h, 4 °C) and mixed in a commercial food processor (Universo; Rowenta, Erbach, Germany) for 4 min. Batters were stored 1 h at 4 °C.

Burgers (40 ± 1 g) were formed using a mold (5 cm diameter and 1.2 cm high), wrapped separately in polyethylene cling film, and sealed in lots of nine in Zip-Lock pouches (C. S. Johnson & Sons de Argentina S.A.I.C., Buenos Aires, Argentina). They were frozen and stored at −20 °C until analysis (less than 3 weeks). All burger formulations (nine samples/formulations) were prepared in duplicate on two different days, each replicate from each batch of meat.

Burger technological properties

Prior to being characterized, burgers were removed from the freezer and immediately cooked (without defrosting) in a double-sided electric household grill (3882, Oster, Newell Brands, Atlanta, United States) until a final internal temperature of 71 °C was reached[31] as measured by a type-T (copper–constantan) thermocouple connected to an acquisition system (Testo175; Testo AG, Lenzkirch, Germany). Samples were then allowed to cool to room temperature over absorbent paper.

Water binding capacity was evaluated through cooking yield and expressible liquid determinations.[32] Six measures were taken for each formulation. In accordance with Andrés *et al.*,[13] the cooking yield was determined as the percentage of weight retained after the cooking treatment. The expressible liquid was measured as the liquid extracted (%) by compression of cooked burgers (cooked weight) at room temperature between two pieces of filter paper (Whatman No. 5, 10 cm diameter; Whatman International Ltd, Maidstone, UK) and a pair of aluminium foil sheets (10 cm diameter) (all this set also preweighed, w_{before}) placed in a TAXT2i Texture Analyzer (Stable Micro Systems, Godalming, UK) with a 100 N force applied for 2 min. The filter and aluminium sheets were weighed after pressing (w_{after}), and the mass of the extracted juice was determined as follows:

$$\text{Expressible liquid}\,(\%) = \frac{w_{\text{after}} - w_{\text{before}}}{\text{Cooked sample weight}} \qquad (1)$$

Additionally, burger diameter reduction was determined according to do Prado *et al.*[33]

Color was measured at room temperature on cooked burger internal surface 2 min after cutting using a Chroma Meter CR-400 colorimeter (Minolta Co.) and CIELAB parameters (L^*, a^*, and b^*) were determined. Ten measures were taken for each formulation. Total color difference ΔE was calculated as the modulus of the distance vector between the commercial burger (L_0, a_0, b_0) and the burgers that included pulse flour (L^*, a^*, b^*) color parameters respectively[34] according to the following equation:

$$\Delta E = \sqrt{(a^* - a_0)^2 + (b^* - b_0)^2 + (L^* - L_0)^2} \qquad (2)$$

The texture profile analysis of the cooked burgers was determined as described by Andrés *et al.*[13] Samples 1.5 cm thickness and 1.7 cm in diameter were cut from the center of the products in a controlled-temperature room (20 °C) and compressed twice to 30% of their original height between flat plates using a TAXT2i Texture Analyzer (Stable Micro Systems, London, UK) with a 75 mm diameter probe at 0.5 mm s^{-1} (SMSP/75), interfaced with a computer, using the software supplied by Texture Technologies Corp. (NY, United States). Hardness (peak force of first compression cycle, N), springiness (distance of the detected height of the product on the second compression divided by the original compression distance, mm mm^{-1}), cohesiveness (ratio of positive areas of second cycle to area of first cycle, J J^{-1}), adhesiveness (negative force area of the first bite representing the work necessary to pull the compressing plunger away from the sample, J), chewiness (hardness × cohesiveness × springiness, N), and resilience (area during the withdrawal of the first compression divided by the area of the first compression, J J^{-1}) were determined.

Sensory evaluation

Sensory analyses were conducted by 60 panelists (25–56 years old), including graduate students and staff members of our institute who were experienced in sensory evaluation of foods and familiar with this kind of product, but received no specific training relevant to these products.

Pork meat burgers with the upper pulse flour level (150 g kg^{-1}) and an intermediate water/flour ratio (1600 g kg^{-1}) for each

Table 2. Pulse flour characterization

	Pea	Chickpea	Lentil	Bean
Moisture (g kg^{-1})	132.8^{a}(0.1)	119.0^{b}(0.3)	117^{b}(1)	87.8^{c}(0.8)
Ash (g kg^{-1})	29.3^{b}(0.1)	22.3^{c}(0.1)	29.6^{b}(0.5)	38^{a}(1)
Protein (g kg^{-1})	174^{a}(1)	129^{c}(3)	175^{a}(3)	155^{b}(2)
Fat (g kg^{-1})	21.1^{b}(0.7)	46.0^{a}(0.1)	14^{c}(3)	11.0^{c}(0.2)
Total dietary fiber (g kg^{-1})	151^{b}(1)	116^{c}(1)	157^{b}(5)	186^{a}(3)
Carbohydrates^{AA}	491.8	567.7	507.4	522.2
L^*	82.6^{c}(0.2)	92.6^{a}(0.2)	85.3^{b}(0.6)	95.9^{a}(0.6)
a^*	−5.51^{c}(0.04)	−0.63^{b}(0.04)	−0.7^{b}(0.1)	−0.01^{a}(0.01)
b^*	22.9^{a}(0.1)	15.1^{b}(0.2)	13.8^{c}(0.3)	7.7^{d}(0.3)
WAC (g g^{-1})	0.99^{d}(0.03)	1.24^{c}(0.02)	1.87^{a}(0.01)	1.59^{b}(0.02)
EA (%)	66.8^{a} (1)	48.9^{b}(5)	70.7^{a}(2)	66.1^{a}(4)
ES (%)	67.3^{a}(3)	51.1^{b}(4)	72.6^{a}(3)	62.3^{ab}(1)
Pasting temperature (°C)	78.8^{a}(0.1)	70.0^{c}(0.1)	68.7^{c}(0.1)	74.3^{b}(0.1)
Final viscosity (Pa s)	0.66^{a}(0.04)	0.39^{b}(0.04)	0.38^{b}(0.04)	0.77^{a}(0.02)

Standard error of the mean is given in parentheses. Different lower-case superscripts within the same line indicate that average values differ significantly ($P < 0.05$).
ACalculated by difference as 1000 − (moisture + protein + ash + fat + fiber).
WAC: water absorption capacity; EA: emulsifying activity; ES: emulsifying stability.

Table 3. Technological properties of pork meat burgers that included pulse flour and controls

Formulation	Cooking yield (%)	Diameter reduction (%)	Expressible liquid (%)
P1	87.9^{cd} (0.3)	2.8^{defg} (0.5)	0.25^{c} (0.02)
P2	87.9^{cd} (0.4)	2.4^{efg} (0.5)	0.254^{c} (0.002)
P3	87.4^{cd} (0.6)	3.4^{cdef} (0.4)	0.36^{c} (0.07)
P4	89.1^{bcd} (0.6)	3.4^{cdef} (0.4)	0.14^{c} (0.01)
P5	90.9^{ab} (0.3)	3.0^{defg} (0.6)	0.20^{c} (0.01)
P6	90.6^{ab} (0.3)	5.8^{c} (0.5)	0.27^{c} (0.02)
C1	86.8^{d} (0.5)	2.8^{defg} (0.7)	0.27^{c} (0.01)
C2	87.5^{cd} (0.4)	2.2^{efg} (0.3)	0.33^{c} (0.02)
C3	87.9^{cd} (0.4)	2.7^{defg} (0.3)	0.19^{c} (0.01)
C4	89.4^{abc} (0.3)	2.0^{fg} (0.4)	0.135^{c} (0.005)
C5	88.9^{bcd} (0.3)	3.7^{cdef} (0.6)	0.17^{c} (0.01)
C6	90.9^{ab} (0.5)	4.9^{cd} (0.7)	0.20^{c} (0.01)
L1	89.6^{abc} (0.3)	4.0^{cdef} (0.3)	0.229^{c} (0.004)
L2	89.8^{abc} (0.6)	4.1^{cdef} (0.3)	0.32^{c} (0.02)
L3	90.0^{abc} (0.4)	4.6^{cde} (0.5)	0.43^{c} (0.04)
L4	91.0^{ab} (0.3)	0.7^{fg} (0.5)	0.16^{c} (0.01)
L5	90.7^{ab} (0.3)	1.9^{fg} (0.3)	0.22^{c} (0.02)
L6	89.3^{abc} (0.4)	3.3^{defg} (0.3)	0.27^{c} (0.01)
B1	91.4^{a} (0.4)	2.1^{fg} (0.4)	0.21^{c} (0.01)
B2	89.4^{abc} (0.3)	1.7^{fg} (0.4)	0.21^{c} (0.02)
B3	88.9^{bcd} (0.3)	2.0^{fg} (0.5)	0.25^{c} (0.02)
B4	91.0^{ab} (0.2)	2.6^{defg} (0.5)	0.112^{c} (0.003)
B5	89.2^{abc} (0.3)	2.5^{efg} (0.4)	0.24^{c} (0.02)
B6	88.6^{bcd} (0.5)	2.4^{efg} (0.3)	0.34^{c} (0.02)
Commercial	84.3^{e} (0.4)	9.6^{b} (0.1)	1.1^{b} (0.1)
Control	76.4^{f} (0.6)	12.4^{a} (0.4)	6.20^{a} (0.2)

P: pea; C: chickpea; L: lentil; B: bean. Burger formulation codes and flour and water levels are given in Table 1.
Different superscripts on same column mean significant difference between average values ($P < 0.05$). Standard error of the mean is given in parentheses.

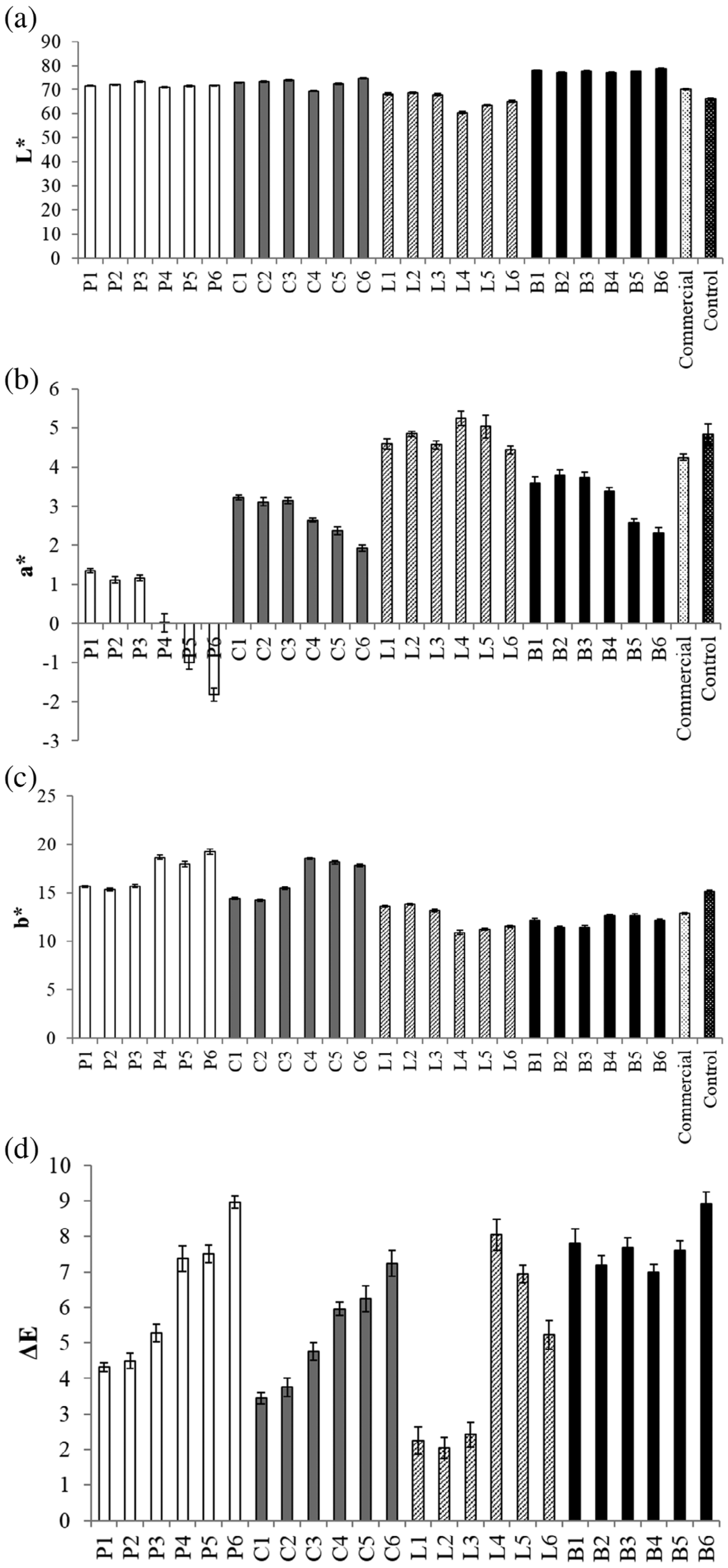

Figure 1. Color parameters (a) L^*, (b) a^*, and (c) b^* and (d) total color difference ΔE of pork meat burgers that included pulse flour and controls. P: pea; C: chickpea; L: lentil; B: bean. Burger formulation codes are given in Table 1.

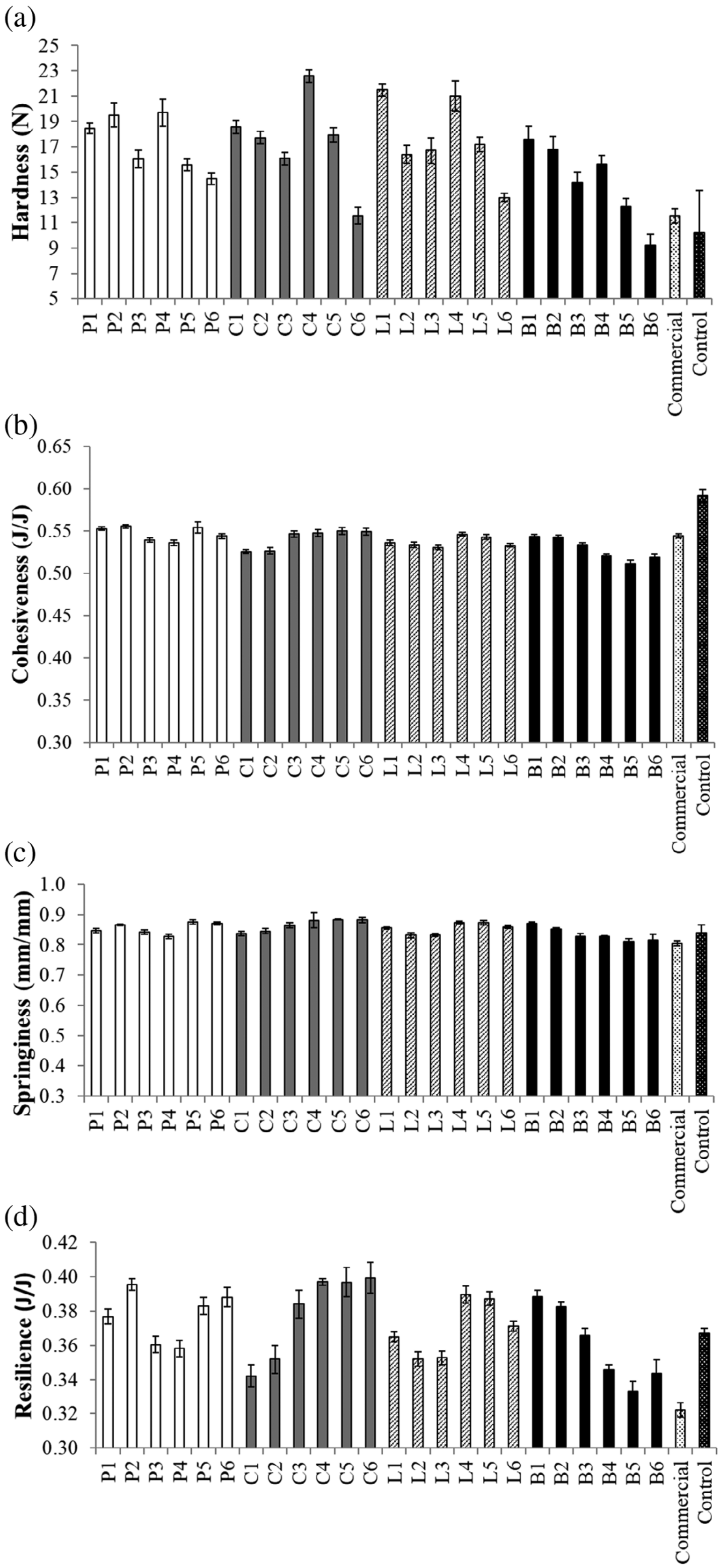

Figure 2. Texture parameters: (a) hardness, (b) cohesiveness, (c) springiness, and (d) resilience of pork meat burgers that included pulse flour and controls. P: pea; C: chickpea; L: lentil; B: bean. Burger formulation codes are given in Table 1.

Table 4. Sensory evaluation of pork meat burgers with 150 g kg^{-1} of pea (P5), chickpea (C5), lentil (L5), and bean (B5) flours with 1600 g kg^{-1} water/flour ratios

Attribute	P5	C5	L5	B5
Appearance	5.17^a (36.1)	5.75^a (58.3)	5.14^a (44.4)	6.22^a (63.8)
Color	4.69^a (30.5)	5.44^a (52.7)	5.25^a (50)	6.00^a (61.1)
Texture	6.11^a (61.1)	6.43^a (72.2)	6.06^a (61.1)	6.08^a (72.2)
Taste	5.78^a (58.3)	6.14^a (61.1)	5.00^a (41.6)	5.72^a (55.5)
Overall acceptability	5.47^a (50)	6.06^a (66.6)	5.25^a (44.4)	5.78^a (52.7)

Burger formulation codes and flour and water levels are given in Table 1. Different lower-case letters in the same row indicate that average values differ significantly ($P < 0.05$). Percentage of panelists who scored each tested property between 6 and 9 is given in parentheses. Liking attributes were scored on a nine-point hedonic scale, where 1 = dislike extremely and 9 = like extremely.

legume type (P5, C5, L5, and B5 as shown in Table 3) were selected for sensory evaluation. New burgers were prepared using both batches of frozen meat, as data analysis indicated there was no significant difference between them (replicates).

Samples were cooked as described earlier and held on a warming tray in covered plates for no longer than 10 min. Warm pieces (10 g) of the four burgers (P5, C5, L5, and B5) were distributed in white polystyrene plates and served to each panelist with three-digit codes in a randomized and balanced manner for evaluation. Tap water was supplied to panelists for rinsing between samples. Experiments were conducted in an appropriately designed and lighted room. Acceptance testing was conducted using a nine-point hedonic scale (9 = like extremely; 5 = indifferent; 1 = dislike extremely) to assess appearance, color, texture, taste, and overall acceptability.

Sensorial observations were also classified into three perception groups: the first one corresponded to those that disliked the product (scores 1–4, dislike extremely to slightly), the second one was indifferent (score 5), and the third group expressed they liked the samples (scores 6–9, slightly like to extremely).

All experiments were conducted in compliance with the national legislation. All the samples tested were made with ingredients approved for human consumption by the national legislation. All participants received written information about the study and the products to be tasted before giving their informed consent.

Statistical analysis

The whole experiment was repeated twice. Experimental data were evaluated by analysis of variance using a linear mixed model considering flour type, pulse flour level, water/flour ratio, and their interactions as fixed effects, and replicates as a random effect, using SYSTAT software (SYSTAT Inc., Evanston, IL, USA). Means were compared using the Tukey test ($P < 0.05$). In sensory data analysis, formulations were considered as fixed effect and panelists were included in the model as a random effect.

RESULTS AND DISCUSSION

Pulse flours characteristics

The compositions and properties of the pulse flours are shown in Table 2. All of them showed high total dietary fiber levels (>116 g kg^{-1}), with the highest for bean flour (186 g kg^{-1}). A positive correlation between total dietary fiber and ash contents ($R = 0.941$, $P < 0.001$) was found, probably related to their hull contents. Protein contents varied in the range 129–175 g kg $^{-1}$, with chickpea the lowest and pea and lentil flours the highest. Fat content varied from 11.0 to 46.0 g kg^{-1} with significant differences ($P < 0.05$) among them, with chickpea the highest.

Pulse flours color parameters are shown in Table 2. Higher L^* values were observed for chickpea and bean flours. Parameters a^* and b^* oppositely varied among flours: the lowest a^* was detected for peas (most greenish color) and the highest for bean, whereas b^* varied from the most slightly yellow color (highest b^*) in pea to a lowest for bean flour.

WAC ranged from 0.99 to 1.87 g g^{-1} (Table 2), where lentil flour WAC was the highest and pea flour WAC the lowest. Regarding OAC, there were no differences ($P < 0.05$) among flour samples (average value 0.81 g g^{-1}) despite the higher lipid content of chickpea flour. However, this flour showed the lowest EA and emulsion stability (ES) properties, whereas the others were higher and similar. In addition, positive correlations were found between flour protein contents and their EA ($R = 0.852$, $P < 0.01$) and between flour protein contents and their ES ($R = 0.882$, $P < 0.01$). Emulsifying properties of pulse flours can be attributed mostly to the protein components of pulses. Proteins act as emulsifiers by forming a film or skin around oil droplets dispersed in an aqueous medium, thereby preventing structural changes such as coalescence, creaming, flocculation, or sedimentation.[35]

When flour pasting properties were analyzed, initial low viscosities that rise as temperature increases were observed due to swelling of intact starch granules. Pasting temperatures (the temperature at the onset of rising in viscosity) ranged from 70.0 to 78.8 °C for different flours (Table 2). The highest pasting temperature was determined for pea flour, indicating a starch highly resistant to swelling and rupture. Further, increases in apparent viscosity after heating to 95 °C and cooling were observed for all flours, probably due to the reassociation of amylose and amylopectin polymers that form networks in the presence of proteins and fiber.[36] Final viscosities (material ability to form a viscous paste) were higher for bean and pea flours than for chickpea and lentil (Table 2).

Burger properties

Properties evaluated on replicate burgers (trials) obtained from each meat batch showed no significant differences ($P < 0.05$), which indicated that the assay was reproducible.

According to Salcedo-Sandoval,[37] cooking yield might be expected to depend on water and fat levels in the product and on how effectively the fat replacer used in the reformulated patties retained fluids. All pulse-added burger cooking yields were higher than 86%; these values were higher than the commercial product or laboratory-prepared pork burger yields (Table 3). For pea and chickpea pulse-added burgers, the highest yields were obtained with the upper flour level (150 g kg^{-1}), but this effect was less noticed for bean and lentil, probably due to lower pea and chickpea flours WAC (Table 2). Similar findings were reported for beef burgers with whole sorghum flour.[33] Pulse protein and starch can imbibe water from gel matrices upon heating and interact with other food matrix components like meat proteins to form a complex three-dimensional gel network, trapping fine particles of emulsified meat with starch and non-meat proteins as fillers.[24] Also, because of the high total dietary fiber content of the pulse flours (Table 2), burgers with pork meat partially replaced with pulse flours at 80 or 150 g kg^{-1} would contain 10–20 g kg^{-1} total dietary fiber that could reinforce product matrices by hydration and produce highly viscous solutions and thereby increase their cooking yields.[38]

Regarding diameter reduction (Table 3), all pulse-added burgers presented lower values ($P < 0.05$) than the commercial control and the laboratory-prepared pork burger. This was due to better oil and water retentions, which were confirmed with lower expressible liquid results (Table 3) that were significantly lower ($P < 0.05$) than controls and with no differences among them ($P > 0.05$). Therefore, pulse flour compositions and the properties of their components adequately compensated for the meat reduction in the burger formulations, resulting in satisfactory product properties.

Pulse flour incorporation led to variations in burger color (Fig. 1 (a)–(c)). The lowest lightness values were observed for burgers with lentil flour at both levels, and the highest were those with bean flour (Fig. 1(a)). Burgers with pea, chickpea, and bean flours showed a^* values lower than controls (Fig. 1(b)), with values for burgers containing pea flour the lowest. The higher pea flour addition (150 g kg^{-1}) and the higher water/flour ratio produced the lowest a^* (greenish) values ($P < 0.05$). Lentil flour incorporation at both levels and all water/flour ratios led to higher a^* (reddish) ($P < 0.05$), probably related to its higher carotenoid content;[39] values were comparable to those for the laboratory-prepared pork product ($P < 0.05$).

All pea and chickpea flour additions resulted in burgers with higher b^* (yellowish) than both controls ($P < 0.05$). Lower b^* values were observed for all burgers containing bean flour and for the upper level of lentil flour addition. When total color difference ΔE based on the commercial burger was calculated, 80 g kg^{-1} lentil-added burgers showed the lowest value, indicating they are most like the commercial burger (Fig. 1(d)), followed by the burgers with chickpea and pea flour at the same level.

Among textural parameters (Fig. 2), burger hardness was affected by flour and water levels. Generally, the combination of higher flour and higher water additions resulted in less hard burgers (Fig. 2(a)). Some formulations (P6, C6, B6, L6, B3, B5) showed hardness similar ($P < 0.05$) to the commercial product. Burgers with 150 g kg^{-1} of pea, chickpea, and lentil flours at the lowest water/flour ratio (P4, C4, and L4 respectively) showed the highest hardness, but this effect was not observed for the equivalent burger formulation with bean flour.

Chewiness followed a similar trend to hardness (data not shown). All pulse burger cohesiveness values (ranging between 0.50 and 0.56 J J^{-1}) were lower than the laboratory-prepared control (Fig. 2(b)), in agreement with several authors.[5,40,41] Springiness varied between 0.78 and 0.88 mm mm^{-1} (Fig. 2(c)). In addition, a positive correlation ($R = 0.60$, $P < 0.001$) was found between cohesiveness and springiness, and also between resilience (Fig. 2(d)) and cohesiveness ($R = 0.85$, $P < 0.001$). The latter would indicate that the ability of elastic recovery, which is related to the nature of the network formed during gelation, is related to its cohesiveness, and probably the internal bonds that make up the body.[42] Pulse burger adhesiveness values were low for all formulations (data not shown) and completely independent of other parameters.

Assorted results were found by other researchers in meat products. Der[43] observed that micronized lentil added to low-fat beef burger resulted in no difference in hardness but a decrease in cohesiveness. Albarracín *et al.*[44] found an increase in hardness and decrease in cohesiveness and springiness with *Phaseolus* spp. flour addition to scalded sausages. As noted, a broad range of possibilities for texture results could be expected, depending on the system and pulse flour incorporation.

Sensory analysis

Results of the sensory analysis of pork meat burgers with 150 g kg^{-1} pulse flour and medium water/flour ratio (P5, C5, L5, B5) are presented in Table 4. As all burger formulations with pulse flours showed adequate technological properties, pork meat burgers with the upper pulse flour level (150 g kg^{-1}) and an intermediate water/flour ratio (1600 g kg^{-1}) for each legume type (P5, C5, L5, and B5, as shown in Table 3) were selected for sensory evaluation. They were chosen because they had the maximum flour level, and therefore the maximum meat replacement, but a water/flour ratio that produced a product with hardness similar to or slightly higher than the commercial and control samples.

All products had acceptable sensory scores (>5) for appearance, taste, texture, and overall acceptability. More than 41.6% of the panelists liked the taste, 61.1% the texture, 30.5% the color, 36.1% the appearance, and over 44.4% agreed with the overall acceptability of all burger formulations. In conclusion, the products showed good quality attributes.

There were no significant differences among flour type ($P < 0.05$) for any of the sensorial parameters studied. These results indicate that if lower levels of pulse flour were used in the formulations they would be acceptable by consumers. In addition, only salt (NaCl) was used as a seasoning; flavor profiles could be further adjusted with other seasonings in subsequent stages of study.

CONCLUSION

Commercial pulse flours (lentil, chickpea, pea, and bean) showed high fiber and protein contents (>116 g kg^{-1} and 129–175 g kg^{-1} respectively) with low fat content (11–46 g kg^{-1}). Among their functional properties, there was no significant difference for OAC among all pulse flours, whereas the WAC was the highest for lentil flour and lowest for pea flour. Pulse flour emulsion activity and emulsion stability were similar among pea, lentil and bean and higher than chickpea flour; both properties showed positive correlations with pulse protein content. Pea flour presented a higher pasting temperature; higher final viscosities were found for bean and pea flours. Partial replacement of pork meat by these commercial legume flours, at two levels (80, 150 g kg^{-1}) and three water/flour ratios (1250, 1600, and 2000 g kg^{-1}), resulted in low-fat burgers with sunflower oil with adequate physicochemical characteristics such as high cooking yields, low diameter reductions and expressible liquid, and variations in color and texture parameters that in some combinations were similar to the controls. Moreover, formulations with the maximum flour addition and intermediate water/flour ratio had good sensorial acceptability regardless of the flour type. It is possible to partially replace pork meat with these vegetal protein sources in burgers with sunflower oil while keeping product quality. Adequate pulse-added burgers were obtained with reduction in the pork meat in the product by up to 44%.

ACKNOWLEDGEMENTS

The authors are members of the HealthyMeat network, funded by CYTED (ref: 119RT0568).

This research was supported by Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET, Argentina), Agencia Nacional de Promoción Científica y Tecnológica, and Universidad Nacional de La Plata.

In memory of Dr Alicia Califano (1951–2019), Lead Scientist (CIDCA-CONICET, Argentina) and highly respected colleague, who will be greatly missed.

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