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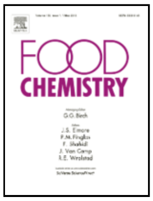

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Baking performance of 25 edible dry bean powders: Correlation between cookie quality and rapid test indices

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ABSTRACT

This study was designed to evaluate the baking performances of 25 edible dry bean (*Phaseolus vulgaris* L.) varieties and to investigate correlations among cookie features and rapid test indices (i.e., water and lactic acid retention capacities, oil binding capacity and Rapid Visco Analyzer indices). Two bean powder particle sizes ($\leq$0.5 mm, $\leq$1.0 mm) were investigated. Cookies were evaluated in terms of nutritional, geometrical and textural properties. Bean powders doubled the amount of cookie protein and increased cookie resistant starch content. Baking potential varied according to bean genotype and powder particle size: coarse powders resulted in larger (+26%) and thinner (−19%) cookies characterized by easier breaking texture (fracture strengths of 41–157 vs. 48–226 kPa for fine powders). Water retention and oil binding capacities and pasting properties significantly ($p < 0.05$) correlated with cookie features. In conclusion, these accumulated findings can be used in designing value-added traditional and gluten-free cookies.

1. Introduction

Cookies generally contain wheat flour, sugar and fat, and have low final water content (<20%, wet basis). The biochemical and physicochemical reactions that occur during the short dough formation and baking are very complex, involving protein denaturation, loss of granular starch structure, melting fat, Maillard reactions, dough expansion due to water evaporation, production and thermal expansion of gases (Chevallier, Colonna, Della Valle, & Lourdin, 2000). Although much research has focused on the functional properties in cookies made with fortified wheat flour, there exists interest in alternative flours in combination with or as substitutes for wheat flour (Kissell & Yamazaki, 1975; Jeltema, Zabik, & Thiel, 1983; Pareyt, Wilderjans, Goesaert, Brijs, & Delcour, 2008).

In the last few years, the attention of researchers has been directed towards pulses (e.g., lentils, peas, beans, and chickpeas) that contribute to reducing the risks for diseases such as cancer, diabetes or coronary heart disease (Geil & Anderson, 1994; Leterme & Munoz, 2002; Luhovyy et al., 2015). Moreover, pulses are nutritionally valuable and healthful, providing complex carbohydrates, proteins, dietary fibers, vitamins and minerals (Hayat, Ahmad, Masud, Ahmed, & Bashir, 2014; Kutoš, Golob, Kač, & Plestenjak, 2003; Tosh & Yada, 2010) consequently their use in enhancing the nutritive quality of baked goods is promising. Furthermore, Luhovyy et al. (2015) reported that obesity and related medical problems require lifestyle modifications that are easy for consumers to implement; consequently, the market demands healthier foods such as bean cookies. For instance, Hoojjat and Zabik (1984) found that navy bean powder can be a good supplement for wheat flour for sugar-snap type cookies, and Ai, Jin, Kelly, and Ng (2017) reported that dry bean powders can be used in wire-cut cookie production after blending with corn starch.

Generally, cookie quality criteria include geometrical properties, color, surface cracking, and bite behavior. For instance, Miller and Hoseney (1997) focused on a large spread and a surface cracking pattern; Chevallier, Della Valle, Colonna, Broyart, and Trystram (2002) were more interested in cookie thickness and color, while Pareyt et al. (2008) focused on spread ratio and texture. All of the above properties are well-established cookie quality parameters, and their importance varies depending on the type of cookie, e.g., French biscuit, sugar-snap cookies or wire-cut cookies. According to the AACC Method 10-54 (AACC, 2000) developed for the wire-cut formulation cookie, high quality cookie flour is usually associated with low thickness, large diameter and tender texture. While maintaining the same processing conditions, cookie quality is highly related to their formulation, thus, when flour substitutes (e.g., bean powders) are used, changes in cookie quality can be expected.

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Test baking has been found to be one of the best methods to evaluate the suitability of wheat flour samples for the production of high quality cookies, however, the test is time consuming. Consequently, the possibility of correlating target cookie quality parameters with time-saving techniques, suitable also with non-wheat flours, is of great interest; especially today when dietary restrictions (e.g., low glycemic response, low fat and gluten-free diets) are proliferating and recipe adjustments are required to satisfy these new requirements. For instance, solvent retention capacities, pentosan content, sedimentation index, and dough rheological properties are commonly used to assess the baking quality of wheat flour (Colombo, Perez, Ribotta, & Leon, 2008; Gaines, 2004; Ozturk, Kahraman, Tiftik, & Koksel, 2008; Zhang, Zhang, Zhang, He, & Peña, 2007).

The aim of this study was to evaluate the baking performance (i.e., nutritional, geometrical and textural properties) of 25 edible dry bean varieties, and to investigate correlations among rapid test indices (i.e., water and lactic acid retention capacities, oil binding capacity and Rapid Visco Analyzer indices) and the baking performances of bean powders blended with corn starch (ratio 7:3, dry basis). The bean powders are proposed here as unconventional ingredients for value-added cookie production, due to their high protein content. Since particle size (i.e., surface area) affects the hydration rate involved in the food-making process, two bean powder particle sizes were investigated: fine (≤0.5 mm) and coarse (≤1.0 mm). Traditional and gluten-free cookies with wheat and rice flour, respectively, were produced for comparison. Target quality parameters were estimated by correlations with rapid test indices.

2. Materials and methods

2.1. Materials

The dry edible beans were grown at the Saginaw Valley Research and Extension Center (Frankenmuth, MI, U.S.A.) in 2015 and provided by the Michigan State University Dry Bean Breeding and Genetics Program (East Lansing, MI, U.S.A.). Bean powders came from 25 bean varieties (*Phaseolus vulgaris* L.; Table 1) and were ground to particle size ≤ 0.5 mm (fine powders) or ≤ 1.0 mm (coarse powders) using a Thomas Wiley® Mill (Model 4, Thomas Scientific Inc., Swedesboro, NJ, U.S.A.). Coop08070 was powdered to fine particle size only due to the small quantity available.

The reference samples: wheat flour (WF; soft red wheat) and rice flour (RF; RL-100 obtained from long grain varieties of rice) were gifts from Mennel Milling Company (Fostoria, OH, U.S.A.) and Riviana Foods (Houston, TX, U.S.A.), respectively. Corn starch (CS; Melojel® 03401048) for blending with reference samples and bean powders was provided by Ingredion Incorporated (Westchester, IL, U.S.A.).

The fine and coarse edible dry bean powders, WF and RF were blended with corn starch (ratio 7:3, dry basis) in order to obtain 25 fine bean blends, 25 coarse bean blends and 2 reference blends (WFCS and RFCS; Table 1), respectively.

2.2. Blend water and lactic acid retention capacities and oil binding capacity

Water retention capacity (WRC) and lactic acid retention capacity (LARC) of fine and coarse edible dry bean powders blended with corn starch and of the reference samples were determined by the AACC Method 56-11 (AACC, 2000), with minor modifications: sample (1.5 g) was weighed in a calibrated 15 mL centrifuge tube with a conical bottom. Then, 7.5 mL of water or of 5.0% (w/w) lactic acid in water were added separately to the samples, and the mixtures were vigorously shaken for 5 s. The mixtures were then shaken every 5 min for 20 min, and centrifuged for 15 min at 1000 × *g* at room temperature (25 °C). The WRC and LARC values were calculated as the weight of solvent held by samples after centrifugation, supernatant separation and gel drainage at 90° angle for 10 min. In accordance with Cappa, Kelly, and Ng (2018), the draining step was avoided for samples containing bean powders; instead the supernatant was carefully decanted and then the tubes directly weighed to prevent loss of sample.

Oil binding capacity (OBC) was measured following the method of Ahn, Kim, and Ng (2005) using Wesson vegetable oil (ConAgra Foods Inc., Omaha, NE, U.S.A.).

All the analyses were performed in triplicate, and the results calculated on a dry basis.

2.3. Blend pasting properties

The pasting properties of fine and coarse edible dry bean powders blended with corn starch were investigated using a Rapid Visco Analyzer (RVA, Model 4, Newport Scientific Pty. Ltd., Warriewood, NSW, Australia). Reference samples and reference blends were evaluated for comparison. The sample (3.5 g) was dispersed in distilled water (25 g), scaling both the sample and water weight on a 14 g/100 g sample moisture basis. The suspensions were subjected to Standard Method 2 (Thermocline Software, Newport Scientific Pty. Ltd., Warriewood, NSW, Australia), thus suspensions were kept at 50 °C for 1.5 min, heated at 6 °C/min up to 95 °C, kept at 95 °C for 5 min, cooled at 3.5 °C/min down to 50 °C and kept at 50 °C for 1.8 min. From the resulting RVA pattern, the following indices were extrapolated: peak viscosity (PV, cP; maximum paste viscosity achieved during the heating phase); breakdown (BD, cP; index of viscosity decrease during the holding period, corresponding to the PV minus the viscosity after the holding period at 95 °C); final viscosity (FV, cP; paste viscosity reached at the end of the cooling cycle), and setback (SB, cP; index of the paste viscosity increase during cooling, corresponding to the difference between FV and the viscosity reached after the holding period at 95 °C). For each sample, results are the average of three measurements.

2.4. Cookie production and characterization

The cookies were produced following the AACC Method 10-54 (AACC, 2000) with minor modifications. The cookie dough was prepared, rolled, and cut according to the described procedure. According to Ai et al. (2017), fine and coarse edible dry bean powders obtained from 25 bean varieties grown in Michigan in 2015 were blended with corn starch (ratio 7:3, db). Since bean powders are naturally gluten-free, both wheat-flour and rice-flour cookies were produced, to serve as traditional and gluten-free references, respectively. Furthermore, their blends with corn starch (ratio 7:3, db) were included in the study as references.

For the 25 blends from the fine bean powders, the cut dough was baked at 190.6 °C for 13 min; for the coarse counterparts, the cut dough was baked at the same temperature for 11.5 min to avoid overbrowning of the cookies (Ai et al., 2017). Doughs of the WF, RF, WFCS and RFCS were baked at 190.6 °C for 13 min and 11.5 min for comparison. Two cookies were baked from one batch for each sample.

The cookies were characterized as reported below. Since textural properties can be affected by product temperature, geometrical features and textural properties of the cookies were measured 1 h after baking, in order to allow time for the product to cool down. After the evaluation of geometrical and textural properties, the cookies were frozen until they were ground and further characterized.

2.4.1. Nutritional properties

In order to evaluate the nutritional properties of the cookies, samples baked from fine and coarse bean powder blends and the reference samples (WF, RF, WRCS and RFCS) were defrosted and then ground for

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Table 1
Water retention (WRC), lactic acid retention (LARC) and oil binding capacities (OBC) of fine (particle size ≤ 0.5 mm) and coarse (≤1.0 mm) bean powders[1] blended with corn starch and of wheat flour (WF), wheat flour blended with corn starch (WFCS), rice flour (RF) and rice flour blended with corn starch (RFCS).[2]

Bean market class	Bean variety name	Sample code	Fine blend (≤0.5 mm)		
			WRC (g/g, db)	LARC (g/g, db)	OBC (g/g, db)
Navy	Alpena	N1	1.62 ± 0.05^{cd}	1.61 ± 0.01^{b}	1.14 ± 0.05^{cde}
Navy	Medalist	N2	1.56 ± 0.01^{bc}	1.65 ± 0.01^{bcd}	1.08 ± 0.03^{abc}
Navy	Merlin	N3	1.55 ± 0.01^{b}	1.70 ± 0.01^{defgh}	1.11 ± 0.03^{bcd}
Navy	T9905	N4	1.64 ± 0.01^{d}	1.68 ± 0.02^{cdef}	1.06 ± 0.01^{ab}
Navy	Coop08070	N5	1.55 ± 0.01^{bc}	1.71 ± 0.0^{3defghi}	1.18 ± 0.02^{ef}
Navy	Coop12064	N6	1.55 ± 0.02^{b}	1.67 ± 0.01^{bcde}	1.15 ± 0.03^{de}
Black	Zorro	B7	1.68 ± 0.02^{def}	1.68 ± 0.01^{cdef}	1.1 ± 0.01^{abcd}
Black	Zenith	B8	1.73 ± 0.01^{fg}	1.63 ± 0.01^{bc}	1.13 ± 0.01^{bcde}
Black	Shania	B9	1.76 ± 0.02^{g}	1.72 ± 0.04^{efghi}	1.1 ± 0.01^{abcd}
Pinto	Eldorado	P10	2.00 ± 0.01^{j}	1.77 ± 0.04^{i}	1.13 ± 0.04^{cde}
Pinto	La Paz	P11	1.92 ± 0.04^{i}	1.70 ± 0.01^{defgh}	1.13 ± 0.05^{cde}
Great Northern	Powderhorn	GN12	1.65 ± 0.03^{de}	1.45 ± 0.01^{a}	1.15 ± 0.03^{cde}
Great Northern	G13479	GN13	1.71 ± 0.01^{efg}	1.69 ± 0.04^{cdefg}	1.13 ± 0.04^{cde}
Otebo	Fuji	O14	1.46 ± 0.01^{a}	1.68 ± 0.04^{cdef}	1.16 ± 0.02^{de}
Otebo	Samurai	O15	1.63 ± 0.02^{d}	1.73 ± 0.06^{fghi}	$1.12 \pm 0.04^{bcd}e$
Small Red	Merlot	SR16	2.07 ± 0.04^{kl}	1.77 ± 0.04^{i}	1.1 ± 0.03^{abcd}
Small Red	Viper	SR17	1.72 ± 0.03^{fg}	1.69 ± 0.03^{cdefg}	1.04 ± 0.03^{a}
Small Red	R12845	SR18	2.11 ± 0.04^{l}	1.86 ± 0.05^{j}	1.1 ± 0.01^{abcd}
Pink	Rosetta	Pink19	1.84 ± 0.02^{h}	1.77 ± 0.01^{hi}	1.13 ± 0.05^{bcde}
Dark Red Kidney	Red Hawk	DRK20	2.12 ± 0.05^{l}	1.99 ± 0.03^{k}	1.16 ± 0.01^{de}
Dark Red Kidney	Montcalm	DRK21	2.23 ± 0.02^{m}	2.02 ± 0.03^{k}	1.06 ± 0.05^{ab}
Light Red Kidney	Clouseau	LRK22	1.96 ± 0.03^{ij}	1.76 ± 0.03^{hi}	1.24 ± 0.01^{f}
Light Red Kidney	CELRK	LRK23	2.00 ± 0.06^{j}	1.70 ± 0.05^{defgh}	1.15 ± 0.05^{de}
White Kidney	Snowdon	WK24	1.85 ± 0.01^{h}	1.75 ± 0.02^{ghi}	1.1 ± 0.04^{abcd}
White Kidney	Beluga	WK25	2.01 ± 0.06^{jk}	1.77 ± 0.01^{hi}	1.11 ± 0.02^{abcd}
		WF	0.90 ± 0.02	1.16 ± 0.02	1.4 ± 0.03
		WRCS	0.95 ± 0.01	1.10 ± 0.02	1.24 ± 0.05
		RF	1.54 ± 0.03	1.67 ± 0.05	1.36 ± 0.03
		RFCS	1.33 ± 0.02	1.28 ± 0.02	1.29 ± 0.03

Bean market class	Bean variety name	Sample code	Coarse blend (≤1.0 mm)		
			WRC (g/g, db)	LARC (g/g, db)	OBC (g/g, db)
Navy	Alpena	N1	1.74 ± 0.01^{efghij}	1.55 ± 0.05^{bcd}	1.16 ± 0.03^{f}
Navy	Medalist	N2	1.54 ± 0.01^{a}	1.6 ± 0.02^{cdef}	1.08 ± 0.03^{de}
Navy	Merlin	N3	1.59 ± 0.02^{abc}	1.57 ± 0.02^{bcdef}	1.02 ± 0.02^{ab}
Navy	T9905	N4	1.66 ± 0.05^{bcd}	1.6 ± 0.02^{cdefg}	1.01 ± 0.01^{ab}
Navy	Coop08070	N5	nd	nd	nd
Navy	Coop12064	N6	1.6 ± 0.01^{abc}	1.59 ± 0.01^{cdef}	1.04 ± 0.02^{abcd}
Black	Zorro	B7	1.75 ± 0.04^{fghij}	1.63 ± 0.01^{fgh}	1.23 ± 0.03^{g}
Black	Zenith	B8	1.7 ± 0.06^{defg}	1.55 ± 0.02^{bc}	1.08 ± 0.02^{de}
Black	Shania	B9	1.67 ± 0.01^{cdef}	1.67 ± 0.03^{hi}	1 ± 0.01^{a}
Pinto	Eldorado	P10	1.81 ± 0.05^{jk}	1.58 ± 0.05^{cdef}	1.07 ± 0.03^{cde}
Pinto	La Paz	P11	1.82 ± 0.01^{jkl}	1.59 ± 0.01^{cdef}	1.1 ± 0.01^{e}
Great Northern	Powderhorn	GN12	1.7 ± 0.06^{defgh}	1.53 ± 0.04^{ab}	1.07 ± 0.01^{de}
Great Northern	G13479	GN13	1.72 ± 0.01^{defghi}	1.61 ± 0.02^{defgh}	1.02 ± 0.03^{abc}
Otebo	Fuji	O14	1.58 ± 0.01^{ab}	1.66 ± 0.04^{ghi}	1.08 ± 0.04^{de}
Otebo	Samurai	O15	1.67 ± 0.01^{cde}	1.71 ± 0.03^{ij}	1.07 ± 0.00^{cde}
Small Red	Merlot	SR16	1.88 ± 0.06^{kl}	1.6 ± 0.01^{cdef}	1.02 ± 0.02^{abc}
Small Red	Viper	SR17	1.75 ± 0.02^{fghij}	1.62 ± 0.04^{efgh}	1.06 ± 0.02^{bcde}
Small Red	R12845	SR18	1.89 ± 0.01^{l}	1.7 ± 0.01^{ij}	1.26 ± 0.04^{g}
Pink	Rosetta	Pink19	1.75 ± 0.07^{fghij}	1.67 ± 0.03^{hij}	1.08 ± 0.04^{de}
Dark Red Kidney	Red Hawk	DRK20	1.8 ± 0.03^{ijk}	1.69 ± 0.04^{ij}	1.16 ± 0.03^{f}

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Table 1 (*Continued*)

Bean market class	Bean variety name	Sample code	Coarse blend (≤1.0 mm)		
			WRC (g/g, db)	LARC (g/g, db)	OBC (g/g, db)
Dark Red Kidney	Montcalm	DRK21	1.88 ± 0.04^{kl}	1.73 ± 0.04^{j}	1.07 ± 0.01^{cde}
Light Red Kidney	Clouseau	LRK22	1.77 ± 0.06^{ghij}	1.47 ± 0.01^{a}	1.07 ± 0.02^{de}
Light Red Kidney	CELRK	LRK23	1.8 ± 0.07^{jk}	1.54 ± 0.01^{bc}	1.15 ± 0.02^{f}
White Kidney	Snowdon	WK24	1.77 ± 0.01^{ghij}	1.59 ± 0.01^{cdef}	1.05 ± 0.04^{abcd}e
White Kidney	Beluga	WK25	1.78 ± 0.01^{hij}	1.56 ± 0.01^{bcde}	1.08 ± 0.02^{de}
		WF			
		WRCS			
		RF			
		RFCS			

[1] For the bean powder blends (sample codes N1-WK25), values with the same letter within a column are not statistically different at $P < 0.05$; nd, not determined due to limited quantity of sample.

[2] Mean values ± standard deviation of three replicates, calculated on a dry basis (db).

45 s at room temperature using a coffee grinder (Hamilton Beach, model 80350). The ground cookies were then frozen until their characterization. The moisture contents of ground cookie samples were measured according to the AACC Method 44-15A (2000). Total nitrogen contents were determined using an N/Protein Analyzer (Model Rapid N Exceed, Elementar Americas Inc., Mt Laurel, NJ, U.S.A.). In accordance with AACC Method 46-30 (AACC, 2000) and Champagne (2004), protein contents were calculated adopting a conversion factor of 6.25 for bean cookies, of 5.70 for wheat cookies (WF and WFCS) and 5.95 for rice cookies (RF and RFCS). Total starch contents (TS) were determined using the "Total Starch Assay Kit" (Megazyme International Ireland Ltd., Bray, Wicklow, Ireland). The analysis was only carried out on reference cookies and fine-bean-powder-based cookies as the Megazyme assay requires that samples have a particle size ≤0.5 mm. All analyses were performed in triplicate, and the data were calculated on a dry basis. The starch digestibility of the cookies containing fine and coarse bean powders was determined following the Englyst Method (Englyst, Kingman & Cummings, 1992) and using the "D-Glucose Assay Kit" (Megazyme International Ireland Ltd., Bray, Wicklow, Ireland). Rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) contents of each sample were calculated on a dry basis. All measurements were performed in at least triplicate for each sample.

2.4.2. Geometrical features

Diameters and heights of the cookies were measured in accordance with the AACC Method 10-54 (AACC, 2000). Diameter-to-thickness ratio (spread ratio) was calculated by dividing the average diameter by the average thickness of each sample. The results are the average of two measurements.

2.4.3. Textural properties

The textural properties of the cookies were determined using a texture analyzer (Model TA.HD, Texture Technologies Corp., Hamilton, MA, U.S.A.) equipped with a 50 N load-cell and a three-point bend rig (TA-92; 45 mm span length). One cookie at a time was set on the appropriate device and broken by a blade moving at a pre-speed of 2.5 mm/s and a test speed of 2 mm/s. From the force-distance curves, the hardness (N, maximum force opposed to fracture) and the breaking deformation (mm) were obtained and then normalized by sample dimensions, calculating the fracture strength (σ_f, kPa) and strain (ε_f, %) with the following equations (Bruns & Bourne, 1975):

$$\sigma_f(kPa) = \frac{3 \times F \times g}{2 \times d \times t^2}$$

$$\varepsilon_f(\%) = \frac{6 \times D \times t}{g^2} \times 100$$

where F is the breaking force (N), g the span length (mm), d the sample diameter (mm), t the sample thickness (mm), and D the breaking deformation (mm).

2.5. Statistical analysis

The results were expressed as the mean ± SD. The data were analyzed by one-way analysis of variance (ANOVA) carried out using the Least Significant Differences (LSD) test to compare sample means; differences were considered significant at $P < 0.05$. The relationship between measured parameters was assessed by Pearson linear correlation test at different significance levels. All data elaboration was performed by STATGRAPHIC®Plus 5.1.

3. Results and discussion

3.1. Rapid test indices

3.1.1. Water and lactic acid retention capacities and oil binding capacity

Interaction among unconventional ingredients (e.g., bean powder has high fiber and protein contents) and the other liquid ingredients can play a crucial role in rheological properties of a food; consequently, water retention capacity, lactic acid retention capacity and oil binding capacity of the powdered ingredients should be taken into account when designing new foods. The WRC, LARC and OBC values of the bean powders blended with corn starch and of the reference samples are listed in Table 1.

WRC, LARC, and OBC values differed significantly ($p < 0.05$) among the 25 bean variety blends. The WRC ranged from 1.46 g/g (Fuji) to 2.23 g/g (Montcalm) and from 1.54 g/g (Medalist) to 1.89 g/g (R12845) for fine and coarse blended powders, respectively. In general, with the only exception of the Fuji sample, bean powders belonging to the Navy market class interacted less with water at room temperature and had WRC values significantly ($p < 0.05$) lower than those of the other samples, while samples belonging to the Kidney market classes had the highest retention capacities. The LARC ranged from 1.45 g/g (Powderhorn) to 2.02 g/g (Montcalm) and from 1.47 g/g (Clouseau) to 1.73 g/g (Montcalm) for fine and coarse blended powders, respectively. The OBC ranged from 1.04 g/g (Viper) to 1.24 g/g (Clouseau) and from 1.00 g/g (Shania) to 1.26 g/g (R12845) for fine and coarse blended powders, respectively. According to LARC and OBC values, no clear trends were seen for any market class, however significant differences

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($p < 0.05$) were found among the bean powder samples and their interactions with lactic acid solvent or oil, indicating that each bean variety's retention capacities have to be considered while developing new products. In general, slightly higher WRC and LARC values were recorded for the fine blended powders with respect to the coarse blended powders; this behavior is in accordance with the retention capacity values of the fine and coarse bean powders, not-blended with CS, reported by Cappa et al. (2018) and it was attributed by the authors to the lower particle surface area per weight of the coarse bean powder. Furthermore, the WRC and LARC of the bean blended powders were higher than the reference samples (range values of 0.90–1.54 g/g and 1.10–1.67 g/g for WRC and LARC, respectively) indicating a stronger interaction of the bean powders with water and lactic acid solution; this behavior could be related to the higher protein content of the bean powder blends. In fact, significant positive correlations ($p < 0.001$) among WRC ($r = 0.75$) and LARC ($r = 0.77$) and blend protein content (data not shown) were found.

On the contrary, bean blended powders had lower OBC values than the reference samples (range values of 1.00–1.26 g/g versus 1.24–1.40 g/g) suggesting that bean blends could be used in low fat food product formulations where the interaction with fat solvent (e.g., oil) is not a predominant factor.

3.1.2. Pasting properties

The pasting profiles of the 25-fine and 25-coarse bean blended powders and the reference samples are reported in Fig. 1. During the heating phase (from 50 to 95 °C) an increase in viscosity was observed in all the samples and a maximum viscosity was reached; then, during the holding period at 95 °C a decline in viscosity was generally observed before the rise occurring during the cooling phase.

The bean blended powders had lower peak viscosity and set back values in comparison to the reference samples (611–1483 cP versus 1820–4925 cP for PV and 557–1108 cP versus 1012–3068 cP for SB). Lower PV and SB values may be due to the lower starch content of blends containing bean powders: starch contents ranged from 49.7 to 54.3% for fine bean powder blends and measured 70.9 ± 0.9% and 74.3 ± 0.7%, for W*R* and RF, respectively (data not shown). Furthermore, the blends containing bean powders exhibited a higher thermal stability during the 95 °C holding period in the RVA; in fact, the viscosity decrease (breakdown) that characterizes reference flours, was not detected in bean blends. Conversely, the reference samples registered huge breakdown values which ranged from 1061 to 2597 cP. Final viscosity values ranged from 1732 to 2259 cP for the fine bean blended powders, from 1163 to 1740 cP for the coarse bean blended powders, and from 1771 to 5606 cP for the reference samples. Thus, it appears evident that bean powders provide equal-to-lower FV than the reference samples and different viscosity depending on the bean genotype (i.e., Beluga had the highest FV and Zorro and Powderhorn the lowest) and on the bean powder particle size; in fact, blends containing fine bean powder had a faster and broader increase in viscosity during the RVA-heating phase and reached higher FV values after the RVA-cooling phase in comparison to coarse blends; this behavior could be partially related to the higher particle surface per weight of the fine powders which absorb water more quickly, as also evidenced by the WRC values.

3.2. Nutritional and technological properties of cookies

Images of the smallest and the largest cookies obtained with the fine and coarse bean powder samples blended with corn starch (ratio of 7:3, db) and of the respective reference cookies are depicted in Fig. 2. The reference samples were baked at 190.6 °C for 13 min and for 11.5 min in order to determine whether baking time affected overall cookie quality (e.g., geometrical properties). Only minor geometrical variations were noticed among the reference samples baked for 13 min (Fig. 2A) and for 11.5 min (Fig. 2B), thus the differences observed among the cookies containing the bean powders can reasonably be attributed to the bean genotype and powder particle size, rather than baking conditions.

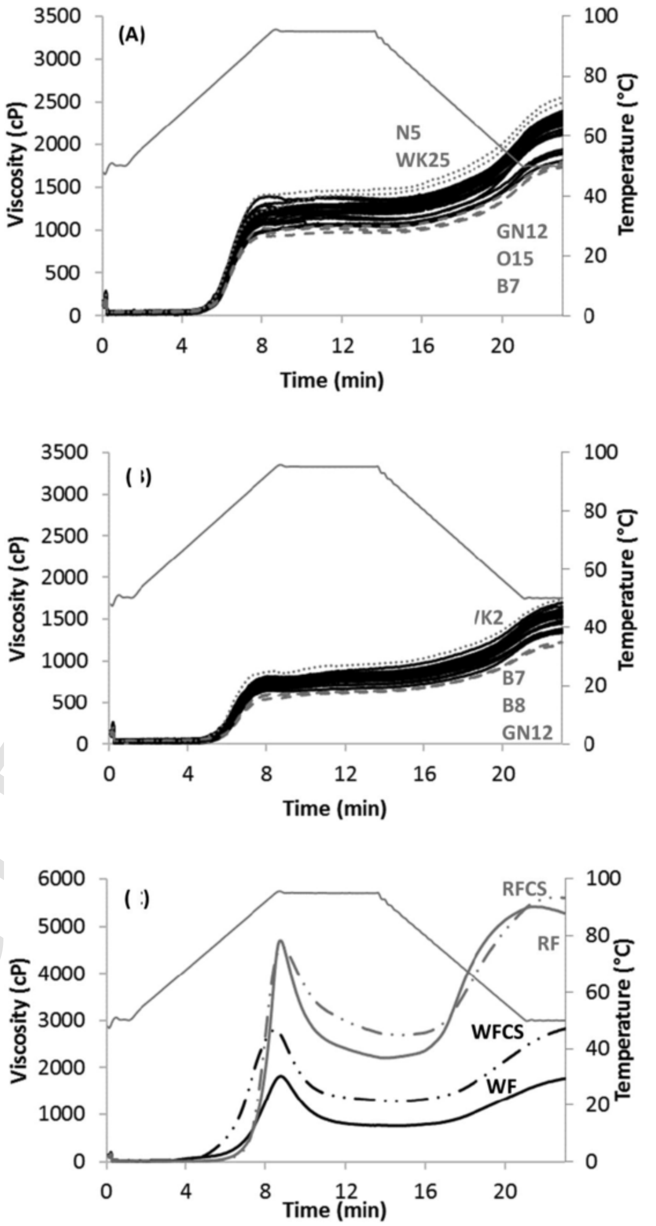

Fig. 1. Pasting properties of (A) fine (particle size ≤ 0.5 mm) and (B) coarse (particle size ≤ 1.0 mm) bean powders[1] blended with corn starch with indications of samples having the highest (round dots) and lowest (dashes) final viscosities, and pasting properties of (C) the reference samples: wheat flour (WF, black line), wheat flour blended with corn starch (WFCS, black round dot and dash), rice flour (RF, gray line) and rice flour blended with corn starch (RFCS, gray round dot and dash).[1] See Table 1 for bean market classes and variety names.

3.2.1. Nutritional properties

For the cookies containing bean powder, the protein content ranged from 7.7% (Medalist) to 10.2% (Snowdon) and starch content from 26.6% (Zorro and Red Hawk) to 28.5% (Fuji), whereas the reference samples had values of 3.5–5.0% and 38.5–42.2% for protein and starch contents, respectively (Table 2). Thus, the bean-cookies had approxi-

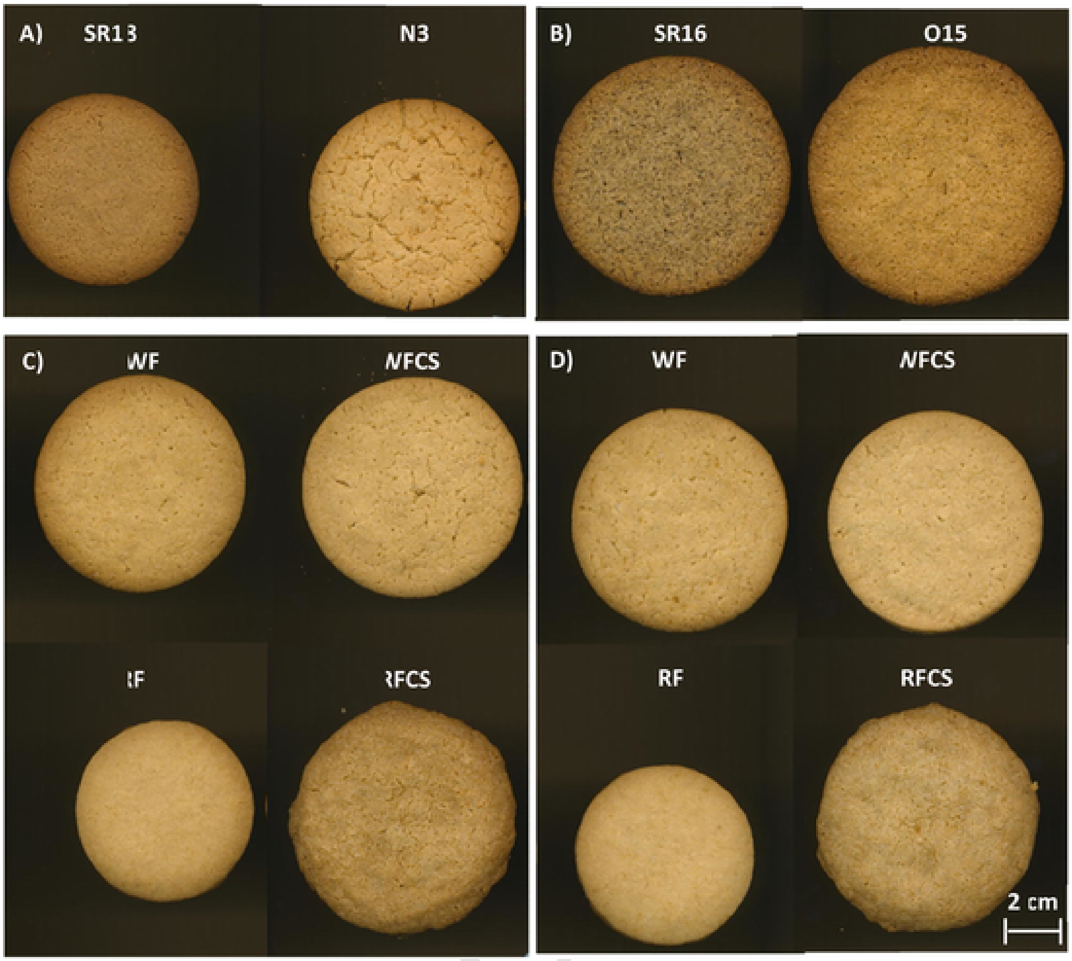

Fig. 2. Images of cookies containing (A) fine (particle size ≤ 0.5 mm) and (B) coarse (particle size ≤ 1.0 mm) bean powders[1] blended with corn starch and having the smallest (left side) and largest (right side) diameters, and of (C and D) the respective reference cookies made with wheat flour (WF), wheat flour blended with corn starch (WFCS), rice flour (RF) and rice flour blended with corn starch (RFCS)[2].[1] See Table 1 for bean market classes and variety names.[2] Bake time for samples in A and C was 13 min, and in B and D was 11.5 min.

mately 52% higher protein and 33–35% lower starch content than the reference samples, exhibiting a clear nutritional benefit. Furthermore, significant differences ($p > 0.05$) were found according to the bean variety, and cookies containing bean powders from the market classes of dark red kidney, light red kidney and white kidney, together with some black and pinto samples (Zorro and Eldorado, respectively), had the highest protein contents.

Rapidly digestible starch, slowly digestible starch and resistant starch contents of the bean cookies differed significantly among the 25 varieties and the two powder particle sizes (Table 2). For the fine-bean-powder cookies, RDS ranged from 5.8% (T9905 and Viper) to 7.9% (Samurai), SDS from 5% (Samurai) to 12.7% (Alpena) and the RS from 7.6% (Zorro) to 13.9% (Coop12064 and G13479). For the coarse-bean-powder cookies, RDS ranged from 5.2% (Montcalm) to 7.1% (Samurai), SDS from 4.5% (Coop12064) to 11.4% (Medalist) and the RS from 9.4% (Samurai) to 17.9% (Coop12064). Thus, starch digestibility properties were affected both by bean genotype and bean powder particle size. In fact, 75% and 63% of the cookie samples containing fine-bean-powders had higher glucose release after enzymatic digestion for 20 min and 120 min (as evidenced by RDS and SDS values), respectively), in comparison to their counterpart cookies containing coarse-bean powder. Moreover, in comparison to cookies containing fine-bean-powders, 71% of cookie samples containing coarse-bean-powders had a higher amount of resistant starch; this finding could be explained by the fact that larger particle size impedes access of the enzymes to starch deeper in the particle, reducing their contribution to RDS. Furthermore, since RS is calculated by the amount leftover after starch digestion, RS increases while digestible starch (RDS + SDS) decreases. In accordance with present results, Luhovyy, Hamilton, Kathirvel, and Mustafaalsaafin (2017) reported that the particle size of navy bean flour had an effect on carbohydrate digestion rate *in vitro*, with smaller particle sizes having higher glucose release rates compared with flour samples of larger particle size. In comparison to the references, the use of bean powders decreased the amount of RDS and increased the amount of the RS. In particular, the increase in RS is even more evident when expressing total starch content values (data not shown): 28–63% of the bean-cookie starch was resistant to amyloglucosidase and pancreatin digestion, whereas the reference cookies had values of 17–41%.

3.2.2. Geometrical properties

The geometrical features of cookies covered a huge range of values (Fig. 3). From a general point of view, the 25 cookies with fine bean powders had lower diameters (ranged from 7.09 to 7.85 cm) and greater thicknesses (ranged from 0.93 to 1.17 cm) in comparison to the WF and WFCS cookies (diameters of 8.59 and 8.37 cm, respectively, and thicknesses of 0.87 and 0.86 cm, respectively). The cookies with RF had the most diverse geometrical features: the lowest diameter (6.79 cm) and higher thickness (1.11 cm); the presence of starch in the RFCS sample determined an increase in diameter and a reduction of

Table 2

Protein, total starch, rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) contents of cookies[1] obtained using fine (particle size ≤ 0.5 mm) and coarse (≤1.0 mm) bean powders[2] blended with corn starch and of reference cookies made with wheat flour (WF), wheat flour blended with corn starch (WFCS), rice flour (RF) and rice flour blended with corn starch (RFCS).[3]

Sample code[2]	Bean powder, ≤0.5 mm					Bean powder, ≤1.0 mm		
	Protein (%, db)	Total starch (%, db)	*RDS* (%, db)	*SDS* (%, db)	*RS* (%, db)	*RDS* (%, db)	*SDS* (%, db)	*RS* (%, db)
N1	8.7 ± 0.1^{fgh}	27.3 ± 0.3^{bcdefg}	6.2 ± 0.9^{ab}	12.7 ± 0.1^{m}	8.4 ± 0.9^{abc}	6.5 ± 0.4^{efgh}	7.9 ± 0.1^{c}	12.8 ± 0.4^{cdef}
N2	7.7 ± 0.1^{a}	27.3 ± 0.8^{bcdef}	6.0 ± 0.2^{ab}	8.7 ± 0.7^{cdefg}	12.5 ± 0.6^{ghi}	5.9 ± 0.3^{abcd}	11.4 ± 0.6^{i}	10.0 ± 0.3^{ab}
N3	8.1 ± 0.1^{b}	27.5 ± 0.5^{defgh}	6.6 ± 0.1^{abcd}	9.2 ± 0.9^{defgh}	11.6 ± 0.8^{fgh}	5.7 ± 0.3^{abc}	10.2 ± 0.8^{fghi}	11.5 ± 1.2^{cdef}
N4	8.2 ± 0.1^{bc}	27.3 ± 0.5^{cdefg}	5.8 ± 0.1^{a}	9.6 ± 0.7^{efghi}	11.9 ± 0.9^{gh}	5.9 ± 0.2^{abcd}	7.9 ± 0.1^{c}	13.5 ± 0.1^{def}
N5	7.9 ± 0.1^{a}	27.8 ± 0.4^{fghij}	6.7 ± 0.6^{abcde}	8.4 ± 0.9^{bcdef}	12.7 ± 1.5^{ghi}	nd	nd	nd
N6	8.2 ± 0.1^{b}	28.4 ± 0.3^{jk}	6.3 ± 0.6^{abc}	8.1 ± 1.1^{bcde}	13.9 ± 0.4^{i}	6.0 ± 0.3^{bcd}	4.5 ± 0.6^{a}	17.9 ± 0.6^{h}
B7	9.6 ± 0.1^{n}	26.6 ± 0.6^{a}	6.8 ± 0.1^{bcde}	12.2 ± 0.8^{lm}	7.6 ± 0.9^{a}	6.2 ± 0.3^{cdefg}	9.0 ± 0.3^{defg}	11.3 ± 0.6^{abc}
B8	8.9 ± 0.1^{ijk}	27.3 ± 0.7^{defg}	6.4 ± 0.4^{abc}	11.5 ± 0.3^{jklm}	9.5 ± 0.6^{cde}	5.9 ± 0.1^{abcd}	9.3 ± 0.3^{defg}	12.1 ± 0.4^{cdef}
B9	8.7 ± 0.1^{ghij}	27.3 ± 0.5^{bcdefg}	6.4 ± 0.3^{abc}	9.7 ± 1.2^{efghij}	11.1 ± 0.9^{efg}	6.0 ± 0.2^{bcde}	8.0 ± 0.7^{cd}	13.2 ± 0.5^{def}
P10	9.5 ± 0.1^{mn}	28.1 ± 0.4^{hijk}	6.7 ± 0.4^{abcde}	8.7 ± 0.2^{cdefg}	12.7 ± 0.6^{ghi}	5.4 ± 0.3^{ab}	10.1 ± 0.2^{efghi}	12.6 ± 0.1^{cdef}
P11	8.5 ± 0.1^{efg}	27.9 ± 0.4^{ghijk}	6.5 ± 0.6^{abcd}	7.7 ± 0.7^{bcd}	13.8 ± 1.3^{i}	5.4 ± 0.3^{ab}	10.9 ± 1.3^{i}	11.7 ± 1.5^{bcdef}
GN12	8.5 ± 0.2^{def}	27.5 ± 0.3^{defgh}	7.2 ± 0.1^{cdef}	10.0 ± 1.1^{fghij}	10.2 ± 1.2^{ef}	5.9 ± 0.1^{abcd}	8.9 ± 1.3^{def}	12.7 ± 1.4^{cdef}
GN13	8.2 ± 0.1^{bc}	27.9 ± 0.4^{fghijk}	7.3 ± 0.4^{cdef}	6.7 ± 1.0^{ab}	13.9 ± 0.6^{i}	6.8 ± 0.1^{fgh}	8.4 ± 0.3^{cd}	12.7 ± 0.4^{cdef}
O14	8.3 ± 0.1^{bcd}	28.5 ± 0.4^{k}	6.9 ± 0.4^{bcde}	12.0 ± 1.3^{klm}	9.6 ± 0.9^{cde}	6.4 ± 0.4^{defgh}	6.3 ± 0.5^{b}	15.8 ± 0.1^{g}
O15	8.4 ± 0.1^{cde}	26.7 ± 0.4^{abc}	7.9 ± 0.1^{f}	5.0 ± 0.6^{a}	13.8 ± 0.6^{i}	7.1 ± 0.2^{h}	10.2 ± 0.3^{fghi}	9.4 ± 0.1^{a}
SR16	8.3 ± 0.1^{bc}	27.6 ± 0.1^{efghi}	6.6 ± 0.3^{abcd}	10.0 ± 0.3^{fghij}	11.1 ± 0.1^{efg}	5.7 ± 0.6^{abc}	9.1 ± 0.5^{defg}	12.8 ± 0.1^{cdef}
SR17	8.9 ± 0.1^{hij}	28.2 ± 0.3^{ijk}	5.8 ± 0.8^{a}	10.9 ± 1.3^{ghijkl}	11.6 ± 0.5^{fgh}	6.0 ± 0.1^{bcde}	10.8 ± 0.1^{hi}	11.4 ± 0.1^{bcd}
SR18	7.8 ± 0.1^{a}	27.1 ± 0.8^{abcde}	7.2 ± 0.4^{cdef}	10.3 ± 1.1^{fghijk}	9.7 ± 0.7^{de}	5.8 ± 0.5^{abcd}	9.2 ± 0.4^{defg}	12.2 ± 0.9^{bcde}
Pink19	8.7 ± 0.1^{ghi}	26.9 ± 0.3^{abcd}	7.6 ± 0.4^{ef}	6.6 ± 0.6^{ab}	12.7 ± 1.0^{ghi}	6.9 ± 0.6^{gh}	9.0 ± 1.0^{def}	11.0 ± 0.4^{abc}
DRK20	9.2 ± 0.1^{l}	26.6 ± 0.2^{ab}	6.6 ± 0.5^{abcd}	7.0 ± 0.4^{bc}	13.0 ± 0.9^{hi}	6.1 ± 0.6^{cdefg}	8.8 ± 1.0^{def}	11.6 ± 1.7^{bcde}
DRK21	9.9 ± 0.1^{o}	27.0 ± 0.3^{abcde}	5.9 ± 0.4^{a}	9.6 ± 1.1^{efghi}	11.5 ± 1.5^{fgh}	5.2 ± 0.6^{a}	10.4 ± 0.8^{ghi}	11.5 ± 0.1^{bcde}
LRK22	8.9 ± 0.1^{jk}	27.3 ± 0.1^{bcdefg}	7.4 ± 0.1^{def}	11.9 ± 0.1^{klm}	8.0 ± 0.2^{ab}	6.1 ± 0.2^{cdefg}	9.1 ± 0.6^{defg}	12.1 ± 0.8^{cdef}
LRK23	9.1 ± 0.1^{kl}	27.5 ± 0.5^{defgh}	6.7 ± 0.9^{abcde}	11.1 ± 1.2^{ijklm}	9.7 ± 0.3^{de}	6.4 ± 0.1^{defgh}	8.6 ± 0.1^{cde}	12.5 ± 0.1^{cdef}
WK24	10.2 ± 0.2^{p}	27.4 ± 0.7^{defg}	6.0 ± 0.3^{ab}	8.3 ± 1.0^{bcdef}	13.0 ± 0.6^{hi}	5.6 ± 0.6^{abc}	5.7 ± 0.4^{b}	16.0 ± 1.0^{g}
WK25	9.3 ± 0.1^{lm}	27.5 ± 0.4^{defgh}	6.7 ± 0.7^{abcde}	11.1 ± 1.6^{ijklm}	9.7 ± 0.8^{de}	6.3 ± 0.7^{defg}	5.8 ± 0.6^{b}	15.4 ± 0.9^{g}
WF	5 ± 0.1	38.5 ± 0.3	18.1 ± 0.7	12.9 ± 0.0	7.5 ± 0.7	20.3 ± 0.1	10.2 ± 0.2	8.1 ± 0.2
WRCS	3.5 ± 0.1	41.2 ± 1.0	20.6 ± 0.1	13.8 ± 1.2	6.8 ± 1.0	18.9 ± 0.8	6.6 ± 0.2	15.8 ± 0.5
RF	4.6 ± 0.1	42.2 ± 0.6	9.9 ± 0.7	15.1 ± 1.1	17.2 ± 1.7	12.4 ± 1.4	12.6 ± 0.9	17.2 ± 2.3
RFCS	3.5 ± 0.1	42.2 ± 0.3	13.3 ± 1.7	16.9 ± 1.7	12.0 ± 0.0	13.1 ± 1.3	16.0 ± 0.8	13.1 ± 0.5

[1] For the bean cookies (sample codes N1-WK25), values with the same letter within a column are not statistically different at $P < 0.05$; nd, not determined due to, limited quantity of sample.

[2] See Table 1 for bean market classes and variety names.

[3] Mean values ± standard deviation of three replicates, calculated as percentage on sample dry basis (db).

thickness (values of up to 8.60 and 0.94 cm, respectively). For the 25 cookies with coarse bean powders, the highest diameters (8.95–9.84 cm) and the lowest thicknesses (0.75–0.89 cm) were measured, indicating that powder particle size affected geometrical features. The cookie diameter was also affected by the blend composition (data not shown), since it negatively correlated with the fine blend protein content ($r = -0.53$, $p < 0.005$) and positively correlated with blend starch content ($r = 0.52$, $p < 0.005$). The inverse correlation between diameter and protein content was already reported by Leon, Rubiolo, and Anon (1996) for cookies containing triticale flours.

An index commonly used for measuring the quality of cookies is the spread ratio: the ratio of diameter to thickness. The spread ratio values (Fig. 3) of the fine-bean-powder cookies were lower than those of the traditional reference samples (6.7–7.9 versus 9.7–9.9). Previous research on wheat cookies revealed that higher protein content leads to decreased cookie spread (Donelson, 1988; Kaldy, Kereliuk, & Kozub, 1993; Kissell & Yamazaki, 1975; Miller & Hoseney, 1997), thus the lower spread ratio of the fine-bean-powder cookies versus the reference samples can be presumably attributed to the higher protein content of the bean cookies (Table 2). However, for coarse-bean-powder cookies, spread ratio values measured higher (range from 10.1 to 13.0) than those of the reference samples, thus the protein content of the blends cannot be considered the only parameter affecting cookie diameter. Jeltema et al. (1983) found a similar spread ratio (11.9) for cookies containing navy bean hulls. The results of the spread ratios for coarse-bean-powder cookies are also in agreement with the findings of Ai et al. (2017). The authors stated that the lower spread ratio values for cookies made of the finest bean powder versus their coarse powder counterparts can be attributed to the easier hydration of the fine powders and to the formation of more cohesive doughs. In the present study, the coarse bean powder samples had WRC values similar to or lower than those of their fine counterparts (Table 1) and their RVA-viscosity values were lower (Fig. 1). Negative correlations among spread ratio and WRC values are reported in the literature for wheat and bean cookies (Ai et al., 2017; Ram & Singh, 2004; Zhang et al., 2007). Moreover, for gluten-enriched wheat cookies, Kissell and Yamazaki (1975) related decreased cookie spread to high water retention. In particular, they stated that higher water retention leads to decreased sugar solubility, and thus, higher internal dough viscosity, resulting in limited cookie spread and top-grain formation. The effect of dough viscosity on the spread ratio values of cookies containing legume flour was also reported by Aziah Noor, Noor Mohamad, and

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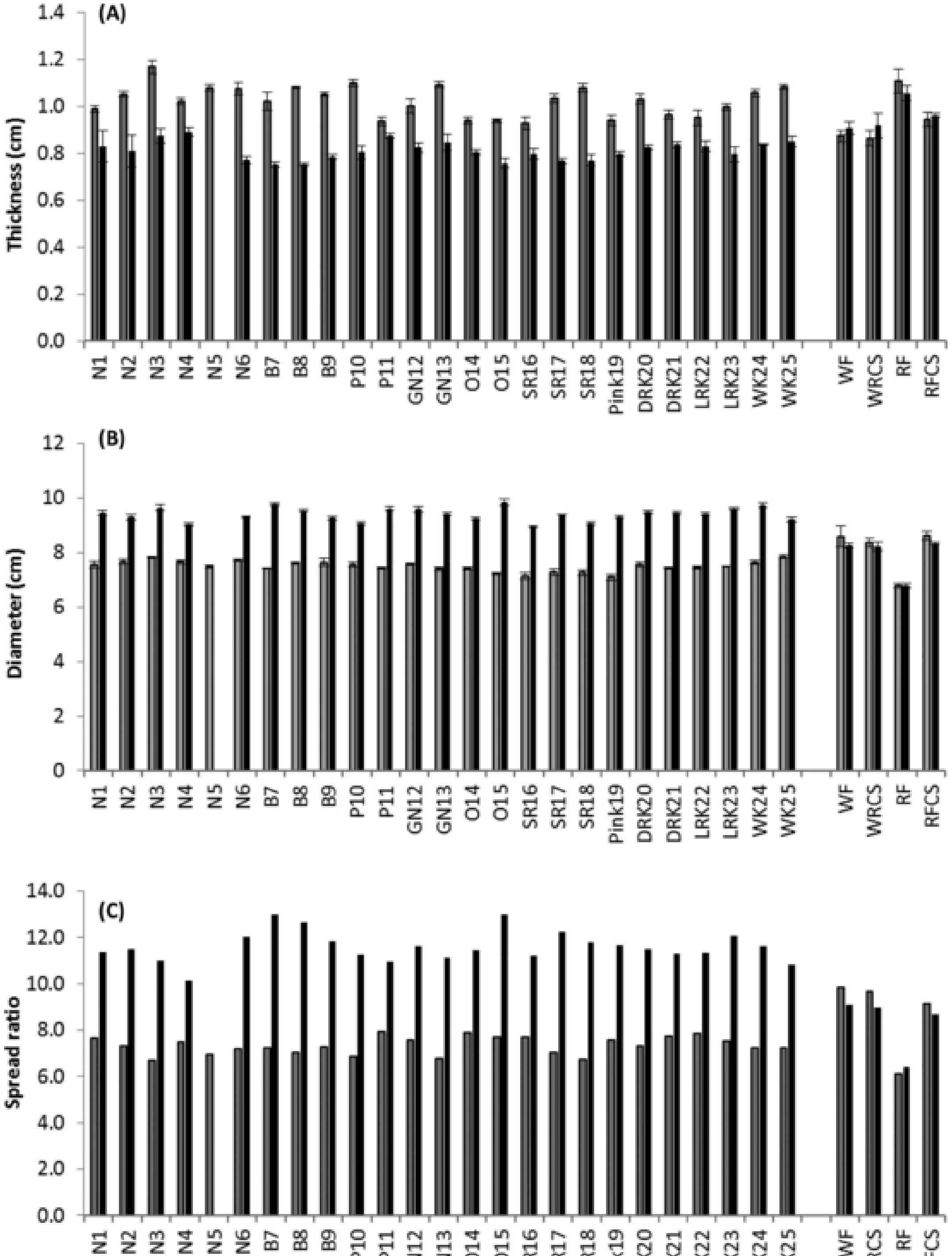

Fig. 3. Geometrical (A, B and C) and textural (D, E and F) features of cookies containing fine (particle size ≤ 0.5 mm; gray bars) and coarse (particle size ≤ 1.0 mm; black bars) bean powders[1] blended with corn starch and of the respective reference cookies made with wheat flour (WF), wheat flour blended with corn starch (WFCS), rice flour (RF) and rice flour blended with corn starch (RFCS)[2].[1] See `Table 1` for bean market classes and variety names.[2] Cookies containing fine bean powder were baked for 13 min and cookies containing coarse bean powder were baked for 11.5 min; reference samples were baked for 13 min (to serve as a "fine-cookie reference") and 11.5 min (to serve as a "coarse-cookie reference") in order to determine whether baking time affected the overall cookie quality.

Ho (2012) who found the highest spread ratios in chickpea cookies due to the lower hydration properties of chickpea flour in comparison with mung bean flour. In addition, it should be considered that the proteins were confined in the large particles (≤1.0 mm) of the coarse bean blends, thereby preventing protein network formation during cookie dough processing, leading to increased cookie spread.

According to the AACC Method 10-54 (AACC, 2000), high quality cookie flour is usually associated with larger cookie diameters and lower thicknesses, thus the coarse bean powders are apparently more suitable for cookie production in comparison with fine bean powders. Nevertheless, even if a huge cookie diameter is desired, it should be associated with a certain thickness, otherwise it can be an indicator of a

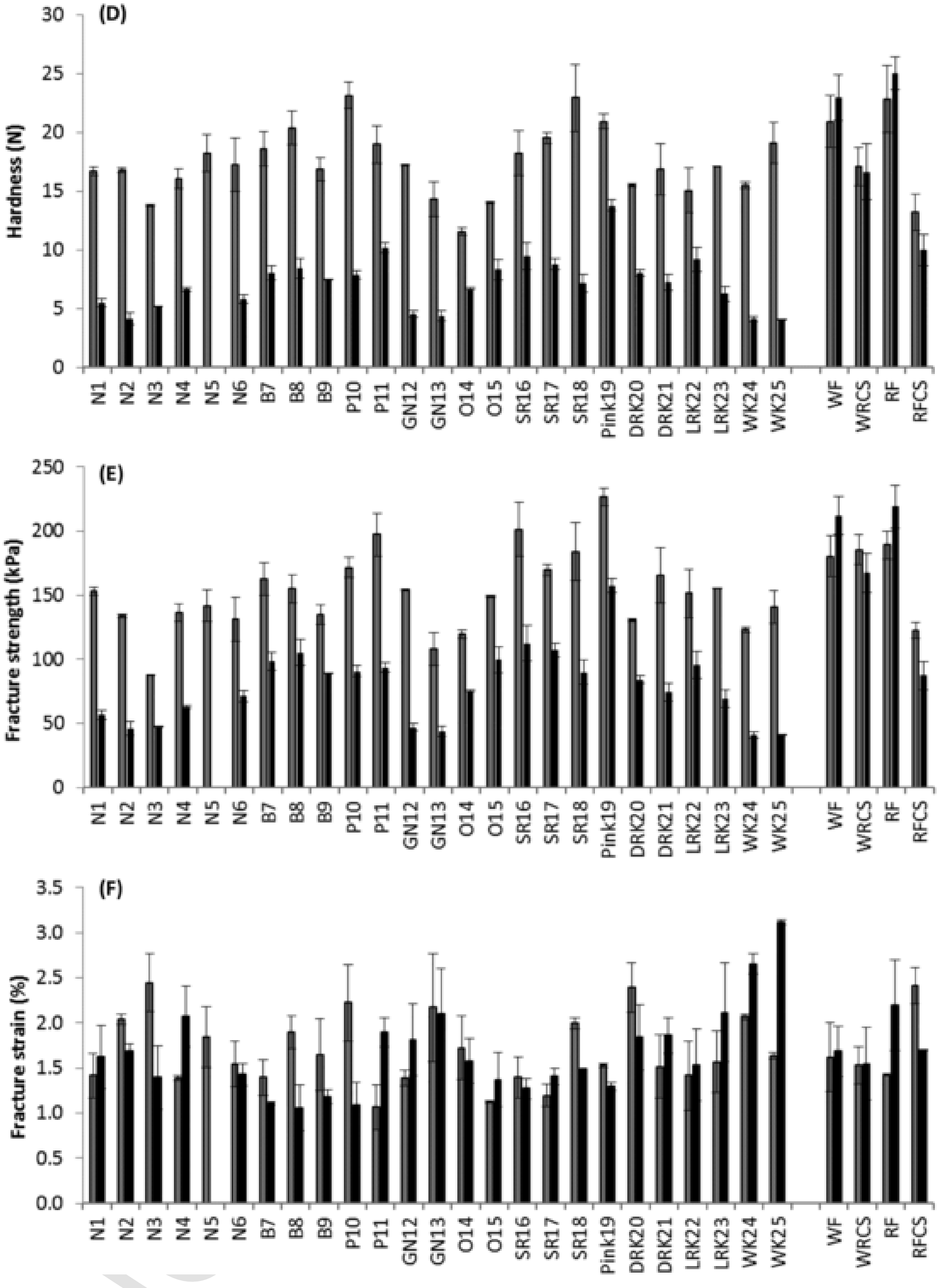

Fig. 3. (*Continued*)

weak dough structure. Thus, in order to investigate the technological quality of cookies, their textural properties have to be considered.

3.2.3. Textural properties

Generally, cookies are brittle food products that break into two or more pieces when a perpendicular force is applied. The breaking curves that characterized the bean cookies and the reference samples typically showed a rapid increment of force till the breaking point, followed by a rapid decrease of the force (sharp breaking peak; Fig. 4). However, similar to breads and cakes that are considered as solid food foam with air bubbles dispersed within a matrix (Zúñiga & Aguilera, 2008), from a rheological point of view, cookies can be defined as solid foam with air bubbles trapped in a continuous matrix.

During a three-point bending test, the cutting force is distributed throughout preferential lines depending on the dough formulation and structure, and it is not unusual to notice more than one breaking peak (Fig. 4).

In order to compare the textures of cookies containing the 25 fine and 25 coarse bean blended powders and the reference samples, the maximum force necessary to break the cookies was recorded as an in-

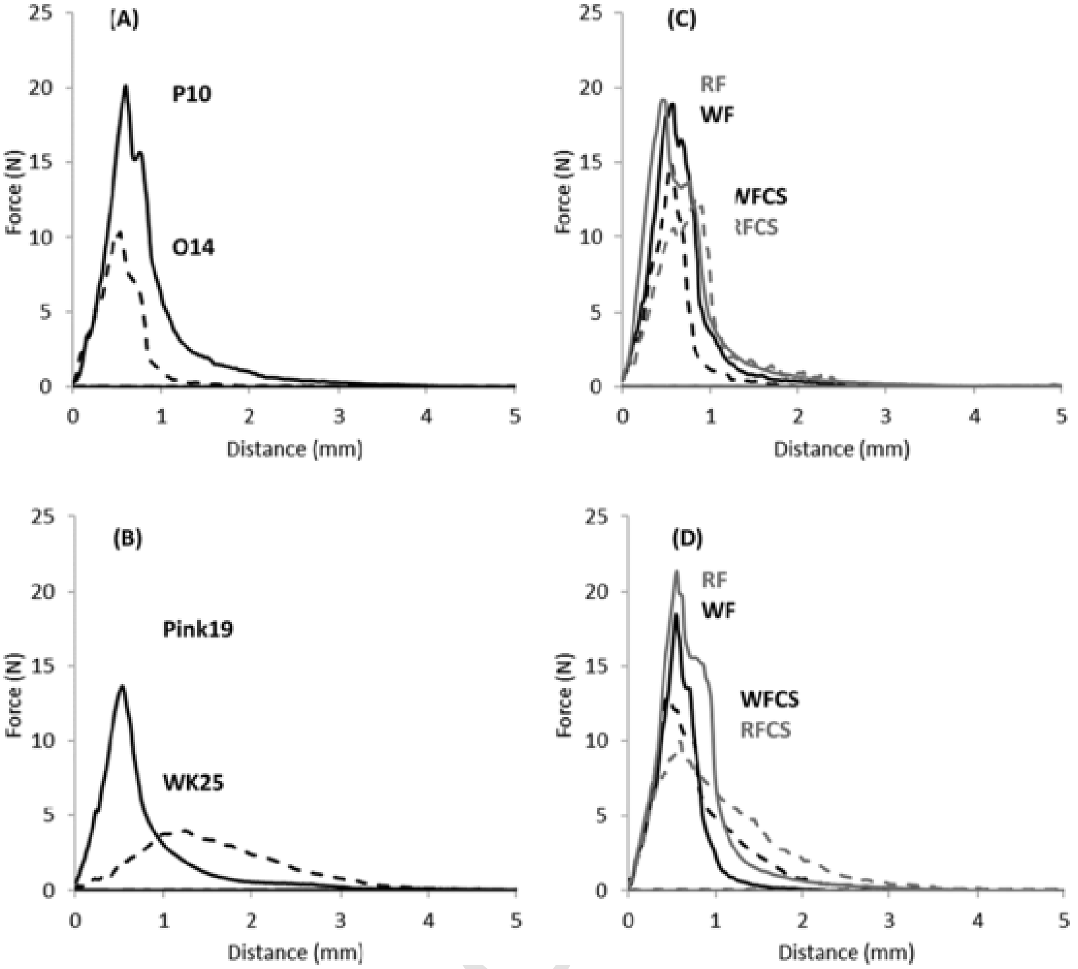

Fig. 4. Breaking curves of the cookies containing (A) fine (particle size ≤ 0.5 mm) and (B) coarse (particle size ≤ 1.0 mm) bean powders[1] blended with corn starch with indication of samples having the lowest (black dash) and the highest (black line) forces necessary to break the sample and of the respective reference cookies (C and D) made with wheat flour (WF, black line), wheat flour blended with corn starch (WFCS, black dash), rice flour (RF, gray line) and rice flour blended with corn starch (RFCS, gray dash)[2].[1] See Table 1 for bean market classes and variety names.[2] Bake time for samples in A and C was 13 min, and in B and D was 11.5 min.

dex of overall cookie hardness (Fig. 3). Even if the protein content (Table 2) was much higher for the cookies containing bean powders, the hardness values of the fine-bean-powder cookies were comparable to the references samples: ranging from 11.5 (Fuji) to 23.1 N (Eldorado) and from 13.2 (RFCS) to 22.8 N (RF). In particular, some bean varieties (e.g., Zenith and Rosetta) had hardness values similar to the cookies containing wheat (20.9 N). This finding is promising as a higher nutritional quality was achieved without compromising the cookie structure. Conversely, Cheng and Bhat (2016) found that increased protein content made for a harder cookie.

For the coarse-bean-powder cookies, much lower hardness values were recorded: from 4 to 4.5 N (Beluga, Snowdown, Medalist, G13479 and Powderhorn) to 10.17–13.76 N (La Paz and Rosetta). This can be attributed to the fact that coarse powders interfere with protein network formation and weaken the dough as already evidenced by higher spread ratio values.

According to the AACC Method 10-54 (AACC, 2000), high quality cookie flour is usually associated with tender cookie texture, however the coarse-bean-powder cookie samples in the present study seemed to be too brittle in comparison with reference samples, suggesting potential difficulties in the industrial handling (e.g., packaging and distribution phases) of this product.

Since the hardness values measured during the three-point bending tests do not account for geometrical dimensions (e.g., thickness), fracture strength was calculated using the equations proposed by Bruns and Bourne (1975). For the fine-bean-powder cookies some differences were noticed in terms of hardness and fracture strength; in fact, Merlin, which had a low-to-intermediate hardness, was the sample requiring less stress to be broken (87 kPa), whereas Rosetta, which had an intermediate-to-high hardness, required the greatest stress (226 kPa). For the coarse-bean-powder cookies, both hardness and fracture strength values evidenced similar trends since the samples that exhibited lower/higher hardness also had similarly lower/higher fracture strength values: Snowdon and Beluga had the lowest hardness and fracture strength values (4 N and 41 kPa, respectively) and Rosetta the highest values (13.8 N and 157 kPa, respectively). It is thus possible to state that the differences noticed among hardness values are affected more by the ingredients used (e.g., type of flour/powder, bean genotype and bean powder particle size) rather than the geometrical features of the cookie.

As can be noticed in Fig. 3, not only the hardness and the fracture strength values but also the fracture strain values differed among the cookies. The fracture strain values refer to the distance covered by the blade in order to break the cookie and it is normalized by the cookie thickness (according to the equations proposed by Bruns & Bourne, 1975). The smaller the fracture strain value, the more brittle the cookie. For fine-bean-powder cookies, the fracture strain values ranged from 1.1% (very brittle; La Paz and Samurai) to 2.4% (not brittle; Red

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Hawk), whereas the reference samples had medium-to-low values (1.4–1.6%; medium brittle), excluding the RFCS sample, which was more deformable (fracture strain of 2.4%). For coarse-bean-powder cookies, the fracture strain values were even more diverse with values ranging from 1.1% (Zorro, Zenith and Eldorado) to 3.1% (Beluga), whereas the wheat and rice reference samples had values of 1.5% and 2.2%, respectively. The white kidney coarse bean powders (Snowdon and Beluga) showed a more "plastic" behavior in comparison with the other bean samples: they required less force to be broken and had higher fracture strain values, suggesting they are not suitable for producing crispy products.

3.3. Correlation among rapid test indices and bean cookie features

The relationships among solvent retention capacity, oil binding capacity, RVA-indices and the baking performance of the 25 edible fine and 24 edible coarse bean powders were investigated. Pearson's product moment correlations between each pair of variables were calculated to measure the strength of the linear relationship between the variables. In order to evidence the difference among the bean varieties, the samples containing fine and coarse bean powders were analyzed separately. The references (WF, WFCS, RF, RFCS) were not accounted for in the correlation analysis as they were too distant from other observations.

For cookies containing fine bean powders (Table 1-Supplementary material), significant ($p < 0.05$) linear correlations among rapid test indices and some nutritional and technological properties of the cookie were found. In particular, WRC values correlated with protein content ($r = 0.49$) and with textural properties [hardness ($r = 0.42$) and fracture strength ($r = 0.47$)]. In accordance with Guttieri, Bowen, Gannon, O'Brien, and Souza (2001) and Moiraghi et al. (2011), no correlations were found between LARC and protein content. Additionally, no correlations were found among WRC, LARC and spread ratio. In contrast, Berak, Mudgil, & Khatkar (2004) reported a negative correlation among cookie spread ratio and WRC and LARC ($r = -0.88$ and $r = -0.85$, respectively) and Guttieri et al. (2001) reported a negative correlation between cookie diameter and LARC ($r = -0.65$, $p < 0.001$). These controversial results are not surprising as the above authors refer to cookies based on wheat flour, whereas in the present study unconventional ingredients, such as bean powder, were used in combination with corn starch to produce value-added gluten-free cookies. To the best of our knowledge, few data are available in the literature concerning cookies containing bean powders (e.g., Ai et al., 2017; Sathe, Lyer, & Salunkhe, 1982) and no one has focused on the correlation among rapid test indices and the nutritional and technological quality of cookies containing bean powders.

OBC values of fine blends correlated with RDS values ($r = 0.55$, $p < 0.005$), indicating that the capacity to bind oil somehow interplays with starch availability. Contrary to expectation, RVA indices did not correlate with the quality of cookies containing fine bean powders.

For cookies containing coarse bean powders (Table 2-Supplementary material), significant ($p < 0.05$) linear correlations among RVA indices and the nutritional, geometrical and textural properties of the cookies were found. RVA peak viscosity correlated with thickness and diameter values ($r = 0.55$ and $r = -0.55$, respectively, $p < 0.01$) and with spread ratio values ($r = -0.72$, $p < 0.001$). RVA final viscosity correlated with thickness ($r = 0.51$, $p < 0.05$), diameter ($r = -0.56$, $p < 0.005$) and spread ratio values ($r = -0.69$, $p < 0.001$). RVA setback correlated with thickness ($r = 0.43$, $p < 0.05$) and diameter ($r = -0.51$, $p < 0.01$) and spread ratio values ($r = -0.62$, $p < 0.001$), and with RDS ($r = -0.44$, $p < 0.05$). Since higher values of spread ratio correlated with better cookie quality (Moiraghi et al., 2011), the advantages of estimating this indicator of cookie quality through RVA indices are clear (e.g., time-saving, low amount of sample required, etc.).

4. Conclusions

Present day interest in developing valuable nutrition-added products is growing. Furthermore, the scientific community and food companies would like to promote the consumption of pulse products (e.g., beans). However, it is difficult to incorporate high levels of fiber powders without changing the textural properties of the final product. The results of this research have demonstrated that bean powders can be used to produce healthier cookies (e.g., having higher protein content, lower RDS, higher RS, etc.) and that bean genotype appears to have a significant effect on cookie nutritional composition and textural properties. Furthermore, different baking properties were observed depending on the bean powder particle size used: fine-bean-powder cookies were more similar to wheat references in terms of cookie diameter and hardness, in contrast with coarse-bean-powder cookies.

The correlation values presented here demonstrate that rapid test indices (i.e., water and lactic acid retention capacity, oil binding capacity, and RVA-indices) could be used to partially design bean cookie features and, depending on bean powder particle size, different indices could be used as independent variables. Accordingly, the outcomes of this research could guide the making of value-added traditional and gluten-free cookies.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2019.125338.

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