Enrichment of rice snacks with pulse seed coat: phenolic compounds, product features and consumer hedonic response

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Abbreviations:

ABTS, 2,2'-Azino-bis(3-ethylbenzthiazoline-6-sulfonic acid); AC, antioxidant capacity; AC-ABTS, antioxidant capacity obtained through the ABTS assay; AC-FRAP, antioxidant capacity obtained using the FRAP assay; ANOVA, Analysis of variance; CC, chickpea seed coats; CWBPAs, cell wall-bound phenolic acids; dw, dry weight; FRAP, ferric reducing antioxidant power; PC, field pea seed coats; R, white rice; RP-HPLC/DAD, reverse phase high-performance liquid chromatography coupled to a diode array detector; SPAs, soluble phenolic acids; WAI, water absorption index; 15_PC, substitution of white rice with 15% of field pea seed coats; 30_PC, substitution of white rice with 30% of field pea seed coats; 15_CC, substitution of white rice with 15% of chickpea seed coats; 30_CC, substitution of white rice with 30% of chickpea seed coats.

Abstract

This study investigated the impact of pulse seed coats on rice-based snacks. Seed coats from peas (PC) and chickpeas (CC) were used at 15% and 30% levels and the co-extruded snacks were produced at industrial levels. Using both PC and CC reduced the content of phenolic acids, but it enhanced the amount and the profile of flavonoids of rice-based snacks, resulting in significantly higher antioxidant activity. Snacks with 15% CC showed a higher bulk density and a lower average pore radius than PC-snacks (at the same enrichment level); however, such features did not affect either texture or porosity. At high enrichment levels, PC resulted in less dense snacks, more porous with smaller pores resulting in a firm product, even higher than the control formulation (i.e., 100% rice). The physical features did not impact on consumer liking: all the seed coat-enriched samples were comparable and preferred to the control.

Keywords: legumes, green field pea, chickpea, bran, co-extruded snacks, sensory analysis

1. Introduction

The increase in snacking and in particular the types of snacks on the market have created a demand for more nutritious snack options (Brennan, Derbyshire, Tiwari, & Brennan, 2013). Indeed, most snacks are made from starch-based products (e.g. corn, wheat, rice), resulting in high starch content, and low nutritional value in terms of vitamins, minerals, amino acids, and fibre (Brennan et al., 2013). This is even more critical for people diagnosed with celiac disease, whose diet does not always contain the daily recommended 20-30 g of dietary fibre (Pellegrini & Agostoni, 2015). Stojceska, Ainsworth, Plunkett, & İbanoğlu (2010) suggested that adding vegetables and fruits (e.g., apple, beetroot, carrot, cranberry) to gluten-free snacks could enable food processors to provide healthy, dietary fibre-enriched products, which are currently missing from the gluten-free market.

With the growing interest in sustainable diets, the addition of food by-products has been proposed as an interesting approach to enhance the nutritional value of ready-to-eat snacks (Grasso, 2020). Pomace and bagasse from fruit and vegetables, oilseed cakes and whey from dairy have been extensively used as sources of fibre, protein and/or antioxidants (Grasso, 2020). As regards milling by-products, a recent review on bran-enriched snacks pointed out that bran from rice and oat has been widely used in the formulation of extruded snacks, while little information is available on the inclusion of seed coat from pulses in these kinds of product (Tyl, Bresciani, & Marti, 2021).

Pulses are increasingly appreciated for their low environmental impact, as well as for their nutritional and health-promoting features. However, their consumption is still somewhat limited in Western countries, due to the presence of both undigested oligosaccharides and anti-nutrient compounds (e.g., phytic acid). Different approaches have been proposed to enhance the nutritional traits of pulses, including dehulling and extrusion-cooking (Patterson, Curran, & Der, 2017). Given the current interest in using pulses (mainly after dehulling) in the formulation of cereal-based products (Bresciani & Marti, 2019), the valorization of their by-products (i.e., seed coats, commercially known as “bran”) represents an opportunity for the development of healthy and sustainable extruded snacks. The high content of dietary fibre in pulse seed coats, along with significant amounts of minerals and polyphenols, suggests they could be more widely utilized as novel dietary fibre ingredients (Zhong et al., 2016).

In particular, seed coats contain most of the antioxidant phytochemical activity of whole pulse seeds, i.e. 70% of the total phenolic acid and flavonoid contents (Luo, Cai, Wu, & Xu, 2016).

Even if fiber-enrichment as well as nutritional enrichment adds value to the consumer (Alava, Verdú, Barat & Grau, 2019), the addition of such ingredients in a food matrix leads to several changes in sensory properties (Wang et al., 2020) potentially influencing consumer hedonic responses. Indeed, it is widely reported that consumers favor taste over nutritional properties (Jaeger, Axten, Wohlers & Sun-Waterhouse, 2009) and consequently perceptual factors - namely the taste, smell, texture, and appearance of a food- are among the main factors influencing consumer choices regarding healthy and sustainable foods (Tuorila & Hartmann, 2020). Therefore, the impact of adding green pea or chickpea seed coats to a specific product needs to be further investigated. Previous studies, mainly performed using legume flour without seed coats, indicated that formulations with up to 40% of pulses can be used to prepare snacks, such as crackers, without reducing their sensory quality (Millar et al., 2017), while other findings depicted a decrease in acceptability scores when only 20% of a wheat flour formulation was substituted with legumes (Venkatachalam & Nagarajan, 2017). Recently, a new rice-based snack formulation with cereals partially replaced with chickpea and green pea coats obtained positive hedonic ratings (Proserpio, Bresciani., Marti & Pagliarini, 2020).

The present study aimed at assessing the effect of different sources of seed coats (field green peas or chickpeas) at two different enrichment levels (15% or 30%) on the content of bioactive compounds and the consequent antioxidant and structural features (porosity, bulk density and firmness) in rice-based co-extruded snacks, as well as their consumer acceptability.

2. Materials and Methods

2.1 Materials

Milled white rice (R), field pea coats (PC) and chickpea coats (CC) were provided by Molino Peila S.p.A. (Valperga, Italy). PC and CC were hulled using a roller mill (Ocrim, Cremona, Italy). 75% and 55% of PC and CC particles, respectively, were in the 500-1500 μm range, with CC showing a higher incidence of coarse fractions (15% > 2000 μm) than PC (Fig. S1). Five formulations were considered: rice was used alone or in combination with PC or CC at 15% and 30% levels for the production of co-extruded snacks (R, 15_PC, 30_PC, 15_CC, 30_CC). Co-extruded snacks were produced by Fudex Group S.p.A. (Settimo Torinese, Italy) using a co-rotating twin-screw extruder (model 2FB90; screw speed: 150 rpm; temperature: 110 °C; pressure: 70 bar). Snacks were milled into powder (particle size <250 μm) using a laboratory mill (IKA Universalmühle M20; IKA Laborteknic, Staufen, Germany), with a water-cooling system to avoid overheating, in order to assess the water absorption index as well as the content in damaged starch, phenolic acids, flavonoids, and antioxidant capacity.

2.2 Methods

2.2.1 Seed coat composition

Moisture content was determined by oven-drying at 105 °C for 24 h and used to express all the results on a dry weight (dw) basis. Total starch content was measured according to the standard AACC 76-13.01 method (AACC, 2001), total protein (AOAC 990.03, by the Dumas method conversion factor: 6.25), total dietary fiber (AOAC 985.29, by the enzymatic-gravimetric method), fat (AOAC 2003.05, Soxhlet method) and ash (AOAC 923.03, muffle furnace) contents were determined according to the AOAC (2005) procedures.

Phytic acid content was measured by means of the colorimetric determination of the phosphorus released by phytase and alkaline phosphatase, using a Phytic acid assay kit (K-PHYT 05/17; Megazyme International, Bray, Ireland).

2.2.2 Phenolic acids, flavonoids and antioxidant capacity (AC)

Phenolic acids, flavonoids and AC were analyzed as raw materials (R, PP and CC) individually, in mixtures of rice and pulse seed coats before extrusion, and in the extruded snacks.

Extraction and quantification of soluble phenolic acids (SPA; both free and conjugated) and cell wall-bound phenolic acids (CWBPA) were performed by means of reverse phase high performance liquid chromatography coupled to a diode array detector RP-HPLC/DAD as reported in Giordano, Reyneri, Locatelli, Coïsson, & Blandino (2019).

Flavonoids were extracted using 80% aqueous acetone as solvent, and then quantified using the RP-HPLC-DAD method, previously reported in Blandino et al. (2022).The total AC was determined by means of FRAP (Ferric Reducing Antioxidant Power) and ABTS [2,2'-Azino-bis(3-ethylbenzthiazoline-6-sulfonic acid)] assays adapted from the QUENCHER method, as described by Giordano et al. (2019). The results were expressed, through a calibration curve, as mmol Trolox equivalents kg^{-1} of sample (dw).

2.2.3 Physical properties of co-extruded snacks

The colour of the snacks was measured using a reflectance colour meter (CR 210, Minolta Co., Osaka, Japan) to measure the lightness and saturation of the colour intensity. Damaged starch was assessed by AACC 76- 31.0 method (AACCI, 2001).

Water Absorption Index (WAI) was determined calculating the amount of water absorbed and retained by the powder. Briefly, 1.0 ± 0.1 g powder was mixed with 10 mL distilled water (WAI), vortexed for 30 s, then left for 30 min at room temperature. Mixtures were centrifuged at 2500 x g for 20 min using a Rotofix 32A centrifuge (Andreas Hettich GmbH & Co. KG, Tuttlingen, Germany), and the supernatant was decanted. WAI was calculated as the ratio between grams of water retained per gram of solid.

Sections and the inner areas of the snacks were measured by image analysis (Image ProPlus software, v6; Media Cybernetics, Inc., Rockville, US), as reported by Bresciani, Giordano, Vanara, Blandino, & Marti (2021). Annulus area was calculated as the difference between sections and the inner area.

Porosity, average pore radius, and bulk density were assessed with a Pascal Mercury Porosimeter (P240; Thermo Fisher Scientific, Waltham, US), according to Lucisano, Pagani, Mariotti, & Locatelli (2008). Samples were subjected to increasing pressure of up to 200 MPa, and pores with a radius of 3.7 × 10−3 to 50 μm were measured.

The firmness of the snacks was determined by means of a three-point bend method as reported by Bresciani et al. (2021).

2.2.4 Sensory evaluation

A total of eighty-seven subjects (35% men; mean age: 29 ± 9 years) were recruited among students and employees of the Faculty of Agriculture and Food Sciences of the University of Milan. Only subjects who liked legumes and rice, and were free of food intolerances and allergies were involved. This study was approved by the Ethics Committee of the University of Milan and was conducted in compliance the Declaration of Helsinki. All participants signed a written informed consent for involvement in the study.

The five co-extruded snacks were subjected to the liking evaluation. Participants attended one session of sampling at the Sensory and Consumer Science Laboratory (SCS_Lab) of the Department of Food, Environmental and Nutritional Sciences of the University of Milan designed according to ISO guidelines (ISO 8589 2007). They were asked to consume only water 2 h before the test. One snack at a time was given to the participants, a 30 g. portion in a plastic plate labelled with a 3-digit code. Water was available for rinsing the palate between samples. Participants were asked to taste each sample and then to express their liking using a labeled affective magnitude (LAM) scale anchored by the extremes "the greatest imaginable dislike" (score 0) and "the greatest imaginable like" (score 100; Schutz & Cardello, 2001). Instructions about the use of the scale were provided to the participants at the beginning of the session which took approximately 15 min. Data acquisition was performed with Fizz v2.31 software (Biosystèmes, Couternon, France).

2.3. Statistics

Damaged starch, WAI, SPA, CWBPA and flavonoid contents, AC-FRAP, AC-ABTS were measured in triplicate. Porosity, average pore radius and bulk density were measured in duplicate, whereas image and texture analyses were carried out on ten and thirty pieces, respectively. Color analysis was carried out on ten pieces.

One-way analysis of variance (ANOVA) was performed by IBM SPSS Statistics for Windows Version 24 (IBM Corp., Armonk, NY, USA) to compare the effect of the combination of raw materials (rice and pulse seed coats at different levels of substitution) and extrusion-cooking processes on the content of polyphenols and AC. As far as the technological traits of snacks and their sensory evaluation are concerned, ANOVA model was performed on the physical properties and overall liking scores considering snack samples as factors. For all the assessments, when a significant difference ($p < 0.05$) was found, the Tukey HSD post hoc test was performed as a multiple comparison test.

3. Results

3.1 Proximal composition and phytochemical contents of raw materials

The total macronutrient composition of pulse seed coats and rice flours is reported in Table 1. PC had more fiber content (92.6%) than CC (78.0%), which otherwise reported more protein (11.2%), lipids (5.3%) and ash (3.4%). Phyitic acid content in pulse coats ranged from 4.5 mg kg^{-1} of CC and 0.8 mg kg^{-1} of PC, while R showed intermediate values.

PC and CC had a significant lower content of SPAs (-58%) and CWBPAs (-69%) than R (Table 1), but a significantly higher total flavonoid content (+7.8 time for CC and +16.8 times for PC). As for pulses, PC showed a higher content of both SPAs (+15%) and CWBPAs (+62%) and flavonoids (+42%) than CC.

Otherwise, marked differences have been reported in their composition. The mains SPAs in rice are sinapic (43%) and ferulic (37%) acids, while sinapic (43%) and hydroxybenzoic (29%) acids are the most abundant SPAs in PC, whereas CC mainly contains hydroxybenzoic (57%) acid. As far as the CWBPAs are concerned, R content referred mainly to ferulic (80%) acid, and lower content of sinapic (12%) and *p*-cumaric (7%) acids. In PC the main CWBPA was ferulic (41%) acid, followed by gallic (19%), hydroxybenzoic (11%), *p*-cumaric (10%) and sinapic (10%) acids, while in CC 41% was hydroxybenzoic acid, followed by ferulic (26%), sinapic (15%) and *p*-cumaric (8%) acids.

As for flavonoids, the main compound identified in rice was apigenin-7-O-glucoside, followed by quercetin-3-O-rhamnoside (Fig. 2). Epicatechin was the most abundant compound identified in both pulse seed coats, accounting for about 75% of total flavonoids in PC and about 37% in CC. Catechin (17%, relative percentage), kaempferol-3-O-rutinoside (4.3%), hyperoside (1.8%) and luteolin-3-O-glucoside (1.7%) were also identified in PC. Excluding flavan-3-ols (epicatechin and catechin), the other identified flavonoids were higher in CC than in PC. Besides epicatechin, CC mainly contains hyperoside (21%), kaempferol-3-O-rutinoside (15%), apigenin-7-O-glucoside (9.1%), quercetin-3-O-rhamnoside (8.8%) and rutin (6.8%). No difference was recorded between the samples for AC measured through FRAP assay, while AC_{ABTS} was significantly higher in PC (+34%) and CC (+95%) than R.

3.2 Effect of processing on polyphenol content

The substitution of white rice with pulse seed coats significantly reduced the content of SPAs (-29%) and CWBPAs (-21%), without significant differences due to replacement level (Fig. 1). On the contrary, total flavonoid content increased as the replacement level increased. For example, the content was up to six times higher in 30_PC than R.

As expected, extrusion significantly reduced SPA content, by 91% in rice alone and by 82% in snacks with pulse seed coats. However, no differences in amounts of SPAs were detected among the snack samples. Regardless of the formulation, the highest reduction was detected for sinapic acid (-93%), followed by ferulic (-85%) and hydroxybenzoic (-77%) acids. As regards CWBPAs, extrusion significantly increased their content in R (+22%), 30_PC (+34%), and 15_CC (+22%) snacks. On average, the main CWBPA increase was reported for sinapic (+84.6%), hydroxybenzoic (+64.5%) and protocatechuic (32.9%).

Total flavonoid content was reduced by the extrusion process mainly in the case of rice alone (-69%), followed by CC-based snacks (relative decrease of 50% and 36% in 15_CC and 30_CC, respectively) and by PC-based snacks (-17% and -15% in 15_PC and 30_PC, respectively). These differences could be mainly associated with the different flavonoid compositions of the raw materials: in fact, the main compounds affected by the process were apigenin-7-O-glucoside and quercetin-3-O-rhamnoside (on average -60% and -58%, respectively), which were both present in higher amounts in R and CC than in PC.

3.3 Effect of processing on antioxidant capacity (AC)

Only the substitution of R with CC at 30% level significantly increased AC_{ABTS}, while no difference was recorded with other treatments (PC and enrichment level) or for AC measured through FRAP assay (Fig. 3).

Extrusion did not increased AC in snacks made with white rice only (R), while AC_{FRAP} was significantly higher in 15_PC (+89%), 30_PC (+116%), 15_CC (+66%) and 30_CC (+152%). With the exception of R and 15_CC snacks, where a reduction was observed compared to raw materials, the extrusion process did not affect AC_{ABTS}. Thus, compared to rice alone, AC_{ABTS} was higher by 35%, 44%, 44% and 109%, for 15_PC, 30_PC, 15_CC and 30_CC snacks, respectively.

3.4 Physical properties of snacks and their liking assessment

The images of the snacks are reported in supplementary Fig. S2, whereas the physical properties are summarized in Table 2. The type of seed coat added and the enrichment level influenced the physical properties of co-extruded snacks to varying degrees. As regards color, seed coat enrichment increased the luminosity (L*), redness (a*) and yellowness (b*) of snacks. Specifically, the highest a* and b* values were obtained for snacks with a 30% addition of chickpea seed coats (30_CC). Increasing the amount of seed coats caused considerable changes in the color of snacks, however these differences were significantly greater in snacks with an addition of CC.

Adding PC to rice decreased WAI regardless of the enrichment level (15 or 30%). A decrease in WAI due to fiber was also shown by Jin, Hsieh, & Huff (1995). On the contrary, CC did not affect hydration properties at the low level (15%), whereas 30_CC resulted in the highest WAI. Regardless of the enrichment level, CC was able to absorb more water than PC.

Adding pulse seed coats significantly decreased the section area (except for 15_CC), as well as the internal area, of rice-based snacks. At the 15% level, CC led to higher section areas, indicating a more expanded product compared to PC. However, such differences were not observed at the 30% level. Regardless of the content of seed coat, CC resulted in co-extruded snacks with a higher annulus and a lower hole/annulus ratio. Although seed coat-enrichment decreased bulk density, CC-based snacks showed a higher bulk density than PC-enriched products. As the CC-enrichment level increased, the section area decreased and the bulk density increased, indicating a less expanded and more compact product, respectively. This is attributable to the increase in the insoluble fiber that limits the expansion of the extrudate (Robin et., 2011; Robin, Schuchmann, & Palzer, 2012). In the case of PC, the enrichment level did not affect the expansion rate, but it affected bulk density. These results are partially supported by previous studies on corn grits enriched with oat, wheat and rye bran, that showed a decrease in expansion rate and an increase in the density of snacks as the percentage of bran increased from 20 to 40% (Makowska, Polcyn, Chudy, & Michniewicz, 2015). The higher fiber content in PC might also account for the lower expansion rate of 15_PC compared to 15_CC. However, at higher seed coat percentages, other factors should be considered, including interactions among biopolymers.

Seed coat enrichment led to a decrease in porosity. However, the type of seed coat did not affect either porosity or firmness when used at the 15% level. On the contrary, 30_CC snacks were less porous and less hard than 30_PC, and the internal structure was characterized by pores with higher average radius. At the 30% level, CC produced a denser extrudate with big air cell size; hence, lower breaking strength was observed compared to PC at the same enrichment level. Liking assessment results are provided in Fig. 4. A significant sample effect was found on liking scores. The 100% rice sample obtained the lowest liking score, while the samples made with 15% or 30% of both PC and CC were the favorites, with similar scores.

4. Discussion

The impact of fiber or sources of fiber, such as cereal bran, on snack characteristics have been extensively studied, as summarized in recent reviews (Grasso, 2020; Tyl et al., 2021). Thus, the following discussion will focus on the effect of the type of seed coat (field pea vs chickpea) rather than on the effect of the level of seed coat enrichment.

As expected, the inclusion of legume seed coats strongly influenced the phenolic composition of snacks (Fig. 1). Rice is a great source of polyphenolic compounds, particularly phenolic acids. Among them, ferulic acid is generally the most prevalent, followed by *p*-coumaric acid, sinapic acid, gallic acid, protocatechuic acid and p-hydroxybenzoic acid; however, their content in the endosperm is up to ten-fold less than in whole grains, resulting in lower amounts in milled white rice than in brown rice (Goufo & Trindade, 2014). In the same manner, flavonoids are mainly located in the outer layers of rice bran, and their content significantly decreases after milling (Ma, Yi, Wu, & Tan, 2020). The most common flavonoids in rice are flavones, such as tricin, luteolin, apigenin (Goufo & Trindade, 2014), but also flavonols and flavanols and/or their corresponding glycosides are also found (Bordiga et al., 2014; Bagchi et al., 2021). Using legume seed coats could be a way to enhance the polyphenolic profile of rice-based snacks (Fig 1; Fig. 2). In fact, as regards phenolic compounds in peas, more flavonoids are present in pea seed coats than in their cotyledons (Duenas, Hernandez, & Estrella, 2006). This evidence is consistent with our results; even if a partial decrease in polyphenols has been observed after extruding (Fig. 1), legume seed coat-based snacks had significantly more flavonoid content than the 100% rice snack (Fig. 2).

Seed coat enrichment also increased the antioxidant capacity of snacks compared to the control formulation (Fig. 3). This improvement may be related to their peculiar phenolic composition (higher total flavonoid content), because flavonoids are generally recognized as having more antioxidant capacity than hydroxybenzoic and hydroxycinnamic acids (Duenas et al., 2006), the main polyphenols in rice. Nonetheless, despite of a major flavonoid content in PC-snacks, the highest antioxidant capacity was observed in 30_CC snacks. This could be due to the different antioxidant activity of individual compounds (PC and CC present different phenolic profiles), but also to the presence of other antioxidant components. The total AC was determined by means of FRAP and ABTS assays performed on solid samples without previous extraction; this means that other compounds could contribute to AC values. As an example, the pectin of chickpea husks is characterized by a dose-dependent free radical scavenging activity (Urias-Orona,et al., 2010).

Although the type of seed coat - especially differences in the composition of its components, including fiber solubility - might affect the characteristics of snacks (Brennan et al., 2008), seed coat enrichment often leads to a denser structure with a lower expansion ratio (Robin et al., 2012; Grasso, 2020). Our results showed an overall decrease in expansion rate, porosity, and bulk density (Table 2). Discrepancies with previous findings might be due to differences in types of seed coats and snacks. Indeed, our study differs from the literature because of the addition of pulse seed coats instead of the widely explored cereal bran. Moreover, most studies have focused on extruded snacks (Tyl et al., 2021), whereas this study has focused on co-extruded snacks that are made of an outer shell that is later filled with either a savory or sweet filling. In this kind of product, structure compactness is desirable, and it might be measured as low section area, high bulk density and porosity (Bresciani et al., 2021).

At 15% enrichment level, snacks showed similar porosity and texture (Table 2). The rice snacks produced in the present study are already available on the market, consequently they represent our control. Overall, at low enrichment levels, either CC or PC can be used since they do not dramatically alter the texture of the product. Although coat-enriched snacks showed similar porosity, the source of seed coats significantly affected the internal structure (i.e., average pore radius) of extrudate. Specifically, CC resulted in a denser structure (i.e., high bulk density) with small pores (i.e., low average pore radius). Bulk density is a very important product quality attribute for the commercial production of extruded products (Brennan et al., 2008). Since most extruded products are filled by weight and not by volume, changes in bulk density might lead the pack to be less than full or to overflow (Brennan et al., 2008).

The effect of the type of seed coat on snack features was greater at high enrichment levels: porosity and texture were higher, whereas bulk density was lower in 30_PC compared to 30_CC. Overall, PC created a less dense structure, but more porous with smaller pores resulting in a more compact product. Our results support previous findings on compact structure with small air cell size resulting in high breaking strength (Jin et al., 1995). Indeed, 30_CC showed the lowest firmness, whereas 30_PC the highest, even higher than control formulation (i.e., 100% rice). The type of seed coat did not significantly affect snack expansion (section area was similar in 30_CC and 30_PC), but significantly decreased the hole/annulus ratio. Besides expansion rate (which substantially determines the quality of snacks), in the case of co-extruded products, a regular hole is desirable since it has to be filled with either a sweet or savory cream (Bresciani et al., 2021). It appears that the size of air cells is related to radial expansion (i.e., annulus area) rather than volume expansion (i.e., section area, bulk density). Similar results were observed by other authors (Jin et al., 1995).

Overall, differences between CC and PC behaviour might be related to differences in chemical composition. The higher fat content in CC might account for the formation of a denser and less porous structure, likely due to the formation of amylose-lipid complex (Thachil, Chouksey & Gudipati, 2014), whereas the higher fiber content in PC would have prevented the formation of large cells (Jin et al., 1995). Larger pores in 30_CC might explain differences in water-sample interactions.

WAI mainly reflects the ability of starch to absorb water and is an indirect measure of the amount of gelatinized starch granules, since native starch granules do not absorb water at room temperature. On the other hand, WAI increases as gelatinization increases but it decreases if starch dextrinization prevails over gelatinization phenomenon (Singh, Hussain, & Sharma, 2015). Regardless of the differences in chemical composition among the raw materials (Table 1), the extrusion conditions applied in the present study promoted a similar degree of gelatinization, evaluated as damaged starch (i.e., the amount of starch granules that are easily susceptible to alpha amylase hydrolysis). Indeed, when normalized for the amount of total starch, the amount of damaged starch was not significantly different among the snacks (data not shown). Thus, damaged starch content cannot account for the differences in WAI. Neither does the amount of fiber: although PC was higher in fiber than CC, both of them decreased the WAI of snacks. It is likely that extrusion-cooking of PC led polysaccharides to interact, making the hydrophilic groups less available for binding water molecules. Differences in lipid content should also be considered, since lipids are known to decrease the shear viscosity in the extruder, resulting in decreased amylopectin depolymerization, thus resulting in lower starch solubility and higher absorption capability (Robin et al., 2012; Makowska et al., 2015).

As regards consumer evaluation, the snack developed with different percentages of pulse seed coats obtained significantly higher liking scores compared with the control made with rice flour only. No differences in hedonic responses have been found according to legume type (chickpea or green pea) or percentages of substitution (15% or 30%). According to present results, previous findings depicted that extruded snacks developed with different amounts of legume bran were well accepted by consumers (Proserpio et al., 2020), thus suggesting that snacks including pulse seed coats could likely have promising market potential, even better compared with more traditional rice-based snacks. In this context, co- extruded legume-based snacks present twofold advantages: on the one hand, they are ready-to-eat foods with increased amounts of fiber, protein and flavonoid, and higher antioxidant capacity than rice snacks; on the other hand, extrusion allows the production of a variety of textures and shapes that could have a positive impact on consumer response (Brennan et al., 2013, Singh et al., 2007). Indeed, consumer acceptance of extruded snacks crucially depends on expansion and texture properties (Tyl et al., 2021). So it has been suggested that highly expanded, extruded commercial snacks are perceived as crispy and light, while poorly extruded ones are evaluated as harder, crunchier and less crisp (Paula, & Conti-Silva, 2014). Moreover, Proserpio et al. (2020) reported that co-extruded snacks enriched with pulse seed coats (chickpeas or peas up to 30% level) negatively affected consumers who perceived the snacks as being ‘hard’, thus supporting findings that highlight the key role texture-related characteristics play in consumer preferred formulations (Jeltema, Beckley & Vahalik, 2016).

5. Conclusions

Extrusion technology is increasingly used for the production of snack foods and has been investigated in connection with improving the dietary profile of snacks. In this study, seed coats from chickpeas and green peas have been proposed as ingredients in rice-based co-extruded snacks produced industrially.

The type of seed coat affected the structure of the product (in terms of density, porosity and firmness), without affecting the liking score as assessed by sensory analysis.

Overall, the addition of bran from pulses in snack formulations can be considered a successful strategy to enrich the product with protein, fiber and flavonoids (e.g., flavan-3-ols, hyperoside, kaempferol-3-O-rutinoside, apigenin-7-O-glucoside) and other bioactive compounds with antioxidant activity, as well as increase consumer acceptability compared to rice snacks.

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