Ready-to-eat chickpea flour purée or cream processed by hydrostatic high pressure with final microwave heating

M. Dolores Alvarez[a]*, Beatriz Herranz[a], Gema Campos[b], Wenceslao Canet[a]

[a]*Department of Characterization, Quality and Safety, Institute of Food Science and Nutrition (ICTAN-CSIC), José Antonio Novais 10, 28040 Madrid, Spain.*

[b]*Analytical, Instrumental, and Microbiological Services Unit, Institute of Food Science and Nutrition (ICTAN-CSIC), José Antonio Novais 10, 28040 Madrid, Spain.*

*Corresponding author: Tel.:+34 915492300; fax: +34 915493627.

E-mail addresses: mayoyes@ictan.csic.es (M. Dolores Alvarez); beatriz.herranz@ictan.csic.es (Beatriz Herranz); gema.campos@ictan.csic.es (Gema Campos); wenceslao@ictan.csic.es (Wenceslao Canet).

ABSTRACT

It was shown that high hydrostatic pressure (HHP) induces either starch gelatinization or protein aggregation in chickpea flour (CF) slurries. The aim of this work was to develop a new "ready-to-eat" semi-solid CF product by using HHP at 600 MPa and 50 °C for 15 or 25 min combined with final microwave heating prior to consumption. Eight combinations with a formulation that includes raw or toasted CF, with or without lemon juice, were evaluated using physicochemical (color and protein content, mechanical and rheological behavior), microbiological and sensory analyses. All the CF products were microbiologically safe and stable during two months at refrigerated storage. Mainly, the HHP-treated CF products differed in their texture depending on the CF used, the holding time and the presence of lemon juice, whereby each individual product could be classified as a CF purée or a cream. Moreover, all the formulations showed similar very high sensory quality.

Industrial relevance: HHP at 600 MPa and 50 °C, applied for 15 or 25 min to chickpea flour (CF) slurries formulated with raw or toasted CF, water in which chickpeas had been cooked, extra virgin olive oil, soy milk, salt, and, optionally, lemon juice induced starch gelatinization (HHP-induced gelatinization) and microbiological preservation that was sustained for two months in refrigerated storage at 4 °C. After microwave heating prior to consumption, CF products with the rheology and texture characteristic of purée or cream were obtained. The development of these refrigerated gluten-free HHP-induced semi-solid CF products which can be given a quick final heating in a microwave oven would be commercially interesting and foreseeably successful, providing the catering industry and consumers with various new CF products with high protein content, thus also helping to increase consumption of pulses and their contribution to food and nutritional safety.

Keywords: High pressure treatment; microwave heating; chickpea flour product; minimal processing; rheology; overall liking.

1. Introduction

Consumer demand for high-quality minimally processed products has increased surprisingly in recent years. Preferences have shifted toward healthier, “*fresh-looking*”, ready-to-eat products with a richer flavor and enhanced shelf life (Krebbers et al., 2003; Picouet, Landl, Abadias, Castellaria, & Viñas 2009). HHP is a very acceptable non-thermal processing technique that can be used to satisfy increased demand for high-quality, minimally processed food that is free of additives and microbiologically safe (Peyrano, Speroni, & Avanza, 2016). It is known that HHP-induced starch gelatinization produces limited granule swelling, lower amylose leaching, and better granule preservation, resulting in starch pastes and gels with unique functional properties (Stute, Klinger, Boguslawski, Eshtiaghi, & Knorr, 1996; Stolt, Oinonen, & Autio, 2001).

Consumption of pulses is associated with reductions of cardiovascular diseases, hypertension, gastrointestinal disorders, cancer, diabetes, osteoporosis, and low-density lipoprotein cholesterol (Villegas et al., 2008) owing to their excellent nutritional composition. They are high in carbohydrate and dietary fiber, mostly low in fat, supply adequate protein and are good sources of vitamins and minerals (Cabrera, Lloris, Giménez, Olalla, & López, 2003). Chickpea (*Cicer arietinum*) is the fifth most important pulse in the world on the basis of total grain production and the first common food pulse consumed in Spain (Aguilera, Benítez, Mollá, Esteban, & Martín-Cabrejas, 2011). Numerous traditional convenience and confectionery food products are prepared directly from concentrated CF dispersions, both in the household and on a commercial scale (Bhat & Bhattacharya, 2001). Recently, Jiménez, Tárrega, Fuentes, Canet and Alvarez (2016) developed a CF-based product similar to hummus in taste but with a different texture.

A previous study showed that the elasticity (*G′*) of pressurized CF slurry (at 150, 300, 450, and 600 MPa) increased with pressure applied and concentration (Alvarez, Fuentes, Olivares, & Canet, 2014), whereas subsequently heat-induced CF paste gradually transformed from solid-like to liquid-like behavior as a function of both pressure level and concentration. HHP treatment at 450 and 600 MPa (at 25 °C for 15 min) was sufficient to complete gelatinization of CF slurry at a 1:5 flour-to-water ratio. The results showed that HHP adopted as a pre-processing instrument in combination with heating processes produced a remarkable decrease in thermo-hardening of heat-induced CF paste, permitting the development of chickpea-based products with desirable handling properties and sensory attributes.

On the other hand, microwave heating has now become a very common method of domestic cooking technology which gives the opportunity of having a fast heat process in a continuous mode (Picouet et al., 2009). In fact, a whole range of ready-to-eat meals are heated in a microwave oven before consumption, as these products require only 1–5 min of preparation.

In Spain there is no commercially available ready-to-eat chickpea purée or cream. Bearing in mind the structural changes induced by HHP in CF slurries, the objective of this work was to investigate the potential of the HHP (at 600 MPa and 50 °C) applied for 15 or 25 min, and its combination with heating in a microwave oven prior to consumption, to develop and stabilize a chickpea-based semi-solid product from eight different combinations of unpressurized dilute CF slurries that includes raw or toasted CF, and with or without lemon juice. After pressurization, the microbiological stability of each CF product was also evaluated during two months at refrigerated storage.

2. Materials and methods

2.1. CF slurry ingredients

Spanish chickpea (*Cicer arietinum* cv. Castellano, Kabuli type) flour and seeds were commercially available products donated by the García del Valle flour milling company (Soria, Spain). Mean values for proximate analysis (g 100 g^{-1}) of CF samples (as provided by the supplier) were: moisture content 14.0 g 100 g^{-1}, protein 19.4 g 100 g^{-1}, crude fiber 15 g 100 g^{-1}, total fat 5 g 100 g^{-1}, total carbohydrate 55 g 100 g^{-1}. This CF is split into six different fractions: ≥ 425 μm (1.17%), < 425 and ≥ 342 μm (3.11%), < 342 and ≥ 250 μm (16.38%), < 250 and ≥ 180 μm (12.68%), < 180 μm and ≥ 132 μm (6.05%), and < 132 μm (60.61%) (as provided by the supplier). The ingredients used in the preparation of the various CF slurries were: CF, water in which chickpea seeds had been cooked, extra virgin olive oil (Carbonell, Córdoba, Spain), soymilk (Vive Soy, Pascual, Burgos, Spain), common salt (NaCl), and lemon juice.

2.2. CF slurry preparation

CF slurries were formulated with water that had been used to cook chickpea seeds in order to enrich their nutritional value and to improve the chickpea taste and flavor of the products. For this purpose, the raw seeds were previously soaked in tap water (1:5 w/v) for 16 h at 20 °C. After the seeds had been hydrated, raw tap water (1:6 w/v) was added, and the soaked seeds were cooked in the water by boiling under pressure (98.07 kPa) for 20 min. After cooking, the cooking water was drained and reserved for subsequent use as an ingredient of the chickpea slurries, whereas the seeds were discarded. CF toasting was performed at 90 °C for 20 min using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). Four CF slurry formulations were prepared in this study: with raw (RCF) or toasted flour (TCF), and with or without lemon juice (RCFL, TCFL, and RCF, TCF, respectively). Half of the formulations were incorporated with lemon juice in order to provide to the product slight lemon aroma. CF slurries without added lemon juice were prepared from 14.29 g 100 g^{-1} (final slurry weight) of raw or toasted flour, 57.14 ml 100 g^{-1} of cooking water, 27.43 ml 100 g^{-1} of soymilk, 0.57 ml 100 g^{-1} of oil, and 0.57 g 100 g^{-1} of salt. In the CF slurries with added lemon juice, the total amount of lemon (0.56 ml 100 g^{-1}) was subtracted from the original soymilk content in the counterparts without lemon juice. The four combinations of ingredients were unpressurized (control CF slurries) and pressurized at 600 MPa and 50 °C for 15 or 25 min (HHP-induced CF products). Individual codes of CF slurries and HHP-induced CF products are listed in Table 1 in accordance with their formulation.

2.3. High hydrostatic pressure treatment

Prepared CF slurries (175 ml) were vacuum-packaged in a very low gas permeability bag type (250 ml), Doypack® (Polyskin XL, Flexibles Hispania, S.L.). The packaged samples were vacuum-packed one more time to prevent contact between pressurization fluid and slurry. HHP treatment was performed using a Stansted Fluid Power Iso-lab 900 High Pressure Food Processor (Model: FPG7100:9/2C, Stansted Fluid Power Ltd, Harlow, Essex, UK), with 2925 ml capacity, maximum pressure of 900 MPa, and a potential maximum temperature of 100 °C. Four packed samples were introduced simultaneously into the pressure unit filled with pressure medium (water), then treated at a pressure of 600 MPa, and subsequently compared with untreated samples. Pressure was increased at a rate of 500 MPa/min and maintained at 600 MPa for a holding time of 15 or 25 min; the decompression time was less than 4 s. The temperature of the pressure unit vessel was thermostatically controlled at 50 °C (Alvarez et al., 2015) throughout all the treatments (Fig. S1). Pressure, time, and temperature were controlled by a computer program. The average adiabatic heating during pressurization was ~2.5 °C/100 MPa. After HHP treatment, samples were immediately stored at 4 °C for one day (for instrumental and sensory evaluations) or two months (for microbial analysis). All the HHP treatments were performed twice (two batches).

2.4. Microwave heating

Each refrigerated packed unpressurized or HHP-treated CF slurry was always placed in the same centered position and irradiated for 2 min at an output power rating of 700 W in a Samsung M1712N (Samsung Electronics S.A., Madrid, Spain) microwave oven. The power setting was 100%. Heating was conducted in two steps. Initially, each individual bag was opened at the top and the sample was irradiated for 1 min and then removed from the microwave and stirred gently (shear rate $\approx 10\ s^{-1}$) with a spoon in order to improve the temperature distribution and homogenize the product temperature. The sample was placed back in the microwave and irradiated for an additional 1 min under the same conditions. After homogenization by stirring, the temperature reached by the thermal center of the product was always measured (50 ± 3 °C). After heating, all the products were maintained at 50 °C by placing them in a Hetofrig CB60VS (Heto Lab Equipment A/S, Birkerød, Denmark) water-bath. The selected sample testing temperature was 50 °C, as previous tests showed that this was the preferred temperature for consumption of this CF product.

2.5. Instrumental CF slurry evaluation

2.5.1. Rheological measurements

All rheological measurements were carried out with a Kinexus pro rotational rheometer (Malvern Instruments Ltd, Worcestershire, UK), using cone and plate geometry (4° cone angle, 40 mm diameter) to measure the unpressurized CF slurries and parallel-plate geometry (40 mm diameter and 2 mm gap) to measure the HHP-treated CF slurries. Samples were allowed to rest for 15 min before analysis to ensure both thermal and mechanical equilibrium. Temperature was controlled to within 0.1 °C by Peltier elements in the lower plates kept at 50 °C.

2.5.1.1. Small-amplitude oscillatory shear (SAOS) measurements

To determine the linear viscoelastic (LVE) region of both unpressurized and HHP-treated CF slurries, stress sweep tests were run at 1 Hz with the shear stress of the input signal varying from 0.1 to 100 Pa. Frequency sweeps were run, subjecting the samples to stress that varied harmonically with time at frequencies (ω) from 1 to 100 rad s^{-1}. The strain amplitude was set at $\gamma = 0.5\%$, always within the LVE range. The storage modulus (G', Pa), loss modulus (G'', Pa) and loss tangent ($\tan \delta = G''/ G'$) values at a frequency of 6.28 rad s^{-1} were chosen for comparison of results.

2.5.1.2. Steady shear measurements

The HHP-induced CF slurry flow behavior was obtained by registering shear stress at shear rates from 0.1 to 100 s^{-1} in 3 min. The Oswald de Waele model was used for the calculations of consistency coefficient and flow behavior index as follows:

$$\eta_a = K\dot{\gamma}^{n-1} \quad (1)$$

where η_a is the apparent viscosity (Pa s), K is the consistency coefficient (Pa s^n), $\dot{\gamma}$ is the shear rate (s^{-1}), and n is the flow behavior index. Apparent viscosity values at 1, 50, and 100 s^{-1} (η_{a1}, η_{a50}, η_{a100}), were also derived from the apparent viscosity vs. shear rate curves and compared with K values from power law fits, which correspond to the apparent viscosity at a shear rate of 1 s^{-1} ($\eta_{a,1}$) obtained from the flow curves. The η_{a50} value would represent the approximate viscosity felt in the mouth (Bourne, 2002).

2.5.2. Texture measurements

A cone penetration (CP) test was carried out on the HHP-treated CF samples with a TA.HD Plus Texture Analyser (Stable Micro Systems Ltd, Godalming, UK) provided with the Texture Exponent software (version 6.1.5.0) and equipped with a 50 N load cell. During CP tests, the HHP-induced CF purées were maintained at 50 °C by means of a Temperature Controlled Peltier Cabinet (XT/PC) coupled to a separate heat exchanger and proportional-integral-derivative (PID) control unit (Canet, Alvarez, Fernández, & Tortosa, 2005). A TTC (Texture Technologies Corporation) spreadability rig (HDP/SR, Stable Micro Systems) was used, consisting of a 45° conical perspex probe (P/45 degree) that penetrated a conical sample holder containing 7 ± 0.1 g of purée to a distance of 17.5 mm at a rate of 3 mm s^{-1}. The force time curve was used to calculate the firmness (N) as maximum resistance to penetration, the work required per displaced volume (J m^{-3}) to accomplish penetration, calculated from the area under the curve up to the maximum penetration force, and the average penetration force (N).

2.5.3. Color and protein content

The color of the HHP-treated CF slurries was measured with a Hunter-Lab model D25 (Reston, VA) color difference meter fitted with a 5-cm-diameter aperture. Results were expressed in accordance with the CIELAB system (D65 illuminant and 10° viewing angle). The following parameters were determined: lightness (L^*), redness (a^*), and yellowness (b^*). Nitrogen was estimated by the Dumas method using a Leco TruMac Nitrogen Determinator (Leco Corporation, St Joseph, MI, USA). The results were expressed as g total nitrogen per 100 g of sample (percentage).

All the instrumental measurements were performed at least six times in all, with unpressurized or pressurized CF samples prepared on two different days.

2.6. Microbial analyses

Microbial analysis was carried out before and after HHP treatment on days 1, 7, 14, 21, 28, and 60 during a period of two months or until the samples became completely contaminated. Quantification of microorganisms was conducted following the corresponding International Organization for Standardization (ISO) or Norme Française (NF) directives: mesophilic lactic acid bacteria (ISO 15214:1998), total Enterobacteria (ISO 21528-2:2004), molds and yeast (NF

V08-059), *Salmonella* (ISO 6579:2002), and *Listeria monocytogenes* (ISO 11290-1:1996). The European current legislation (Commission Regulation (EC) No 1441/2007) on microbiological criteria for foodstuffs stablishes absence of *Salmonella* and *Listeria* in ready-to-eat foods.

Sulfite-reducing clostridia counts were evaluated by the surface spread plate method. A total amount of 10 g of each sample (unpressurized and pressurized CF slurries), from at least 3 different packages, was collected and placed in a sterile plastic bag (Daslab, Barcelona, Spain) with 90 ml of buffered 0.1% peptone water (Oxoid, Basingstoke, UK) in a vertical laminar-flow cabinet (model AV 30/70 Telstar, Madrid, Spain). After 1 min in a Stomacher blender (model Colworth 400, Seward, London, UK), appropriate serial decimal dilutions were prepared to determine the microbial plate counts of Trypcase Sulfite Neomycin agar (Biomerieux, Spain) incubated in anaerobic jars with Anaerocult® (Merck, Darmstadt, Germany) at 46 ± 1 °C for 48 ± 3 h. Microbiological counts were expressed as Log CFU g^{-1} of sample, except for *Salmonella* and *Listeria*, which were expressed as absence/presence in 25 g of sample.

2.7. Consumer sensory analysis

A total of 50 untrained Spanish panelists (consumers) aged from 15 to 65 years took part in the study. Each consumer received a sample, heated up to 50 °C in a microwave oven, of the eight pressurized CF slurries, presented individually in a single session following a balanced complete block design to avoid a serving order effect. The samples were coded with random three-digit numbers. Each consumer first evaluated their “overall liking” for each of the 8 formulations, using a 9-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely). The consumers were asked to score “overall liking” for each CF sample, taking into account the “appearance,” “color,” “texture,” and “chickpea taste.” The consumers were also asked to classify each processed CF sample evaluated in the category of “CF purée” or “CF cream” in terms of perception of consistency. When considered necessary, opinions regarding the suitability of the sensory consistency intensity of each CF sample, such as weak purée, too weak purée, purée with just about right consistency, strong cream, too strong purée, or similar were allowed in order to facilitate interpretation of the product type to which the consumers were referring.

2.8. Statistical analysis

One-way analysis of variance (ANOVA) was performed to study the total effect (comparison of the eight HHP-treated CF slurries) of the three factors considered (holding time, flour type, and presence or absence of lemon juice) on the instrumental measurements of each sample and the overall liking. One-way ANOVAs were also carried out to compare the means between pairs of pressurized CF slurries, fixing either the flour type level (raw or toasted) or the lemon juice level (with or without) in order to study the holding time effect separately, and fixing both the holding time (15 or 25 min) and the lemon juice level in order to investigate the toasting effect individually. Minimum significant differences were calculated using Fisher’s least significant difference (LSD) test at 1% for the instrumental measurements and at 5% for the overall liking. Data analyses were carried out with Statgraphics Plus 5.1 (Statistical Graphics Corporation, Inc., Rockville, MD, USA).

3. Results and discussion

3.1. SAOS measurements of unpressurized CF slurry

The frequency dependence of storage or elastic (*G*′) and loss or viscous (*G*″) moduli in the linear region at 50 °C for the four unpressurized CF slurries made with raw or toasted CF, with or without added lemon juice, is shown in Fig. 1. *G*′ predominates over *G*″ in the frequency range of 1–100 rad s^{-1} for all four untreated CF slurries, all of which exhibit a solid-like character. A previous study showed that the behavior of unpressurized CF slurries prepared at 1:5, 1:4, 1:3, and 1:2 flour-to-water ratios at 25 °C resembled that of an entangled system, with $G'' > G'$ until the cross-over frequency (ω) was reached (Alvarez et al., 2014). In the present study, the CF slurries were made with a still lower flour-to-water ratio (1:6). Therefore, the significant increase in mechanical strength observed in these CF slurries is attributed, at least partially, to the replacement of part of the water with olive oil and soy milk and the incorporation of salt. On the other hand, the unpressurized CF slurries were also subjected to microwave heating for 2 min before the measurements. It is well known that microwave heating causes localized areas of relative high and low temperatures and therefore some starch granule swelling might occur, contributing partially to the viscoelastic character that was found in these control untreated CF slurries. Finally, it is also thought that in the present study the higher measurement temperature used (50 °C) during this test might induce slight swelling of some starch granules, partly determining the rheological behavior observed in these more complex systems.

On the other hand, the elasticity or solid-like behavior ($G' > G''$ values) of unpressurized CF slurries formulated with toasted CF was also significantly greater than that of the slurries made with raw CF (Fig. 1). Both the TCF-0.1 and the TCFL-0.1 slurries formed a firmer gel with characteristics of higher G' and G'' values than their counterparts made with raw CF (RCF-0.1 and RCFL-0.1 slurries). This increase in both elasticity (G') and viscosity (G'') is attributed to the weakening of the starch granule integrity by hot together higher water absorption capacity and swelling power of the toasted flour (Ikegwu et al., 2013). In turn, Meares, Bogracheva, Hill, and Hedley (2004) reported temperatures for protein denaturation of CF in the range of 100–120 °C. Consequently, although CF contains a considerable quantity of protein (19.4 g 100 g^{-1}), it is presumed that denaturation or aggregation of the protein component did not occur during toasting at 90 °C, and therefore this phenomenon did not affect the rheological properties of control slurries prepared with toasted CF. It also appears that the presence of lemon juice had no significant effect on the viscoelasticity of the unpressurized CF slurries (Fig. 1).

Mean SAOS rheological properties of unpressurized CF slurries at 6.28 rad $^{-1}$ are presented in Table 2 for each formulation. A power law model was used to characterize the frequency (ω) dependence of the storage and loss moduli as follows (Eqs. (2) and (3)):

$$G' = G'_0\,\omega^{n'} \tag{2}$$

$$G'' = G''_0\,\omega^{n''} \tag{3}$$

where G'_0 (Pa) and G''_0 (Pa) are storage and loss moduli at 1 rad s^{-1}, respectively, and exponents n' and n'' (both dimensionless) denote the influence of ω on the two moduli.

The effect of the formulation on the power law parameters of the control CF slurries derived from Eqs. (2) and (3) is also shown in Table 2. As expected, the effect of toasting and lemon juice on the G'_0 and G''_0 intercepts was very similar to the present results obtained for G' and G'', i.e. TCF-0.1 and TCFL-0.1 slurries had higher G'_0 and G''_0 values than their RCF-0.1 and RCFL-0.1 counterparts, although there were no significant differences between the G''_0 values of the RCF-0.1 and TCF-0.1 samples without added lemon. In addition, presence of lemon juice did not have significant effect on the G'_0 and G''_0 values of the control CF slurries. The ranges of the corresponding n' and n'' values were 0.054–0.092 and 0.129−0.145, respectively. Therefore, G' was relatively independent of frequency, while G'' showed some dependence on frequency, which is also associated with the weak gel behavior ($G' > G''$) observed in Fig. 1 in accordance with Lopes da Silva and Rao (2007). Even though CF slurries with toasted CF exhibited more solid-like characteristics with much higher magnitudes of G'_0 and G''_0 than their counterparts with raw CF, G' was more dependent on frequency (higher n' values) in the two slurries formulated with toasted CF. This result may be associated with weakening of the starch granule integrity produced by the CF toasting process, causing higher frequency dependence.

3.2. SAOS measurements of HHP-treated CF slurry

Mechanical spectra obtained at 50 °C for CF slurries HHP-treated at 600 MPa and 50 °C for holding times of 15 and 25 min are shown in Fig. 2. After pressurization, the CF samples again behaved like weak gels, with higher magnitudes of G' than G'' in the complete frequency range studied. Apparently, there were no significant differences between the G' values of CF slurries made with either raw or toasted CF without lemon juice and treated with HHP for 15 min (RCF-15 and TCF-15 samples) and those of raw CF slurry containing lemon juice (RCFL-15 sample). In contrast, CF slurry made with toasted CF and lemon juice (TCFL-15 sample) had the highest G' values (Fig. 2a); however, after a longer holding time its HHP-treated TCFL-25 counterpart sample had the lowest elasticity (Fig. 2b). Therefore, the significance of either toasting or lemon juice effects on mechanical strength of pressurized CF slurries was dependent on HHP holding time. For example, only HHP-treated TCFL-15 sample had a G' value significantly higher than its HHP-treated RCFL-15 counterpart. On the other hand, lemon juice increased the G' values of the CF slurries after a shorter holding time, but decreased them after a longer HHP treatment.

From a comparison of the mean SAOS rheological properties at either 6.28 or 1 rad s^{-1} of the eight HHP-treated CF slurries (Table 3), it can be seen that CF slurry containing both toasted CF and lemon juice and pressurized for 15 min (TCFL-15 sample) showed the significantly highest G', G'_0, G'', and G''_0 values, while the lowest moduli were obtained for its counterpart HHP-treated for the longer holding time (TCFL-25 sample). The holding time effect on both G' and G'_0 values was only significant between pairs of HHP-treated CF slurries containing lemon juice, regardless of the flour type used. Both the RCFL-15 and the TCFL-15 samples had higher G', G'_0 and G'' values than their RCFL-25 and TCFL-25 counterparts pressurized for the longer time. In contrast, CF slurry made with toasted CF and without lemon juice and treated with HHP for 25 min (TCF-25 sample) had significantly higher G'' and G''_0 values than its TCF-15 counterpart. Thus it seems that the viscoelasticity of the HHP-treated CF slurries decreased with increasing holding time, which is primarily associated with the degree of HHP-induced starch gelatinization. At 50 °C and 15 min, HHP treatment at 600 MPa was sufficient to complete gelatinization of these CF slurries, especially when toasted CF was used, and subsequent microwave heating could probably also induce swelling and gelatinization of remnants of granules or remaining granules (temperature-induced gelatinization). However, a longer holding time could also produce a breakdown of granules, thus increasing amylopectin solubilization and resulting in a decrease in consistency (Thomas & Atwell, 1999). It was found that the degree of gelatinization of CF slurries estimated from enthalpy gelatinization (ΔH_{gel}) values was 100% for

CF slurries at a 1:5 flour-to-water ratio after HHP with 600 MPa and 25 °C for 15 min, reflecting complete starch gelatinization, while more concentrated slurries require higher pressures, temperatures or treatment times (Alvarez et al., 2014). However, a further factor to be taken into account is that denaturation of the protein component could also affect the rheological properties of the HHP-treated CF slurries. For example, it was possible to denature the protein components of lentil slurries completely by a combination of pressure and high temperature (Ahmed, Varshney, & Ramaswamy, 2009). Therefore, the decrease in elasticity observed in the TCFL-25 sample cannot be attributed solely to starch gelatinization or to unfolding of proteins; rather, it might be a result of a combination of these components. It also seems that the final microwave heating of the slurries pressurized for 25 min did not cause temperature-induced gelatinization.

With regard to the CF toasting effect, only the TCFL-15 slurry had significantly higher G', G'_0, G'', and G''_0 values than its counterpart formulated with raw CF (RCFL-15). Also, the G'', G''_0, and tan δ values of the TCF-25 sample were significantly ($P < 0.01$) higher than those of its RCF-25 counterpart (Table 3). Therefore, it seems that HHP-induced gelatinization partially masked the observed effect that the toasting treatment had on the viscoelastic properties of the unpressurized CF slurries (Table 2).

The slopes of the storage and loss moduli (n' and n'', respectively) from the regressions of all the HHP-treated CF slurries are also shown in Table 3. The magnitudes of the resulting straight lines were small, and after pressurization at 50 °C the n'' values were higher than the n' values, showing that G'' was more frequency-dependent than G' (Fig. 3). The two CF slurries prepared with added lemon juice and pressurized for 25 min had significantly higher n' and n'' values, in accordance with their slightly less solid-like behavior.

From a comparison of the *G*′ and *G*″ values of unpressurized and HHP-treated CF slurries (Tables 2 and 3) it is possible to see that after a pressurization treatment at 600 MPa and 50 °C, for either 15 or 25 min, the *G*′ and *G*″ values of the CF samples were always higher than those of the unpressurized controls, probably reflecting HHP-induced starch gelatinization and unfolding of proteins. However, there were differences in the extent of these phenomena induced by the pressure treatment, depending on the CF type used in the formulation. For example, HHP-treated CF slurries made with raw flour had *G*′ values between 2.8 and 4.2 times higher than the *G*′ values of the unpressurized slurries. In contrast, HHP-treated CF slurries made with toasted flour had lower gelatinization capability, with *G*′ values only between 1.2 and 2.5 times higher than those of the untreated slurries. The *G*′ value was 1618 Pa in unpressurized TCFL-0.1 slurry (Table 2), 4075 Pa in pressurized TCFL-15 slurry, and 1900 Pa in pressurized TCFL-25 slurry. Note that comparisons are performed between HHP-treated CF slurries and unpressurized ones with and without lemon juice separately. In CF slurries made with toasted CF, weaker products are formed in subsequent pressurization because there is weakening of the starch granule integrity by heat (Ikegwu et al., 2013), and the final products are formed by melting of the crystallites that remain undamaged, and also probably by HHP-induced structural changes at both the molecular and the sub-molecular level of the chickpea protein. HHP treatment has been shown to influence functional properties of proteins through disruption and reformation of hydrogen bonds and hydrophobic interactions leading to denaturation, aggregation, and gelation of proteins (Ahmed et al., 2009). Consequently, differences in elasticity increases between HHP-treated CF slurries formulated with raw and toasted CF are associated with higher water absorption capacity caused by the preceding CF toasting treatment.

3.3. Steady shear measurements of HHP-treated CF slurry

The apparent viscosity of the various HHP-treated CF slurries decreased with increase in shear rate, showing non-Newtonian shear-thinning behavior without a tendency to reach a yield stress value (Fig. S2). The flow behavior was expressed in terms of the Oswald de Waele or power law model ($R^2 > 0.997$). Oswald de Waele parameters and apparent viscosities at 1, 50, and 100 s^{-1}, as a function of formulation and holding time, are shown in Table 4. The flow behavior of all the pressurized CF slurries was qualitatively similar, and viscosity values decreased with holding time, with one exception. The consistency coefficient (K) increased significantly with holding time in the case of HHP-treated CF slurry made with raw CF and without lemon juice (RCF-15 vs. RCF-25 samples) (Table 4), although there were no significant differences between the flow index and the η_{a1}, η_{a50}, and η_{a100} values of the two samples. This result could indicate, therefore, that the process of gelatinization of the CF slurry made with raw CF and without added lemon juice remained incomplete after 15 min at 600 MPa and 50 °C (RCF-15 sample), and a longer holding time further increased the degree of HHP-induced starch gelatinization and/or protein gelation (RCF-25 sample), as evidenced by the increase in consistency and viscosity. Interestingly, however, HHP treatment at 600 MPa and 50 °C for 15 min seems to have been sufficient to nearly complete gelatinization of CF slurry made with raw CF and lemon juice (RCFL-15 sample), and with toasted CF either with or without lemon juice (TCFL-15 and TCF-15 samples), while longer holding times appear to break down starch granules, reducing the viscosity values in all three cases (Alvarez et al., 2014). The toasting treatment increasing water absorption capacity seems to help to achieve complete starch gelatinization with a treatment time of only 15 min.

On the other hand, the toasting effect was more significant at the shorter holding time, and both TCF-15 and TCFL-15 samples had significantly higher K and viscosity values at low shear rate (η_{a1}) than their corresponding counterparts made with raw CF, although only TCFL-15 also had significantly higher viscosity values at moderate and high shear rates (η_{a50} and η_{a100} values) than its RCFL-15 counterpart. However, the toasting effect also affected the η_{a50} and η_{a100} values of HHP-treated CF slurries pressurized for the longer holding time, which were significantly higher in the TCFL-25 sample than in the RCFL-25 one. Exceptionally, RCF-25 had significantly higher K and η_{a1} values and consequently a lower flow index than its TCF-25 counterpart, but this effect is associated with a hidden toasting effect as a consequence of the considerable starch gelatinization and protein denaturation that occurred during pressurization for 25 min. As can be seen in Table 4, of the eight HHP-treated CF slurries, the TCF-15 and TCFL-15 samples had the highest K, η_{a1}, η_{a50}, and η_{a100} values and the lowest n values, showing that the toasting effect seen in the unpressurized CF slurries (Table 2) was also detected after pressurization at 600 MPa and 50 °C for 15 min.

3.4. Instrumental texture measurements of HHP-treated CF slurry

Fig. 3 illustrates the effect that the CF slurry formulation and pressurization had on the firmness obtained in the cone penetration test. All three cone penetration parameters (firmness, work required per volume displaced, and average force) were high and positively correlated with each other according to the correlation coefficients (data not shown). The two HHP-treated CF slurries pressurized for 15 min and made with toasted flour were the firmest (TCF-15 and TCFL-15), while the firmness was significantly lower when the CF slurries were pressurized for 25 min

(TCF-25 and TCFL-25). In contrast, there were no significant differences between the firmness of the RCF-15 and RCF-25 samples. Probably, as a consequence of the additional 10 min of pressurization at 600 MPa and 50 °C, disintegration of the starch granular structure occurred, resulting in the formation of a weaker gel matrix after heating. Information gathered from the rheological and textural measurements needs to be related to other analyses (Alvarez et al., 2014), to characterize the degree of HHP-induced gelatinization and/or denaturation of starch and proteins of CF slurry in the presence of other ingredients.

It must also be mentioned that as the time of storage at 4 °C of the pressurized CF slurries increases (from 1 day to 2 months), starch retrogradation phenomena will probably occur, influencing their rheological properties and texture. For retrogradation studies, Stolt et al. (2001) reported that a 25% starch suspension pressurized at 550 MPa and 30 °C for 10 min induced a gel that, after 1 day of storage at 4 °C, showed a small broad peak – typical for retrogradation – in a differential scanning calorimetry (DSC) thermogram, and the enthalpy of the amylopectin crystals formed during storage increased with increasing storage time. Gel aging in HHP-treated CF slurries after refrigeration at 4 °C for 1 week was also supported by rheological measurements (Alvarez et al., 2015), and the retrogradation of pressure-induced CF slurries prior to temperature-induced gelatinization increased the gel strength. Other studies showed the presence of a residual crystalline order after HHP treatment, referred to as “rapid retrogradation,” occurring even during or immediately after pressurization (Stute et al., 1996; Vallons et al., 2014), and the greater the degree of gelatinization induced by the HHP treatment, the greater the extent of “rapid retrogradation.” Therefore, as the samples in the present work were stored, after HHP treatment, for 24 h at 4 °C prior to measurement, it is also possible that there was starch retrogradation in the HHP-treated CF slurry samples, affecting both rheological and textural measurements.

3.5. Color and protein content of HHP-treated CF slurry

Significant differences ($P < 0.01$) in both product color and protein content depended on the formulation and holding time (Table 5). RCFL-25 was the lightest-colored product while TCFL-25 was the darkest. The effect of toasting on lightness (L^*) was only significant after pressurization for 25 min. Both the TCF-25 and TCFL-25 samples had significantly lower L^* values than their counterparts made with raw CF, which could be clearly explained by the toasty brown color conferred by the CF toasting treatment, as also evidenced by the detection of a significant increase in both a^* and b^* values in these samples (TCF-15 vs. RCF-15, and TCF-25 vs. RCF-25). Between pairs of formulations, longer holding time reduced the a^* and b^* values (indicating significantly increased sample greenness and decreased yellowness, respectively) with respect to shorter treatment time. RCF-25, TCF-25, and RCFL-25 samples had a significantly lower protein content than their counterparts pressurized for 15 min, which is associated with a greater extent of protein aggregation, also determining the decrease found in the a^* and b^* values. It might be possible to denature the protein components of lentils completely by a combination of pressure and high temperature (Ahmed et al., 2009). On the other hand, the instrumental color analysis also revealed decreasing Hunter L^* and b^* values in the absence of lemon juice (Jiménez et al., 2016). Therefore, its presence gave rise to lighter-colored products.

3.6. Microbiological analysis

The effect of different formulations and holding times on the microbial population of the four selected HHP-treated CF slurries can be observed in Fig. 4, and compared with that of two of the untreated CF slurries. Microbial population counts in unpressurized CF slurries were determined only at 1, 7, and 14 days, as after 2 weeks of storage all the population counts were very high in comparison with those of the HHP-treated samples. For example, in the case of untreated CF slurries the high lactic acid bacteria counts (Fig. 4a) are due to fermentation of the samples. Note that some microbial populations decreased significantly after 2 weeks in refrigeration, such as enterobacteria and molds and yeast (Figs. 4b, 4c).

In contrast, the counts of both lactic acid bacteria and molds and yeast made after one day of pressurization were already below the detection limit (10 and 100 CFU g^{-1}, respectively) in the four HHP-treated samples, and they remained stable throughout the storage period. With respect to holding time, no significant decrease in the molds and yeast or the lactic acid bacteria counts was observed as a result of increasing the duration of the treatment. An increase in pressure is related to high microbial inactivation (Barcenilla, Román, Martínez, Martínez, & Gómez, 2016), but this relationship was not found at the time of treatment. On the contrary, at day 1 the pressurization did not induce changes in total enterobacteria or sulfite-reducing clostridia (anaerobic bacteria) populations in comparison with unpressurized CF slurries (Figs. 4b, 4d). However, throughout the storage period studied (up to 2 months), total enterobacteria counts of HHP-treated samples were below 10 CFU g^{-1}. In the HHP-treated CF slurries, the sulfite-reducing clostridia population presented a slight increase on day 14, although with final populations of 1.0 Log CFU g^{-1}. This increase may possibly be because a maximum pressure of

600 MPa was used, which was effective against the vegetative forms, but not against the sporulated ones (Téllez-Luis et al., 2001). The authors just cited reported that HHP can trigger spore germination. However, the mechanism whereby HHP triggers spore germination varies depending on the exact pressure used (Black et al., 2007), and this appears to be the major reason that HPP can result in spore killing. In addition, the authors just cited reported that very high pressures (400 to 800 MPa) do not trigger germination via the nutrient receptors. Therefore, in this study, sulfite-reducing clostridia spores whose germination was triggered by HHP may have been able to continue through of the stages of the germination during the first weeks of storage (Fig. 4d), but finally decreased due to that the spores were through outgrowth only slowly. F

Furthermore, *Salmonella* and *Listeria monocytogenes* were not detected (data not shown), while the others were within the accepted limits. Therefore, the results indicate that the HHP-treated CF products were microbiologically safe and free of pathogenic bacteria during a period of two months.

3.7. Consumer sensory analysis

Overall liking scores given by the consumers to each of the eight HHP-treated CF slurries are shown in Table 6. In terms of overall liking, the TCFL-25 sample was rated the highest (8.05), although the differences in comparison with any of the others were not significant ($P >$ 0.05) as the differences were very small (the maximum difference was 1.35/9 points). The HHP-treated CF slurries containing lemon juice were rated with scores considerably higher (always over 7.2) than those of their counterparts without lemon juice. This might be an indication that lemon may influence some aspects related to the perception of chickpea taste and flavor. The addition of lemon juice probably reduced the chickpea taste considerably, as observed previously (Jiménez at al., 2016). Differences in overall liking appear to be related mainly to the difference in the texture and the presence of an acid lemon taste. Although these differences were not significant, it seems clear that the consumers preferred a cream-like CF product to any of the others.

Table 6 also shows the type of product category into which each HHP-induced CF product was classified in accordance with the responses given by the consumers. The RCF-15, TCF-15, RCFL-15, RCF-25 and TCF-25 samples were classified as “CF purées” by 76%, 82%, 78%, 52%, and 74% of the consumers, respectively. Although the TCFL-15 sample was also considered a purée by 88% of the consumers, they said that its consistency was too strong. Curiously, whilst some consumers indicated that RCF-25 had just about the right purée consistency, over 48% of the consumers classified it as “CF cream”. Finally, the RCFL-25 and TCFL-25 products were considered “creams” by 77 and 90% of the consumers, respectively. According to the consumers’ liking criteria and homogeneity of response, the most acceptable formulation for this product type is a soft CF cream containing either toasted flour or lemon juice.

Conclusions

A new “fresh-looking”, nutritious, ready-to-eat HHP-treated (at 600 MPa and 50 °C) CF product requiring final quick microwave heating was developed with a total of eight possible combinations from a formulation that comprises raw or toasted chickpea flour, with or without lemon juice, pressurized for 15 or 25 min, microbiologically safe and stable for two months (at 4 °C). CF slurries formulated with toasted flour were firmer owing to temperature-induced starch gelatinization. However, the significance of the effect of either toasting or lemon juice on the mechanical strength of the HHP-treated CF products was dependent on the holding time and related to the extent of the degree of HHP-induced starch gelatinization and protein aggregation. Longer pressure–time treatments reduced the solid-like character of the HHP-induced CF products with added lemon juice. According to the consumers' liking criteria, storage and loss moduli (G', G'') of ~ 2200 and 240 Pa, a consistency index (K) of ~ 27 Pa s^n, apparent viscosities at 1, 50, and 100 s^{-1} (η_{a1}, η_{a50}, and η_{a100}) of ~ 23, 2.0, and 1.3 Pa s, respectively, and firmness, work required per displaced volume, and average penetration force of ~ 3.6 N, 1000 J m^{-3}, and 0.700 N, respectively, could be considered as threshold instrumental values for categorizing the products prepared in accordance with the different specifications given as a CF purée or a CF cream. Therefore, the application of HHP at 600 MPa and 50 °C for 25 min, adopted as a pre-processing instrument in combination with a microwave heating process, leads to the development of CF creams that possess a desirable soft consistency. Conversely, pre-processing at 600 MPa and 50 °C for 15 min may be a desirable feature for consumers who prefer a firm, solid-like CF purée.

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Supplementary material

Additional Supplementary material may be found in the online version of this article:

Fig. S1. Representation of the pressure and temperature vs. time variation during HHP treatments (600 MPa at 50 °C for 15 and 25 min).

Fig. S2. Effect of formulation and holding time on apparent viscosity changes versus shear rate of HHP-treated chickpea flour slurries. Mean values of six measurements ± standard deviation.

Figure captions

Fig. 1. Effect of formulation on the mechanical spectra of chickpea flour slurries. Mean values of six measurements ± standard deviation.

Fig. 2. Effect of formulation and holding time on the mechanical spectra of chickpea flour slurries HHP-treated for (a) 15 min, and (b) 25 min. Mean values of six measurements ± standard deviation.

Fig. 3. Effect of formulation and holding time on the firmness of HHP-treated chickpea flour slurries. $^{A\text{-}E}$ Comparison between all the HHP-treated chickpea slurries. $_{a,b}$ Holding time effect between pairs of HHP-treated chickpea slurries with identical formulation pressurized for 15 or 25 min. * Toasting effect between pairs of HHP-treated chickpea slurries pressurized during the same holding time. Mean values of six measurements ± standard deviation.

Fig. 4. Microbiological counts of untreated and HHP-treated chickpea flour slurries during two months of refrigerated storage. Expressed in colony-forming units per gram. (a) Lactic acid bacteria; (b) Total enterobacteria; (c) Molds and yeast; (d) Sulfite-reducing clostridia.

Table 1. Nomenclature of control CF slurries and HHP-induced CF products according to CF type, content of lemon juice and holding time.

Code	**Type**	**CF type**	**Lemon juice**	**Pressure level**	**Holding time**
RCF-0.1	CF slurry	raw	without	0.1 MPa	-
TCF-0.1	CF slurry	toasted	without	0.1 MPa	-
RCFL-0.1	CF slurry	raw	with	0.1 MPa	-
TCFL-0.1	CF slurry	toasted	with	0.1 MPa	-
RCF-15	CF product	raw	without	600 MPa	15 min
TCF-15	CF product	toasted	without	600 MPa	15 min
RCFL-15	CF product	raw	with	600 MPa	15 min
TCFL-15	CF product	toasted	with	600 MPa	15 min
RCF-25	CF product	raw	without	600 MPa	25 min
TCF-25	CF product	toasted	without	600 MPa	25 min
RCFL-25	CF product	raw	with	600 MPa	25 min
TCFL-25	CF product	toasted	with	600 MPa	25 min

CF, chickpea flour; HHP, high hydrostatic pressure.

Table 2. Oscillatory rheological properties at 6.28 rad s^{-1} (1 Hz) and power law parameters of unpressurized CF slurries.

CF slurries	G' (Pa)	G'' (Pa)	tan δ	G'_0 (Pa $s^{n'}$)	n'	R^2	G''_0 (Pa $s^{n''}$)	n''	R^2
RCF-0.1	$873.1 \pm 68.2^{B}_{b}$	$152.4 \pm 22.3^{B}_{b}$	$0.174 \pm 0.013^{B}_{a}$	$799.0 \pm 74.8^{B}_{b}$	$0.054 \pm 0.017^{C}_{a}$	0.967 ± 0.038	$127.4 \pm 24.0^{B}_{b}$	$0.129 \pm 0.024^{A}_{a}$	0.955 ± 0.026
TCF-0.1	$1673.3 \pm 212.5^{A}_{a}$	$314.8 \pm 31.99^{A}_{a}$	$0.189 \pm 0.007^{A,B}_{a}$	$1425.4 \pm 162.9^{A}_{a}$	$0.086 \pm 0.002^{A,B}_{a}$	0.999 ± 0.000	$246.7 \pm 39.8^{A}_{b}$	$0.143 \pm 0.025^{A}_{a}$	0.986 ± 0.005
RCFL-0.1	$674.6 \pm 171.7^{B}_{b}$	$154.2 \pm 54.5^{B}_{b}$	$0.225 \pm 0.023^{A}_{a}$	$597.2 \pm 125.6^{B}_{b}$	$0.059 \pm 0.015^{B,C}_{a}$	0.989 ± 0.003	$117.3 \pm 28.5^{B}_{b}$	$0.138 \pm 0.028^{A}_{a}$	0.957 ± 0.041
TCFL-0.1	$1618.0 \pm 258.9^{A}_{a}$	$373.4 \pm 38.4^{A}_{a}$	$0.233 \pm 0.023^{A}_{a}$	$1370.6 \pm 235.1^{A}_{a}$	$0.092 \pm 0.006^{A}_{a}$	0.999 ± 0.001	$290.1 \pm 31.8^{A}_{a}$	$0.145 \pm 0.005^{A}_{a}$	0.987 ± 0.017

Mean of six replications ± SD. Identification of chickpea flour (CF) slurries as shown in Table 1.

$^{A\text{-}C}$ Comparison between all the unpressurized chickpea flour slurries. For each viscoelastic property and power law coefficient, mean values without the same letter are significantly different ($P < 0.01$).

$_{a,b}$ Toasting effect between pairs of unpressurized chickpea flour slurries made with or without added lemon juice. For each viscoelastic property, mean values without the same letter are significantly different ($P < 0.01$).

G', storage modulus; G'', loss modulus; tan δ, loss tangent; G'_0, G''_0, n', and n'', regression coefficients relating G' or G'' and frequency (ω); R^2, determination coefficient of power law fits.

Table 3. Oscillatory rheological properties at 6.28 rad/s (1 Hz) and power law parameters of CF slurries HHP-treated at 600 MPa and 50 °C for 15 and 25 min.

HHP-treated CF slurries	**G' (Pa)**	**G'' (Pa)**	**tan δ**	**G'_0 (Pa s$^{n'}$)**	**n'**	**R^2**	**G''_0 (Pa s$^{n''}$)**	**n''**	**R^2**
RCF-15	$2650.0\pm 74.9^{B,C}_{a}$	$322.2\pm 28.5^{B,C}_{a}$	$0.121\pm 0.011^{A,B}_{a}$	$2238.2\pm 56.2^{B,C}_{a}$	$0.095\pm 0.007^{C}_{a}$	0.984 ± 0.012	$253.0\pm 2.8^{C}_{a}*$	$0.142\pm 0.006^{B}_{a}$	0.948 ± 0.038
TCF-15	$2437.0\pm 69.5^{C,D}_{a}$	$258.9\pm 8.2^{D,E}_{b}$	$0.106\pm 0.001^{C}_{b}$	$2124.8\pm 23.9^{B,C}_{a}$	$0.077\pm 0.005^{D}_{b}$	0.973 ± 0.010	$192.4\pm 4.6^{D,E}_{b}$	$0.164\pm 0.004^{A}_{a}*$	0.981 ± 0.011
RCFL-15	$2800.7\pm 9.3^{B}_{a}$	$288.0\pm 8.0^{C,D}_{a}$	$0.103\pm 0.003^{C}_{a}$	$2284.8\pm 52.1^{B}_{a}$	$0.103\pm 0.009^{C}_{a}$	0.972 ± 0.017	$236.9\pm 8.0^{C}_{a}$	$0.144\pm 0.010^{B}_{a}$	0.953 ± 0.021
TCFL-15	$4075.0\pm 122.5^{A}_{a}*$	$444.6\pm 44.8^{A}_{a}*$	$0.109\pm 0.008^{C}_{a}$	$3393.9\pm 108.2^{A}_{a}*$	$0.094\pm 0.008^{C,D}_{b}$	0.974 ± 0.014	$361.2\pm 25.0^{A}_{a}*$	$0.143\pm 0.010^{B}_{b}$	0.939 ± 0.017
RCF-25	$2445.0\pm 66.0^{C,D}_{a}$	$263.5\pm 7.2^{D}_{a}$	$0.108\pm 0.001^{C}_{a}$	$2079.2\pm 147.2^{C}_{a}$	$0.087\pm 0.008^{C,D}_{a}$	0.980 ± 0.022	$199.1\pm 24.9^{D}_{a}$	$0.177\pm 0.012^{A}_{a}*$	0.972 ± 0.015
TCF-25	$2791.0\pm 116.6^{B}_{a}$	$358.4\pm 17.2^{B}_{a}*$	$0.128\pm 0.006^{A}_{a}*$	$2202.1\pm 86.5^{B,C}_{a}$	$0.123\pm 0.007^{B}_{a}*$	0.981 ± 0.005	$293.3\pm 13.1^{B}_{a}*$	$0.127\pm 0.006^{B}_{b}$	0.978 ± 0.005
RCFL-25	$2274.5\pm 115.5^{D}_{b}$	$243.8\pm 9.0^{D,E}_{b}$	$0.107\pm 0.001^{C}_{a}$	$1729.3\pm 21.4^{D}_{b}*$	$0.129\pm 0.008^{A,B}_{a}$	0.958 ± 0.007	$189.6.0\pm 16.4^{D,E}_{a}$	$0.175\pm 0.007^{A}_{a}$	0.886 ± 0.074
TCFL-25	$1900.0\pm 126.0^{E}_{b}$	$211.4\pm 13.6^{E}_{b}$	$0.111\pm 0.0002^{B,C}_{a}$	$1421.9\pm 57.4^{E}_{b}$	$0.142\pm 0.005^{A}_{a}$	0.964 ± 0.017	$158.6\pm 9.8^{E}_{b}$	$0.181\pm 0.008^{A}_{a}$	0.975 ± 0.008

Mean of six replications ± SD. Identification of HHP-treated chickpea flour (CF) slurries as shown in Table 1.

$^{A\text{-}E}$ Comparison between all the HHP-treated chickpea slurries. For each viscoelastic property and power law coefficient, mean values without the same letter are significantly different ($P < 0.01$).

$_{a,b}$ Holding time effect between pairs of HHP-treated chickpea slurries with identical formulation pressurized for 15 or 25 min. For each viscoelastic property and power law coefficient, mean values without the same letter are significantly different ($P < 0.01$).

* Toasting effect between pairs of HHP-treated chickpea slurries pressurized the same holding time. For each viscoelastic property and power law coefficient, and for the same lemon juice level, mean values of the raw CF sample and its toasted CF counterpart are significantly different ($P < 0.01$).

G', storage modulus; G'', loss modulus; tan δ, loss tangent; G'_0, G''_0, n', and n'', regression coefficients relating G' or G'' and frequency (ω); R^2, determination coefficient of power law fits.

Table 4. Steady shear rheological parameters of CF slurries HHP-treated at 600 MPa and 50 °C for 15 and 25 min.

HHP-treated CF slurries	**K (Pa s^{n})**	**n**	**R^2**	**η_{a1} (Pa s)**	**η_{a50} (Pa s)**	**η_{a100}(Pa s)**
RCF-15	$50.1 \pm 1.58^{C}_{b}$	$0.244 \pm 0.009^{D}_{a}*$	0.998 ± 0.000	$46.7 \pm 1.07^{B,C}_{b}$	$2.47 \pm 0.010^{C,D}_{a}$	$1.44 \pm 0.004^{C-E}_{a}$
TCF-15	$80.7 \pm 6.53^{A}_{a}*$	$0.161 \pm 0.002^{F}_{b}$	0.999 ± 0.000	$76.9 \pm 6.94^{A}_{a}*$	$2.92 \pm 0.220^{B}_{a}$	$1.74 \pm 0.126^{B}_{a}$
RCFL-15	$46.1 \pm 0.276^{C}_{a}$	$0.228 \pm 0.011^{D}_{b}$	0.999 ± 0.000	$41.9 \pm 0.235^{C,D}_{a}$	$2.20 \pm 0.080^{D,E}_{a}$	$1.29 \pm 0.044^{E}_{a}$
TCFL-15	$85.5 \pm 2.34^{A}_{a}*$	$0.194 \pm 0.022^{E}_{b}$	0.998 ± 0.001	$81.4 \pm 3.39^{A}_{a}*$	$3.44 \pm 0.220^{A}_{a}*$	$2.02 \pm 0.143^{A}_{a}*$
RCF-25	$56.6 \pm 1.65^{B}_{a}*$	$0.232 \pm 0.005^{D}_{a}$	0.998 ± 0.000	$52.7 \pm 1.39^{B}_{a}*$	$2.67 \pm 0.097^{B,C}_{a}$	$1.56 \pm 0.052^{B,C}_{a}$
TCF-25	$38.9 \pm 0.294^{D}_{b}$	$0.294 \pm 0.002^{C}_{a}*$	0.999 ± 0.000	$35.7 \pm 0.345^{D}_{b}$	$2.39 \pm 0.042^{C,D}_{a}$	$1.46 \pm 0.035^{C,D}_{a}$
RCFL-25	$26.5 \pm 0.629^{E}_{b}$	$0.317 \pm 0.007^{B}_{a}$	0.998 ± 0.000	$23.5 \pm 0.635^{E}_{b}$	$1.80 \pm 0.008^{F}_{b}$	$1.10 \pm 0.006^{F}_{b}$
TCFL-25	$26.9 \pm 0.714^{E}_{b}$	$0.346 \pm 0.0003^{A}_{a}*$	0.998 ± 0.000	$23.5 \pm 0.855^{E}_{b}$	$2.09 \pm 0.018^{E}_{b}*$	$1.32 \pm 0.006^{D,E}_{b}*$

Mean of six replications ± SD. Identification of HHP-treated chickpea flour (CF) slurries as shown in Table 1.

$^{A-E}$ Comparison between all the HHP-treated chickpea slurries. For each steady shear parameter, mean values without the same letter are significantly different ($P < 0.01$).

$_{a,b}$ Holding time effect between pairs of HHP-treated chickpea slurries with identical formulation pressurized for 15 or 25 min. For each steady shear parameter, mean values without the same letter are significantly different ($P < 0.01$).

* Toasting effect between pairs of HHP-treated chickpea slurries pressurized the same holding time. For each steady shear parameter, and for the same lemon juice level, mean values of the raw CF sample and its toasted CF counterpart are significantly different ($P < 0.01$).

K, consistency index; n, flow behavior index; R^2, determination coefficients of power law fits. η_{a1}, η_{a50}, η_{a100}, apparent viscosity at 1, 50, and 100 s^{-1}, respectively.

Table 5. Color parameters and protein content of CF slurries HHP-treated at 600 MPa and 50 °C for 15 and 25 min.

HHP-treated CF slurries	***L****	***a****	***b****	**Protein (%)**
RCF-15	$61.4\pm0.135^{D}_{a}$	$0.937\pm0.021^{B}_{a}$	$15.8\pm0.061^{D}_{a}$	$4.55\pm0.031^{B}_{a}$
TCF-15	$61.1\pm0.047^{D}_{a}$	$1.05\pm0.015^{A}_{a}*$	$16.3\pm0.072^{B}_{a}*$	$4.63\pm0.013^{A}_{a}$
RCFL-15	$62.8\pm0.042^{B}_{b}$	$1.10\pm0.015^{A}_{a}$	$17.0\pm0.040^{A}_{a}$	$4.42\pm0.045^{C}_{a}$
TCFL-15	$62.0\pm0.446^{C}_{a}$	$1.07\pm0.026^{A}_{a}$	$17.0\pm0.066^{A}_{a}$	$4.38\pm0.042^{C}_{a}$
RCF-25	$61.5\pm0.212^{C,D}_{a}*$	$0.723\pm0.015^{D}_{b}$	$14.9\pm0.036^{F}_{b}$	$4.39\pm0.025^{C}_{b}$
TCF-25	$60.0\pm0.015^{E}_{b}$	$0.967\pm0.006^{B}_{b}*$	$15.9\pm0.182^{C,D}_{a}*$	$4.53\pm0.032^{B}_{b}*$
RCFL-25	$63.6\pm0.106^{A}_{a}*$	$0.847\pm0.050^{C}_{b}$	$16.1\pm0.110^{B,C}_{b}*$	$4.26\pm0.018^{D}_{b}$
TCFL-25	$61.4\pm0.403^{C,D}_{a}$	$0.853\pm0.040^{C}_{b}$	$15.5\pm0.100^{E}_{b}$	$4.39\pm0.024^{C}_{a}*$

Mean of six replications ± SD. Identification of HHP-treated chickpea flour (CF) slurries as shown in Table 1.

$^{A\text{-}E}$ Comparison between all the HHP-treated chickpea slurries. For each parameter, mean values without the same letter are significantly different ($P < 0.01$).

$_{a,b}$ Holding time effect between pairs of HHP-treated chickpea slurries with identical formulation pressurized 15 or 25 min. For each parameter, mean values without the same letter are significantly different ($P < 0.01$).

* Toasting effect between pairs of HHP-treated chickpea slurries pressurized the same holding time. For each parameter and for the same lemon juice level, mean values of the raw CF sample and its toasted CF counterpart are significantly different ($P < 0.01$).

Table 6. Overall liking and product category in accordance with consistency perception performed by the consumers for the chickpea flour slurries HHP-treated at 600 MPa and 50 °C for 15 and 25 min.

HHP-treated chickpea slurries	**Overall liking**	**Product category**
RCF-15	$6.45 \pm 1.75^{A}_{a}$	purée (*n*=38)
TCF-15	$6.70 \pm 2.20^{A}_{a}$	purée (*n*=41)
RCFL-15	$7.45 \pm 1.55^{A}_{a}$	purée (*n*=39)
TCFL-15	$7.20 \pm 1.60^{A}_{a}$	too strong purée (*n*=44)
RCF-25	$7.20 \pm 1.20^{A}_{a}$	purée (*n*=26)
TCF-25	$7.15 \pm 1.55^{A}_{a}$	purée (*n*=37)
RCFL-25	$7.40 \pm 1.40^{A}_{a}$	cream (*n*=39)
TCFL-25	$8.05 \pm 0.85^{A}_{a}$	cream (*n*=45)

Identification of HHP-treated chickpea flour (CF) slurries as shown in Table 1.

^{A} Comparison between all the HHP-treated chickpea slurries. Mean values without the same letter are significantly different ($P < 0.05$).

$_{a}$ Holding time effect between pairs of HHP-treated chickpea slurries with identical formulation pressurized for 15 or 25 min. Mean values without the same letter are significantly different ($P < 0.05$).

* Toasting effect between pairs of HHP-treated chickpea slurries pressurized the same holding time. For overall liking and for the same lemon juice level mean values of the raw CF sample and its toasted CF counterpart are significantly different ($P < 0.05$).