Physicochemical and rheological properties of gluten-free blends containing differently treated chickpea flours

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Abstract

This study focused on the evaluation of the physicochemical and rheological properties of chickpea flours and blends obtained by partially substituting rice flour (25%) with raw, roasted and dehulled chickpea flour. The characteristics of the resultant doughs were evaluated. In comparison with rice flour, blends containing chickpea flours exhibited high protein and fat content, a reduced retrogradation tendency (setback values of 404-415 vs. 479 BU) and a higher foaming capacity and stability, which can be beneficial for their use in baked food formulations. However, roasting decreased foaming capacity and stability. Even if the rheofermentographic test evidenced a slight reduction in dough development, high CO_2 retention capacity (> 98%) and similar-to-lower leavening times were observed for doughs containing chickpea flours. Incorporating chickpea flours also caused an increase in the viscous and elastic moduli of rice-based doughs, resulting in a good structuring of the dough. The results of this study indicated that chickpea flours could be used as a healthy ingredient in gluten-free rice-based formulations.

Keywords: Gluten-free dough; chickpea flour; physicochemical properties; dough viscoelasticity

1. Introduction

Gluten, a viscoelastic protein complex formed following the kneading process of wheat, rye or barley, may cause health problems such as celiac disease (CD), wheat allergy and non-celiac gluten sensitivity in a broad spectrum of populations. Among these disorders, CD is an autoimmune metabolic disease occurring in 1% of population worldwide (Reilly

& Green, 2012). In CD patients, the consumption of gluten-containing foods leads to damage of the small intestine with a consequent reduction in the absorption of nutrients. The remedy for celiac and other gluten-related diseases is to exclude gluten from the diet. The gluten-free (GF) diet is a real challenge, especially for celiac patients, since very low amounts of gluten can trigger the symptoms.

In the last few decades, despite some improvements in the technological and nutritional quality of GF bread (Alvarez-Jubete, Auty, Arendt, & Gallagher, 2010; Cappa, Barbosa-Cánovas, Lucisano, & Mariotti et al., 2016; Cappa, Lucisano, & Mariotti, 2016; Mariotti, Lucisano, Pagani, & Ng, 2009; Mariotti et al., 2017), the protein enrichment of GF bread is still a research target for GF producing companies. Thus, the use of legumes is nowadays considered a promising strategy for GF bread production with enhanced nutritional properties.

Legumes are plants of the Leguminosae family, which are mostly planted for their seeds called pulses such as peas, beans, chickpeas, lentils and cowpeas (FAO, 2016b). Recently, pulses are of increasing interest due to their nutritional benefits (e.g., high levels of proteins, complex carbohydrates, micronutrients and vitamins), and thus their consumption is highly recommended. Indeed, 2016 was declared the International Year of Pulses by the United Nations. Apart from their consumption as a whole seed, pulses are used, after milling, in many food formulations (e.g., bakery products, pasta, baby foods, etc.).

Chickpeas, one of the most important pulses, are mostly produced in Turkey, India, Australia and Pakistan (FAO, 2016a). Chickpeas can be consumed as grains, meal or snack. A special type of roasted chickpea snack, which is widely consumed in Turkey and countries nearby, is called leblebi. During leblebi-processing several steps such as tempering, moistening, resting and roasting are applied (Coşkuner & Karababa, 2004) and the hulls of the chickpea seeds are almost completely removed. Moreover, some chickpeas are split in half during processing and separated from the whole seeds as by-products. After milling, these broken parts could be introduced in different food formulations (e.g., bakery products, desserts, soups, etc.) as a cheap, sustainable and nutritious ingredient.

To date, few studies related to the evaluation of doughs containing chickpea flour alone or blended with other ingredients have been published (Aguilar, Albanell, Minarro, & Capellas, 2015; Burešová, Kráčmar, Dvořáková, & Středa, 2014; Ouazib, Garzon, Zaidi, & Rosell, 2016). Furthermore, to the best of our knowledge, no comprehensive study has been published related to the evaluation of the properties of doughs containing chickpea flours in combination with rice flour.

The aim of this study was to evaluate the physicochemical properties of raw, dehulled and roasted chickpea flours and to study the effects of their addition to a rice flour-based dough. During the production of roasted chickpeas, heat was applied and hulls were almost completely removed. For this reason, raw and dehulled chickpea flours were also included in the experimental plan in order to assess the effect of the roasting. Dough containing 100% rice flour was considered as reference.

2. Materials and methods

2.1. Materials

The flours used were rice flour (RF; Beneo-Remy NV, Leuven-Wijgmaal, Belgium), roasted (RCF), dehulled (DCF; Homecraft Pulse 4101, Ingredion, Germany) and raw

(CF) chickpea flours. RCF and CF were obtained from a local market and milled by a laboratory mill to obtain flours having particle size ≤ 1 mm. The other ingredients used in the dough were hydroxypropyl methyl cellulose (HPMC, Benecel F4M, Ashland, USA), instant yeast (Pakmaya, Istanbul, Turkey), sugar, salt and sunflower oil.

2.2. Design of experiments

In order to evidence the effects of raw, roasted and dehulled chickpea flours on a rice flour-based dough, the physicochemical properties of RF, CF, RCF, DCF were first assessed. According to preliminary trails and the results of a previous study (Kahraman, 2016), three flour blends composed of 75.15% RF and 24.85% CF, RCF or DCF and their respective bread doughs (RF+CF, RF+RCF and RF+DCF) were prepared and characterized.

2.3. Flour and blends properties

2.3.1. Proximate composition and particle size distribution

The moisture content of the flour samples was determined via oven drying at 105 °C until a constant weight was reached. The total nitrogen content of samples was determined according to the Official Standard Method AOAC 920.87 (AOAC, 1999) by using a block digestion system (Kjeldatherm, C. Gerhardt GmbH & Co. KG, Germany) and a distillation system (Vapodest 50s, C. Gerhardt GmbH & Co. KG, Germany). Protein content was calculated using 5.95 and 6.25 as conversion factors for rice and chickpea flours, respectively. For fat content determination, flour samples (4 g) were extracted with n-hexane (Sigma-Aldrich, Germany) by using an automatic extraction system (Soxtherm, Gerhardt, Germany). Ash content was analyzed according to AACC (1999) by using a muffle furnace (Protherm, Turkey). The evaluations were done at least in duplicate and the results were expressed as percentages on a dry basis (db).

For the flour particle size distributions, 50 g of sample was placed in an analytical sieve shaker (Octagon Digital, Endecotts Ltd., England) equipped with 6 sieves with 40, 90, 125, 250, 500 and 1000 µm openings. Plastic balls having diameters of 3 cm were placed on sieves in order to facilitate sample distribution. Each fraction was collected after sieving at amplitude 8 for 10 min. Results are the average of two determinations and are given as percentages of each fraction per 100 g flour.

2.3.2. Scanning electron microscopy (SEM) analysis

In order to investigate the effects of the different treatment on the flour microstructure the images of flours were captured by scanning electron microscope (XL 30S FEG, Philips) under a voltage of 2.0 kV. Double-sided carbon tape having flour samples on one side was attached to an aluminum stub and coated with gold under vacuum (0.09 mbar).

2.3.3. Water binding capacities and foaming properties

To assess water binding capacity (WBC) of blends and RF, each sample (2 g) was mixed with deionized water (24 mL), shaken for 60 min (KS 130 Basic, IKA, Germany) and centrifuged at 3460 x g at 25 °C for 10 min (Universal 320R, Hettich, Germany). The supernatant was carefully discarded and the weights of the tubes were recorded. The results (average of at least two measurements) were given as percentages of water held by the dry sample.

Foam capacity (FC) and stability (FS) of blends and RF were determined according to Shevkani, Singh, Kaur, & Rana (2015) with some modifications. The sample (2 g) was mixed with deionized water (50 mL) and homogenized for 2 min (Ultra-Turrax T 25, 18G Dispenser, IKA, Germany). FC (%) was calculated as the volume ratio of foam and initial volume, and FS (%) was given as the ratio of foam volume measured after 60 min with respect to initial foam volume. At least three replications were performed.

2.3.4. Pasting properties

Blends and RF were analyzed for their pasting properties by using Brabender® Micro-Visco-Amylograph (MVA) (Brabender OHG, Duisburg, Germany) according to Cappa et al. (2013). Sample slurry was prepared by dispersing sample (12 g) in distilled water (100 mL), scaling sample and water weight on 14% sample moisture basis. The measured indices were: gelatinization temperature (GT, °C; temperature at which an initial increase in viscosity occurs); peak viscosity (PV, Brabender units, BU; maximum paste viscosity achieved during heating), breakdown (BD, BU; viscosity decrease index while kept at 95 °C); final viscosity (FV, BU; paste viscosity at the end of the cooling), and setback (SB, BU; index of the viscosity increase during cooling). The analysis was performed in triplicate.

2.4. Dough preparation

The doughs (RF, RF+CF, RF+RCF and RF+DCF) were prepared by using the Brabender Farinograph (Brabender OHG, Germany). In addition to RF or flour blends, the bread dough formulation included HPMC (1.72%), sugar (2%), salt (1.5%), instant yeasts (2.5%), sunflower oil (5.27%) and water. All these percentages were based on flour weight. The amount of water added to each formulation was determined in order to achieve a dough consistency of 125±5 BU (Kahraman, 2016). Dry components (rice flour or blends, HPMC, instant yeast, sugar and salt) were added to the farinograph bowl (300 g capacity) and mixed for 1 min. Then, within 2 min, part of the water, vegetable oil and the remaining water were added. The dough was eventually mixed for 8 min at 25 °C and consistency was recorded.

2.5. Dough evaluation

2.5.1. Leavening properties

The leavening behavior of the dough samples was evaluated with a Chopin Rheofermentometer F3 (Chopin, Villeneuve-La-Garenne, Cedex, France) according to a method developed for gluten-free dough samples (Cappa et al., 2013). The proofing was carried out at 30 °C for 60 min. Maximum and final heights (Hm and Hf, mm) of the doughs, time necessary to reach maximum height (T1, min), time for dough porosity to appear (Tx, min), total CO_2 production ($CO_{2\text{-TOT}}$, ml), CO_2 retention ($CO_{2\text{-RET}}$, ml), released CO_2 ($CO_{2\text{-REL}}$, ml) and coefficient of retention (Rc, %) were measured.

As a parallel test to the rheofermentometric test, the leavening properties of dough samples were measured by using image analysis with the method developed by Cappa et al. (2013). The dough area increase (%) during proofing time was calculated. Six petri dishes per each sampling time (every 10 min) were analyzed.

2.5.3. Rheological properties

The fundamental rheological behavior of the dough was studied by dynamic oscillatory measurements performed on a Physica MCR300 Rheometer (Anton Paar, Graz, Austria). The measurements were carried out with a corrugated parallel plate system (PP25/P2, diameter: 25 mm) having a gap of 2 mm. The dough samples were prepared and rested for 60 min at 25 °C before each measurement. The instant yeast was not included in the formulations to avoid perturbation of the system. The dough was loaded between the plates and the excess amount was trimmed off. In order to avoid moisture loss during analysis, a humidity cover (H-PTD 150) having a water trap and wet pads was used, and mineral oil was carefully applied to dough borders. After five minutes of resting to relax stresses, the measurements were carried out and the data were recorded by using Universal Software US200 (version 2.5) (Anton Paar, Ostfildern, Germany). The strain sweep test was performed at a constant frequency of 1 Hz and in the range of 0.01-100% strain to determine the maximum strain amplitude at which the viscoelastic properties such as G' and G'' were independent of strain (linear viscoelastic region). According to strain sweep tests, 0.04% strain was selected as the strain amplitude for all the doughs analyzed. Frequency sweep tests were carried out in the range of 10 to 0.1 Hz at a constant strain of 0.04%. For both tests, storage modulus (G′, Pa), loss modulus (G″, Pa) and damping factor (tan δ, the ratio of G″ to G′) were calculated. For each formulation, the analysis was performed on two separate doughs, each having at least two replications.

2.6. Statistical evaluation

Statistical evaluation of the data was performed by using MINITAB 16 (Minitab Inc., U.S.). The results were given as “mean ± SD”. The significance of the data was tested by analysis of variance (ANOVA) at $p<0.05$ and, in the significant models, means were compared by Tukey’s test at 95% confidence interval.

3. Results and discussion

3.1. Flour and blend physicochemical properties

3.1.1. Proximate composition and particle size distribution

The proximate composition of rice and chickpea flours is listed in Table 1. The chickpea flours resulted richer in protein, fat and ash in comparison to RF. In particular, the protein content of chickpea flours was approximately three times the RF amount thus making the addition of chickpea flours into GF formulations an interesting strategy to increase the protein content of GF products. The fat content was comparable to the values reported by Alajaji & El-Adawy (2006) and Kaur, Singh, & Sodhi (2005). It must be emphasized that chickpea contains a higher level of linoleic and oleic acid and polyunsaturated fatty acids (PUFA) (Jukanti, Gaur, Gowda, & Chibbar, 2012) in comparison with other pulses. Comparing the different chickpea treatments, since heat was applied during the roasting process, RCF showed almost three times lower moisture content than CF. Also the dehulling process resulted in a reduction of moisture, but to a lower extent than roasting. Even if some modifications in carbohydrates and proteins were reported by Coşkuner & Karababa (2004), roasting caused no statistical change in the amount of protein. No significant changes in protein content, as well as in ash and fiber, during roasting processing were previously observed by Sağlam (2006). the removal of hulls, rich in minerals, caused a 25% reduction in ash as evidenced by Ghavidel & Prakash (2007). Incorporating unconventional flours in baked products has to consider the particle size distribution of the new ingredients as it may affect some properties such as the hydration rate and the pasting behavior. The particle size distribution of the flours was quite different and covered a wide range ($90 \geq x > 500$ µm). In general, the chickpea flours had a larger particle size than RF. In fact, if the sample particle size is divided into two classes (i.e., below or higher 250 µm), the flours could be ranked as CF (24% fine particles) > RCF (48% fine particles) > DCF (55% fine particles) > RF (85% fine particles). The particle size distribution may be affected by the structure of the seed and the milling process (Schober, 2009). Comparing the two samples milled on laboratory scale (CF and RCF), the effect of the roasting process on the chickpea structure appears clear: due to the expansion of air, gas cells are formed inside the seed. The presence of air gaps made the seed very brittle and after milling, the resulting flour consisted of smaller particles.

3.1.2. Microstructure

The scanning electron micrographs of RF and chickpea flours can be seen in Figure 1. According to micrograph, the granule sizes of starches ranged from 5 to 12 µm (average size: 10 µm) for RF, from 13 to 30 µm (average size: 22 µm) for CF, from 14 to 26 µm (average size: 19 µm) for RCF, and from 11 to 27 µm (average size: 19 µm) for DCF. Previously, average granule sizes of 19-35 µm and 19-26 µm for raw and roasted pulse flours were reported, respectively (Ma et al., 2011). As seen in Figure 1 rice starch granules had a polyhedral shape and, although large granules (≤12 µm) were observed, they were smaller and in aggregated form in comparison with chickpea granules. Chickpea flours (CF, RCF, DCF), on the other hand, exhibited starch granules of spherical shapes covered with protein fragments. For all samples, intact starch granules were detected, although partial gelatinization of starch occurred in RCF, suggesting the roasting and dehulling treatments do not affect starch granula organization so much. Similarly, Köksel, Sivri, Scanlon, & Bushuk (1998) stated that starch was not completely gelatinized during roasting due to limited kernel hydration.

3.1.3. Water binding capacity and foaming properties

The addition of CF, RCF, and DCF to RF caused a slight decrease in WBC (Figure 2), which was significant ($p<0.05$) only for DCF. In the literature it is reported that flour having small particle size has high water binding capacity (Kim & Shin, 2014) and this behavior has been related to the greater specific surface area of the flour. However, DCF, the chickpea flour with the smallest particle size, had the lowest water binding capacity.

This contradictory finding can be attributed to husk removal during the dehulling process and thus to the different sample composition (Table 1). Since husks are sources of non-starch polysaccharides and proteins, their removal might have modified flour water binding capacity and dough rheology (Witczak, Ziobro, Juszczak, & Korus, 2015).

As in GF dough production, the absence of gluten penalizes dough structuring, hydrocolloids and proteins are often used for their property of binding water, and foaming capacity. The foaming capacity and stability of RF and chickpea blends are reported in Figure 2. Increased foam formation was observed in chickpea-containing blends ($p<0.05$). However, RF+RCF showed significantly lower FC compared to CF and DCF containing blends. The reduced foaming capacity of roasted chickpeas in comparison to the raw chickpea flour was previously reported by Ma et al. (2011) and related to the lower solubility of proteins as a result of the heat treatment.

As regards foam stability, rice flour exhibited no detectable foam after 60 min at room temperature; whereas the replacement of 24.85% of RF with chickpea flours highly improved foam stability. These findings are promising as the chickpea flours here are suggested as ingredients for GF bread dough in which a high capacity to retain leavening gas during baking is desirable. Of all the chickpea-containing samples, RF+RCF exhibited the lowest foam stability. Conversely, Ma et al. (2011) did not find any difference between raw and roasted chickpea flours in terms of foam stability. This can be related to the procedure of the roasting process; in this study, roasting was directly applied to whole chickpea seeds and a heating and a roasting process was applied in sequence instead of one stage of roasting, as carried out on flour by Ma et al. (2011).

3.1.4. Pasting properties

The pasting curves of RF and blends (*data not shown*) were characterized by an increase in viscosity upon heating, since starch granules started to uptake water and swelled, and then a paste was obtained. During the holding period at 95 °C the starch gel viscosity decreased due to the shearing force applied. With cooling, the reordering of starch molecules caused a new increase in viscosity. This trend was displayed by all samples but to different extents. The pasting curve indices are reported in Table 2. It is well known that the pasting properties are mainly affected by the quantity and quality of starch and by flour particle size (Kim & Shin, 2014). All blends, in comparison to RF, exhibited lower peak, final viscosity, breakdown and setback values. This behavior is mainly due to the composition of chickpea flours and it indicates that the addition of chickpea flour, besides producing a lower strength gel, may slow down paste retrogradation (i.e., low SB) and thus limit the staling of baked food.

Of the three chickpea-containing blends, the maximum viscosity reached during the heating period (PV) and the final viscosity were lower for RF+RCF, which indicates that roasting had a slight effect on starch gelatinization in accordance with the scanning images. It is to note that roasting was performed with the addition of a small amount of water and thus the heat treatment did not exhibit a relevant effect on pasting behavior.

3.2. Dough properties

In order to reach the desired (125±5 BU; Kahraman, 2016) dough consistency, and in accordance with the WBC data, RF+ DCF required less water in comparison to the other dough (90.07% vs. 101.14%, 99.47%, 104.70%, for RF+DCF, RF, RF+CF, RF+RCF, respectively). These differences are related to flour composition and to their ability to adsorb water, as previously discussed.

3.2.1. Dough proofing properties

The best leaving preformance in terms of maximum and final dough height was evidenced by RF dough (Table 3). This is in accordance with the general findings that flour ingredients containing fiber – such as chickpea flours – resulted in weak dough structure. However, the CO_2 retention capacity of RF+RCF (99.0%) was higher than RF+CF (97.9%) and RF+DCF (98.1%), and slightly lower than RF (99.4%). This suggests a slight weakening of the dough containing chickpea flours, which were in any case able to retain the majority of the CO_2 produced by the yeast. The advantages of using chickpea flours can be seen in terms of leavening time before the dough porosity appearance (Tx) and total CO_2 produced. In fact, for the three formulations containing chickpea flours, the production of CO_2 was 5-12% higher than in RF. This can be due to the faster action of the yeast in these samples, presumably due to a higher amount of sugars (10.85 g sugar/100 g chickpea flour; 0.12 g sugar/100 g rice flour) (USDA, 2016). Accordingly, RF+CF and RF+DCF were also characterized by an earlier appearance of Tx, thus a shorter leavening process is recommended for their baking.

Dough leavening behavior was also monitored by means of image analysis. This technique has been proposed as an alternative tool to the Rheofermentometer by evaluating dough development as an increase in dough area (Cappa et al., 2013). All doughs were able to increase their area (up to a maximum value of 114% after 60 min of proofing) and for each formulation, the dough area increase during leavening was highly correlated to the values of dough height obtained from the Rheofermentometer test ($R^2 \geq 0.989$), suggesting that both tests can be used to study dough development.

3.2.2. Dough rheology

Even if the deformation applied during the dynamic test are often very different from those experienced by the dough during real processing (i.e., mixing, leavening, baking), these measurements provide unique information about the viscoelastic characteristic of the dough by preserving the dough structure during the test; thus, the viscoelastic properties measured can be used to compare different dough formulations. The strain sweep test was firstly performed to delineate the region of linear viscosity in order to define when dough characteristics do not depend on the magnitude of the deforming strain. For all the samples, G' and G" remained almost constant at least up to 0.04% strain (*data not shown*). Beyond this limit, the storage and loss moduli decrease, indicating a progressive destruction of the dough structure. Similar limits of linear viscoelasticity were found in the literature for GF doughs (Mariotti et al., 2009).

According to the region of linear viscosity, the frequency sweep test was performed at a constant strain of 0.04%, in the range of 10 to 0.1 Hz. Frequency sweep curves are reported in Figure 3. Although all the dough samples had the same final farinographic consistency (125±5 BU), they differed in terms of fundamental rheological properties. According to Mariotti et al., 2009, no relationships were found between the different water levels in the GF doughs and the values of their respective dynamic moduli. For all dough formulations, G' values were higher than G" to indicate a solid-like behavior. This behavior is in agreement with the literature regarding the rheology of GF batters (Hüttner, Bello, & Arendt, 2010; Mariotti et al., 2009; Sciarini, Ribotta, León, & Pérez, 2012) and gels (Cappa et al., 2016). The addition of chickpea flours to rice dough formulations caused an increase in both G' and G". In particular, CF and DCF showed the highest values for all frequencies investigated and RCF had an intermediate behavior in comparison to RF. A similar increase in G' and G" was previously observed after the addition of chickpea flour (Aguilar et al., 2015) in starch-based gluten-free dough. The damping factor was lower than 1 at all frequencies indicating the prevalence of a solid-like behavior and was slightly affected by the addition of chickpea flour as it remained constant for all formulations; in particular values of 0.41±0.02, 0.41±0.02, 0.42±0.02, 0.37±0.01 for RF, RCF+RF, CF+RCF and RF+DCF respectively, were obtained at 1 Hz.

4. Conclusions

The nutritional quality of food products is drawing considerable interest due to the increasing awareness of healthy diet. The use of pulse flours in food formulations is becoming an interesting strategy due to the important nutritional benefits of pulses. In this study, the effects of roasted, dehulled and raw chickpea flour when added (25%) to rice dough formulations were evaluated. Besides increasing protein and fat content, the addition of all types of chickpea flours created positive effects on the technological performance of the doughs. Although the dough development of the formulations containing chickpea flours was slightly lower than the reference samples, high CO_2 retention was evidenced and shorter leavening times were necessary to obtain maximum dough development. Also the viscoelastic properties of the dough were positively affected; higher storage moduli were obtained for the samples containing raw and dehulled chickpea flours. Furthermore, the viscoamylographic test indicated a slower retrogradation tendency of the slurry containing chickpea flours, which is a promising result for baking food applications. This study showed the potential of using raw, dehulled and roasted chickpea flour in combination with rice flour in gluten-free bread formulations.

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Declaration of conflict of interest

The Authors declare that there is no conflict of interest.

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Table 1

Table 1. Proximate composition of rice and chickpea flours

Sample	Moisture (%)	Protein (% db)	Fat (% db)	Ash (% db)
RF	11.85 ± 0.09^{a}	8.29 ± 0.18^{c}	1.28 ± 0.19^{c}	0.68 ± 0.00^{b}
CF	9.15 ± 0.06^{b}	23.52 ± 0.30^{a}	5.71 ± 0.24^{b}	3.09 ± 0.01^{a}
RCF	3.25 ± 0.06^{d}	23.10 ± 0.79^{a}	7.57 ± 0.08^{a}	2.68 ± 0.03^{a}
DCF	7.12 ± 0.00^{c}	21.15 ± 0.41^{b}	7.55 ± 0.05^{a}	2.32 ± 0.77^{a}

RF, rice flour; CF, chickpea flour; RCF, roasted chickpea flour; DCF, dehulled chickpea flour.
Values are mean ± SD.
Means having different letters in the same column are significantly different ($p<0.05$).

Table 2

Table 2. Pasting properties

Sample	GT (°C)	PV (BU)	BD (BU)	SB (BU)	FV (BU)
RF	77.15 ± 0.07^{bc}	716.50 ± 7.78^{a}	326.50 ± 12.02^{a}	478.50 ± 9.19^{a}	868.50 ± 13.44^{a}
RF+CF	76.80 ± 0.14^{ab}	503.50 ± 2.12^{b}	196.50 ± 6.36^{b}	410.00 ± 4.24^{b}	717.00 ± 0.01^{b}
RF+RCF	77.60 ± 0.01^{a}	435.50 ± 12.02^{c}	161.50 ± 9.19^{c}	404.00 ± 7.07^{b}	678.00 ± 9.90^{c}
RF+DCF	77.40 ± 0.14^{c}	498.00 ± 5.66^{b}	164.00 ± 4.24^{bc}	415.00 ± 5.66^{b}	749.00 ± 4.24^{b}

RF, rice flour; CF, chickpea flour; RCF, roasted chickpea flour; DCF, dehulled chickpea flour; GT, gelatinization temperature; PV, peak viscosity; BD, breakdown; SB, setback; FV, final viscosity. Values are mean ± SD. Means having different letters in the same column are significantly different ($p<0.05$).

Table 3

Table 3. Dough proofing properties

Sample	Hm (mm)	Hf (mm)	Tx (min)	$CO_{2\text{-TOT}}$ (mL)	$CO_{2\text{-REL}}$ (mL)	$CO_{2\text{-RET}}$ (mL)	Rc (%)
RF	49.2	49.2	>60	783	5	779	99.4
RF+CF	41.3	36.9	40.5	875	18	857	97.9
RF+RCF	41.7	35.8	>60	821	8	812	99.0
RF+DCF	43.2	41.0	45.0	879	17	862	98.1

RF, rice flour; CF, chickpea flour; RCF, roasted chickpea flour; DCF, dehulled chickpea flour; Hm, dough maximum height; Hf, dough final height; Tx, time of dough porosity appearance; $CO_{2\text{-TOT}}$, total gas production; $CO_{2\text{-REL}}$, CO_2 released by the dough; $CO_{2\text{-RET}}$, CO_2 retained by the dough; Rc, gas retention coefficient.

Figure 1

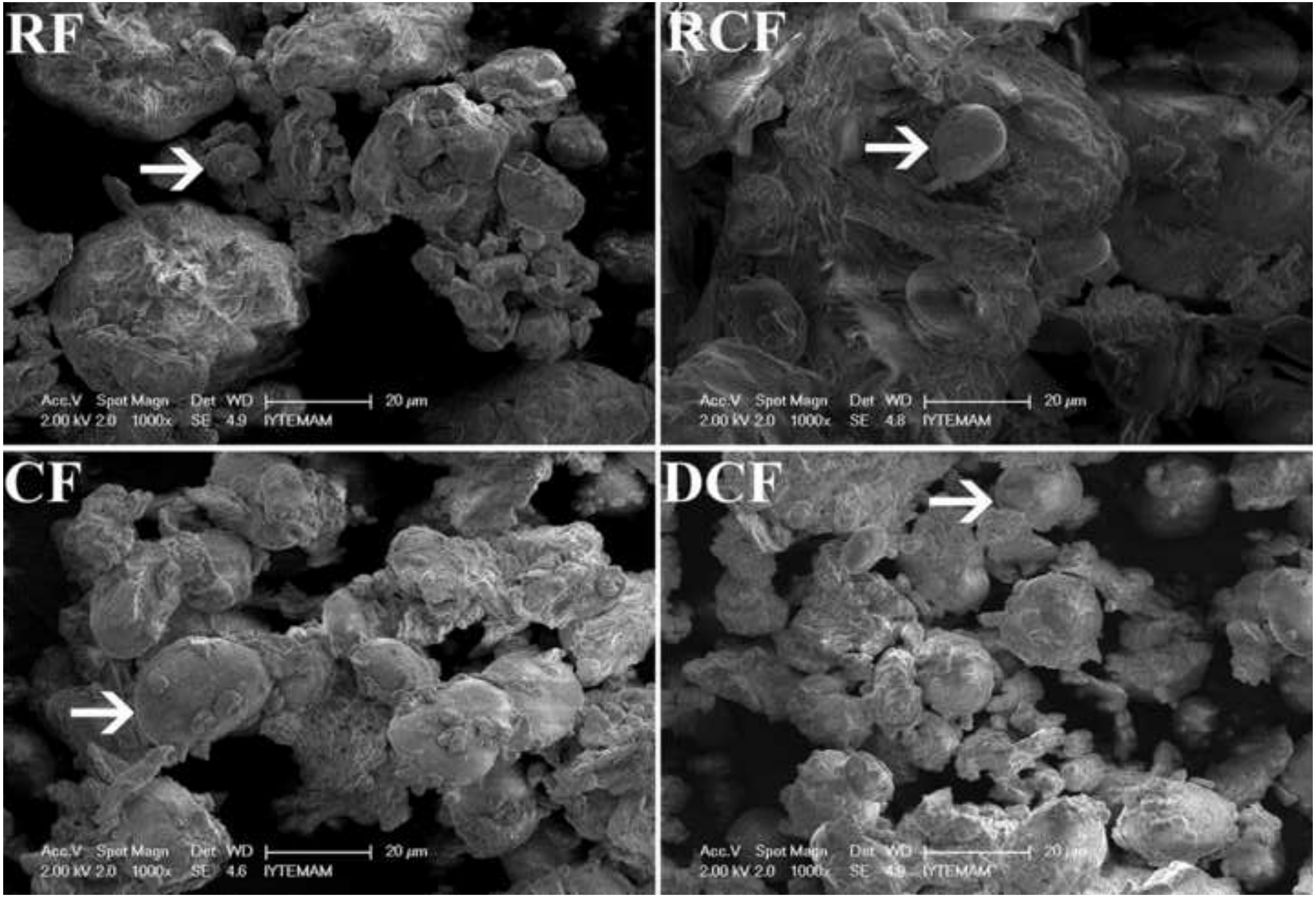
RF
Acc.V Spot Magn Det WD 20 µm
2.00 kV 2.0 1000x SE 4.9 IYTEMAM
RCF
Acc.V Spot Magn Det WD 20 µm
2.00 kV 2.0 1000x SE 4.8 IYTEMAM
CF
Acc.V Spot Magn Det WD 20 µm
2.00 kV 2.0 1000x SE 4.6 IYTEMAM
DCF
Acc.V Spot Magn Det WD 20 µm
2.00 kV 2.0 1000x SE 4.9 IYTEMAM

Figure 2

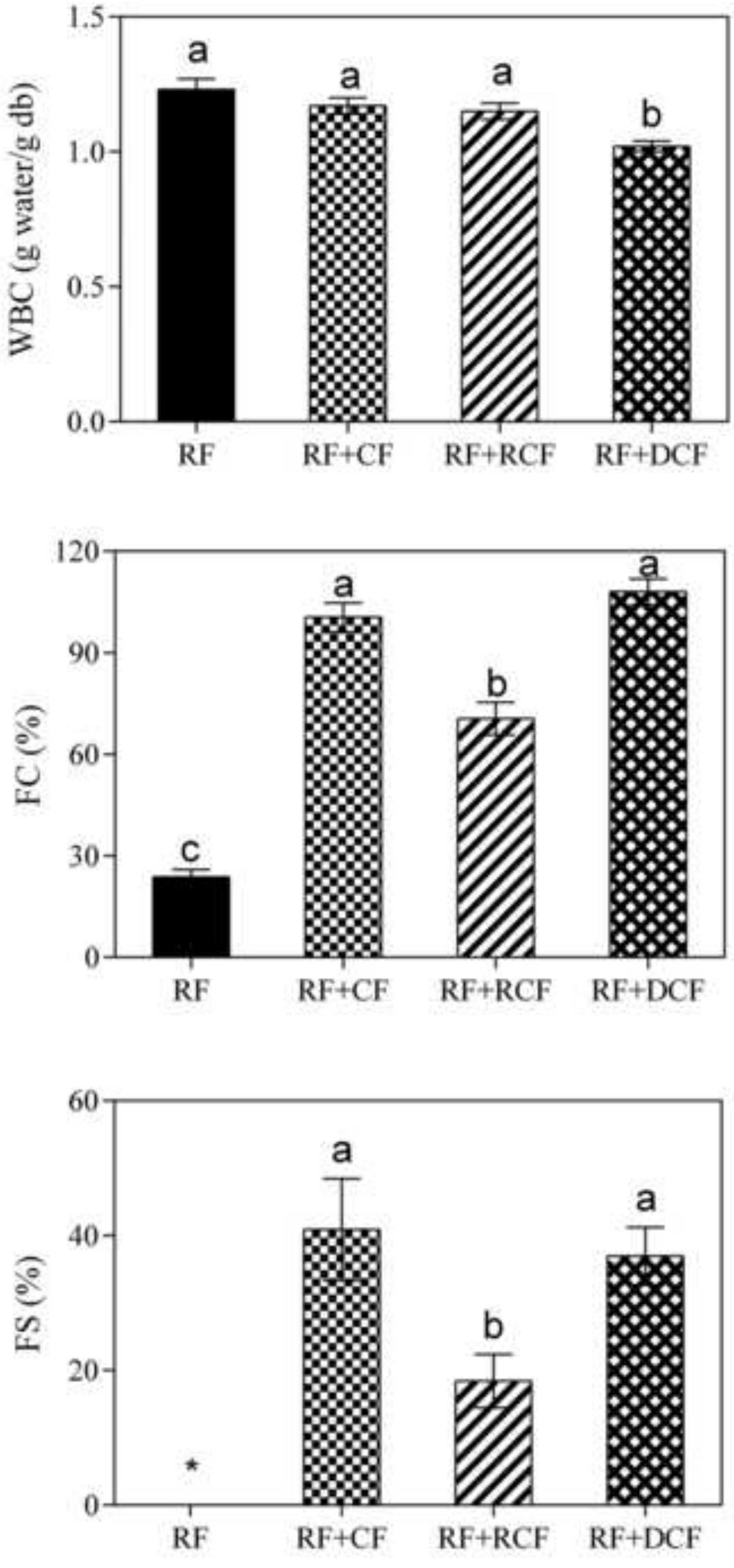
WBC (g water/g db)
1.5
1.0
0.5
0.0
a
a
a
b
RF
RF+CF
RF+RCF
RF+DCF
FC (%)
120
90
60
30
0
c
a
b
a
RF
RF+CF
RF+RCF
RF+DCF
FS (%)
60
40
20
0
*
a
b
a
RF
RF+CF
RF+RCF
RF+DCF

Figure 3

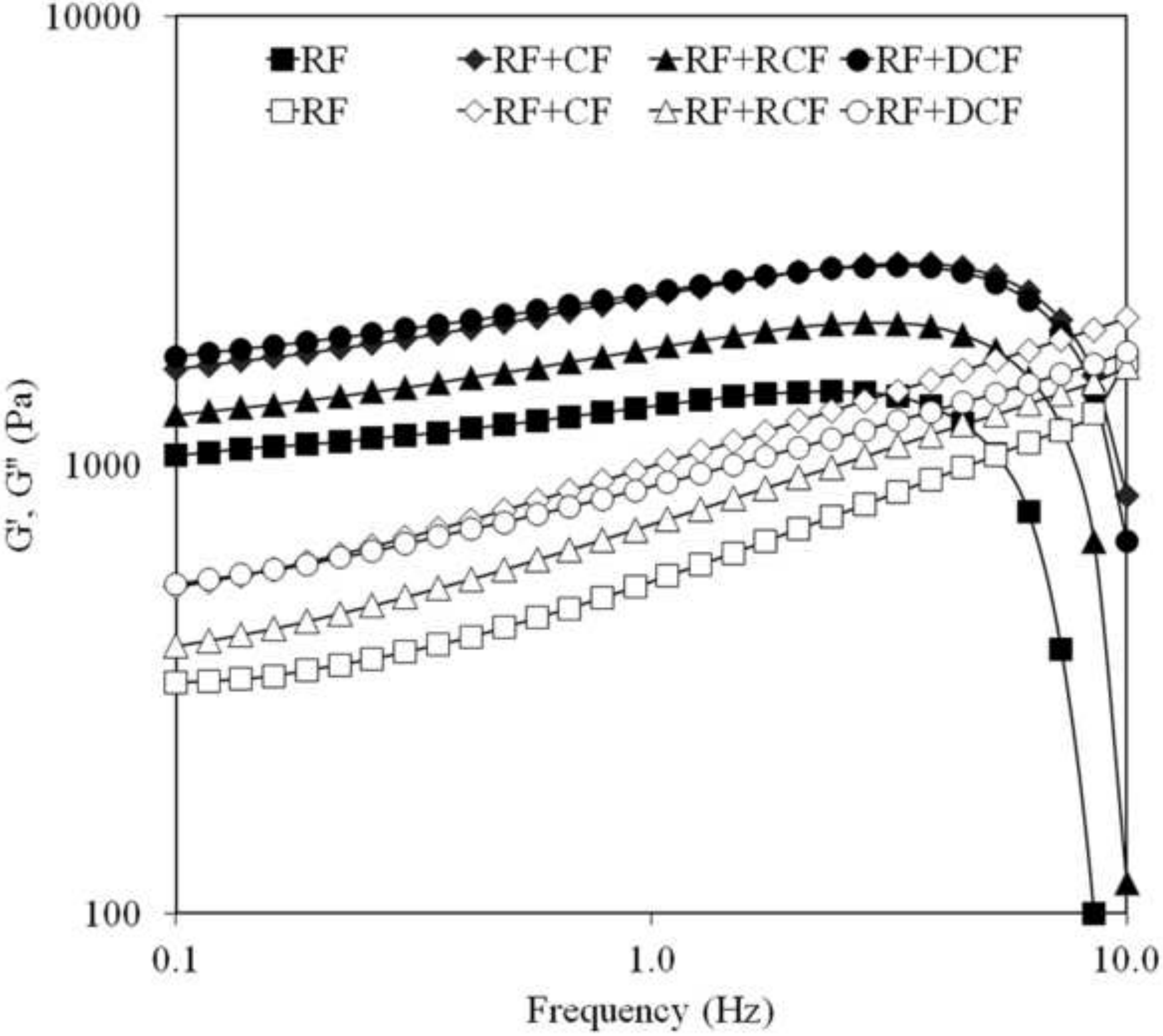
■RF
◆RF+CF
▲RF+RCF
●RF+DCF
□RF
◇RF+CF
△RF+RCF
○RF+DCF
10000
1000
100
G', G" (Pa)
0.1
1.0
10.0
Frequency (Hz)

FIGURE CAPTIONS

Figure 1. SEM images of flour samples (x1000). The starch granules were shown with the arrow. RF, rice flour; CF, chickpea flour; RCF, roasted chickpea flour; DCF, dehulled chickpea flour.

Figure 2. Water binding capacities (WBC), foaming capacity (FC) and foam stability (FS) of RF and blends. RF, rice flour; CF, chickpea flour; RCF, roasted chickpea flour; DCF, dehulled chickpea flour; * no detectable foam after 60 min. Means having different letters are significantly different ($p<0.05$).

Figure 3. Dough viscoelastic properties: frequency sweep tests. RF, rice flour; CF, chickpea flour; RCF, roasted chickpea flour; DCF, dehulled chickpea flour. Storage modulus (G', dark), loss modulus (G'', white), RF (■), RF+CF (♦), RF+RCF (▲) and RF+DCF (●).