AGRICULTURE AND FOOD DEVELOPMENT AUTHORITY

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Effect of pulse flours on the physiochemical characteristics and sensory acceptance of baked crackers.

Running title: Pulse flours in baked crackers

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Recommended citation:

Millar, K. A., Barry-Ryan, C., Burke, R., Hussey, K., McCarthy, S. and Gallagher, E. (2017), Effect of pulse flours on the physiochemical characteristics and sensory acceptance of baked crackers. *Int J Food Sci Technol*, 52: 1155–1163. doi:10.1111/ijfs.13388.

Summary

Pulse flours offer nutritional alternatives to wheat flour in the production of baked snacks due to their high protein and fibre levels and low glycaemic index. In this study, broad-bean (*Vicia faba*), yellow-pea and green-pea (*Pisum sativum*) flours were each blended with wheat flour at 40% in the formulation of chemically-leavened crackers. The effects of flour type and baking time on the physiochemical properties, sensory acceptability, nutritional composition and antioxidant activity of the crackers were observed in comparison to 100% wheat crackers. Broad-bean crackers had the highest protein content and antioxidant activity (13g/100g DM and 38.8 mgAAE/100g DM respectively). Yellow-pea crackers had the highest fibre content (12g/100g DM). Physical dimensions and colour attributes were significantly affected by pulse flour substitution. Yellow-pea and broad-bean crackers were significantly preferred by consumers compared to the control, demonstrating the potential application of these flours to improve the eating quality and nutritional profile of crackers.

Keywords: Pulse flours, crackers, texture, sensory evaluation, plant protein, fibre, antioxidant, polyphenols.

Introduction

The snack market is an ever-expanding area, including foods such as crisps, crackers, cookies, biscuits and bars. Now more than ever, consumers are seeking broader and more nutritive functions from their snacks as they become a bigger part of their daily diet (Bord Bia, 2014). Crackers currently represent a significant share of the snack market and provide key opportunities for new product development particularly in the area of functional foods (Business Insights, 2012). Crackers have been traditionally prepared and consumed due to their convenience and stable shelf-life, and include three broad varieties: soda crackers or saltines, chemically-leavened crackers, and savoury (flavoured) crackers (Han *et al.*, 2010). Soda crackers are made using a sponge and dough method and are fermented for up to 24 hours, which contributes to their unique texture and flavour attributes; while chemically-leavened crackers have a much quicker production method, using leavening agents such as sodium bicarbonate or monocalcium phosphate (Kweon *et al.*, 2011). Savoury crackers are most often produced using the fermentation method, during which flavourings such as cheeses, herbs or spices may be added (Han *et al.*, 2010).

Pulse vegetables are leguminous grains which are harvested solely for the seed. They have a long history as a staple food in Eastern countries such as India, China, Japan as well as many parts of Africa (Tiwari *et al.*, 2011). Consumption of pulses in the Western world however, remains limited to vegetarians and vegans, despite their increasing association with nutritional and health benefits (Ramdath *et al.*, 2016; Reynolds *et al.*, 2016; Abeysekara *et al.*, 2012). Such benefits have been attributed to their soluble and insoluble dietary fibres, low glycaemic index and high levels of polyphenolic compounds (Magalhães *et al.*, 2017; Campos-Vega *et al.*, 2010; Chung *et al.*, 2008). They are naturally low in fat, rich in vitamins and minerals including iron, folate and potassium, and phytochemicals such as phenolic acids, flavonoids and proanthocyanidins (Campos-Vega *et al.*, 2010). They also offer a relatively inexpensive and sustainable alternative to animal proteins (Day, 2013). With demand for sustainable and healthy food ingredients continuing to rise, the United Nations declared 2016 the International Year of the Pulse to identify pulses as key future resources and encourage research and innovation in Agri-Food industries.

Pulses lack sufficient essential amino acids to match the quality of those from animal sources, particularly sulphur-containing amino acids. They are, however, a rich source of lysine and when combined with cereals such as wheat, barley or maize they can offer a balanced proportion of essential amino acids (Temba *et al.*, 2016). Crackers, which are primarily a wheat-based snack, provide a key opportunity to the food industry to increase consumption of pulses through convenient and healthy food products.

In recent years, a number of studies have focused on using composite flours which contain pulses in breads, pasta, and baked goods (Herranz *et al.*, 2016; Zafar *et al.*, 2015; Giménez *et al.*, 2012). Addition of pulse flours to baked goods has proven to significantly increase protein content and antioxidant activity in comparison to wheat-only products (Zucco *et al.*, 2011; Giménez *et al.*, 2012).

The purpose of the current study was to examine the effect of supplementation of yellow-pea, green-pea (*Pisum sativum*) and broad-bean (*Vicia faba*) flours on the physical, nutritional and sensory characteristics of wheat- and pulse- based chemically-leavened crackers.

Materials and methods

Raw materials

Commercial plain (weak) wheat flour was obtained from Shackelton's Milling (Co. Meath, Ireland). Pulse flours were purchased from Hodmedod Ltd (Suffolk, United Kingdom): green pea (carboydrate 54.0%; fat 1.4%; protein 21.1%; total fibre 10.6%, moisture 10.8%, ash 2.1%), yellow pea (carboydrate 55.3%; fat 1.6%; protein 21.0%; total fibre 7.9%, moisture 10.5%, ash 3.7%) and broad bean (carboydrate 47.6%; fat 1.5%; protein 26.5%; total fibre 9.8%, moisture 12.3%, ash 2.3%). Other baking ingredients included palm fat, sugar, salt (all purchased locally) and sodium stearoyl lactylate (SSL) dough conditioner (DuPont, Cernay, France).

Chemicals

Methanol, Ethanol, Folin ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), sodium carbonate (Na_2CO_3) and hydrochloric acid (HCl) were obtained from Fisher Scientific (Fisher Scientific Ireland, Dublin, Ireland). Enzymes (protease, amylase and amyloglucosidase) were purchased from Megazyme (Bray, Ireland).

Preparation of crackers

A basic un-yeasted cracker formulation was chosen as the control formulation. Preliminary baking trials were carried out to establish the maximum flour substitution level and most appropriate baking times. Following these trials, 40% was established as the upper level for pulse flour substitution. It was also found that different flour blends required different baking times, therefore a minimum (21 min) and maximum (31 min) time was established for all blends. Crackers containing 100% wheat flour were cooked at 31 min only as crackers of suitable eating quality could not be produced at 21 min. Crackers were produced from 100% wheat flour (control) and wheat-pulse flour blends, each containing 60% wheat flour and 40% of pulse flour: broad bean (BB), yellow pea (YP) or green pea (GP). Dough samples were prepared by mixing all ingredients (Table 1) with water in a Kenwood mixer with a K-beater attachment for 2 mins. The dough was allowed to rest at room temperature for 10 mins and was subsequently sheeted to 2.5 mm thickness using a pastry dough sheeter (Rondo Doge Econom; RONDO Burgdorf AG, Switzerland) and cut into shape (44mm x 44mm). Each batch was baked at 175^{o}C in a deck oven (MacPan, Thienne, Italy). The crackers were allowed to cool at room temperature for 2 h before being placed in sealed polyethylene bags at room temperature until analysis took place. All crackers were prepared in triplicate and 45 crackers per replicate were prepared for analysis.

Physical analysis and chemical composition of flours and crackers

Water holding capacity (WHC) of the pulse flours and the wheat-pulse flour blends was measured using AACC method 56-30.01 (2001) with some modifications as carried out by Park *et al.* (2015). Moisture content of the flours and crackers was carried out using AACC method 44-15.02 and was measured on days 1, 7 and 28.

Protein content was determined according to AOAC Method 968.06, using a nitrogen analyser (FP-328 Leco Instrument; Leco Corporation, St Joseph, Michigan, USA) based on the Dumas principle (Nx6.25). Results were corrected for moisture and are reported as g/100g dry matter (DM).

Soluble (SDF), insoluble (IDF) and total (TDF) dietary fibre was determined according to AOAC Method 991.43, using the ANKOM dietary fibre analyser (ANKOM technology, New York, USA). Results were corrected for moisture and are reported as g/100g DM.

Dimensions

The weight and dimensions of 30 crackers were averaged for each formulation and replicate. Length, width and thickness were measured with Vernier callipers; spread ratio, specific volume and density were calculated for each sample.

Colour

Colour measurements were carried out using a Minolta Lab colorimeter (CR-400/410, Konica, Minolta, Ireland). $L*$, $a*$, and $b*$ values were recorded; Chroma (C) and colour difference from the control (δE) were calculated using the equations 1 and 2 (Wibowo *et al.*, 2015). The results are the average of 10 measurements per formulation and replicate.

$$C = \sqrt{a*^2 + b*^2} \quad \text{Eq. (1)}$$

$$\delta E = \sqrt{(L*_C - L*_S)^2 + (a*_C - a*_S)^2 + (b*_C - b*_S)^2} \quad \text{Eq. (2)}$$

Where,

C = control

S = test sample

If δE > 3, the difference should be visible.

Texture

Texture characteristics of all dough and cracker formulations were assessed using a Texture Analyzer (TA-XT2*i*; Stable Microsystems, Surrey, UK) equipped with a 25-kg load cell and connected to Exponent software version 5.0.6.0. Dough texture profile analysis was measured using a 20-mm cylindrical Perspex probe and a 40% compression rate at a test speed of 1 mm $sec^{-}1$. Hardness of the baked crackers was measured using a three-point bending rig (HDP/ 3PB). The two adjustable supports of the base plate were set 26 mm apart, and the sample was placed on top. The upper blade moved downwards at a speed of 2 mm $sec^{-}1$, measuring maximum force required to break the sample and distance at the point of break. An average of 10 samples was taken for each formulation and replicate; measurements were taken on days 1, 7 and 28.

Water activity

Water activity (a_w) of all samples was measured using an AquaLab meter (Decagon Devices Inc., Pullman, WA, USA). Approx. 2 g of ground sample was placed in the water activity metre and a_w and the temperature was recorded. Five measurements were taken for each sample on days 1, 7 and 28.

Sensory evaluation

Sensory evaluation was undertaken 24 h after baking with 40 untrained panellists recruited from Teagasc Food Research Centre and Dublin Institute of Technology. Sensory evaluation was conducted in a sensory laboratory with separate booths designed according to ISO standard 8589:2007. Samples were placed on white polystyrene plates labelled with three-digit random codes, for not more than one hour prior to testing and presented to consumers in a randomized order. Consumers evaluated samples in a sequential monadic order and the samples were presented according to a balanced Williams Latin-square design. A 60 second time lapse was employed between each sensory test where panellists were given water to rinse their palate, to reduce sensory fatigue. Panellists evaluated the samples for overall appearance, colour, hardness and mouthfeel using a 9-point hedonic scale with “extremely dislike” to “extremely like” as left and right anchors, respectively.

Antioxidant analysis

For quantification of total phenolic content (TPC) and antioxidant activity (AOX), 1g of finely ground cracker was extracted in 10 ml of methanol (80%) for 1 h at 40^{o}C in a rotary incubator. Extractions were carried out in acidified conditions (1% HCl) to prevent oxidation of polyphenols (Reis *et al.*, 2012). Samples were centrifuged at 10,000rpm for 10 minutes and the supernatant was collected. The remaining pellet was extracted twice more and the supernatants were pooled and concentrated using a rotary evaporator at 60^{o}C. The samples were adjusted to 10 ml with deionised water and stored in the dark at -20^{o}C until analysis. TPC was measured according to the Folin-Ciocalteu method as carried out by Cox *et al.* (2010). Results were corrected for moisture and expressed as mg gallic acid equivalents (GAE) per 100 g of dry matter. The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay was carried according to Rajauria *et al*. (2010). DPPH radical scavenging activity was calculated using the following equation:

$$\%\ radical\ scavenging\ activity = \left(\frac{control\ abs - test\ abs}{control\ abs}\right) * 100 \qquad \text{Eq. (3)}$$

Results were corrected for moisture and expressed as mg ascorbic acid equivalents (AAE) per 100 g of dry matter.

Statistical analysis

Crackers were prepared in triplicate batches; mean values and standard deviations were calculated and all results were expressed as mean ± SD. Analysis of variance (ANOVA) was carried out using SPSS (IBM SPSS statistics version 21). A 2 x 4 factorial experiment for baking time and flour type respectively, was conducted to determine the effect of each treatment. Statistical significance was considered at $p \leq 0.05$. Where ANOVA indicated significant differences were present, Scheffe's multiple comparison was conducted to identify where sample differences occurred. To identify relationships between physiochemical parameters, bivariate Pearson's correlation analysis was carried out.

Results and discussion

Physical analysis and chemical composition of flours and crackers

Moisture content and water holding capacity

Both yellow-pea and green-pea crackers had lower moisture content than the control and broad-bean crackers (Table 2), though results were not significant. This reflected the lower moisture content of the yellow-pea and green-pea flours compared to the wheat and broad-bean flours (results not shown). In comparison to similar studies (Colla and Gamlath, 2015; Smith *et al.*, 2004), it was found that the crackers in the present study had a higher moisture content, particularly those baked at 21 min (Table 2), which may have implications for sensory evaluation (Vickers *et al.*, 2014). There was no change observed in moisture content over the 28-day testing period.

The water holding capacity (WHC) of green-pea and yellow-pea flours was significantly higher than wheat flour (results not shown). However, there was no significant difference in WHC for any of wheat-pulse flour blends.

Protein content

Addition of pulse flour significantly increased the protein content of the crackers which ranged from 10.20 to 13.02g/100g DM in the pulse-flour crackers, compared to 8.36g/100g DM in the control (Table 2). Broad-bean crackers had the highest protein content ($p < 0.05$) which supports the work of Tazrart *et al.* (2016) who observed a similar increase in protein content of pasta following addition of broad-bean flour. Substitution of wheat flour for pulse flours can increase the quantity of certain amino acids such as lysine which are low in wheat flour, enhancing the overall protein quality, as demonstrated in fresh spaghetti by Giménez *et al.* (2012). Crackers baked for 31 min had higher protein content than those baked for 21 min. Higher protein concentrations (g/kg DM) have been observed in several cooked bean varieties versus raw beans by Pujolà *et al.* (2007) and Wang *et al.* (2010). They attributed this increase to a loss of soluble solids during cooking which may have also occurred in this study as a result of longer baking time.

Fibre content

TDF in pulse-flour crackers ranged from 9.61 to 12.33 g/100g DM compared to the control cracker which contained 7.92 g/100g DM (Table 2). Yellow-pea crackers had the highest TDF, SDF and IDF (12.3, 7.18 and 5.15 g/100g DM respectively). Similar increases in TDF, SDF and IDF were reported in bread by Mastromatteo *et al.* (2014), following addition of pea flour. Broad-bean crackers had the lowest TDF though they were higher than those reported by Tazrart *et al.* (2016) for pasta substituted with broad-bean flour at 50%.

Cracker analysis

Dimensions

A significant decrease on cracker diameter, thickness, weight and volume was observed as a result of pulse flour inclusion (Table 3a). A reduction in weight (Table 3b) is in contrast with Zucco *et al.* (2011), who observed an increase in weight with following pulse flour substitution in cookies. Kamaljit *et al.* (2010) similarly reported a reduction in bread volume following pea flour addition. The reduction in thickness in yellow- and green-pea crackers was negatively correlated with an increase in spread ratio ($r^2 = -0.975$) which Park *et al.* (2015) also observed in cookies substituted with okara and soy flour. Only cracker diameter appeared to be reduced by baking time ($p < 0.01$), with no significant two-way interaction effects on cracker dimensions (results not shown).

Colour

The surface colour of a baked product is an important parameter for initial consumer acceptability. Both flour type and baking time significantly affected all colour parameters of the baked crackers (Table 4). The *L** value, which measures lightness on a scale of 0-100 (where 0 = black and 100 = white), was significantly higher in wheat-flour crackers than all other crackers irrespective of baking time, indicating a lighter appearance (Table 4). A significant negative correlation was observed between *L** values and protein content (r^2 = -.791), which suggests the darker colour of the crackers containing pulse flours can be partly attributed to Maillard-browning reactions (García-Baños *et al.*, 2004). Zucco *et al.* (2011) reported a similar reduction in *L** values following substitution of wheat flour with pulse flours in cookies. Results for *a** values (positive *a** values indicate red undertone, negative *a** values indicate green undertone) indicate that introduction of broad-bean and yellow-pea flours significantly increased the red hue of the crackers. As expected, green-pea flour increased the green hue of the crackers, particularly those baked at 21 min. At the prolonged baking time of 31 min however, the red hue increased which suggests increased Maillard-browning may counteract the effect of green-pea flour (Rothschild *et al.*, 2015). Results for *b** values (positive *b** = yellow undertone, negative *b** = blue undertone) were significantly higher in crackers formulated with each of the pulse flours than the wheat control, indicating an enhanced golden colour. The increased *a** and *b** values observed in this study are comparable to those reported by Han *et al.* (2010), who substituted wheat flour for a blend of pulse flours in crackers including yellow pea.

Chroma value (C^*_{ab}), a quantitative indicator of colourfulness, was significantly lower for control crackers, in comparison to those supplemented with pulse flours, indicating it had the least colour intensity (Wibowo *et al.*, 2015). The colour difference (δE), combines the change in *L**, *a** and *b** values to quantify the colour deviation from that of a standard or reference sample; those with a value > 3, display a visible colour deviation (Wibowo *et al.*, 2015). As expected, pulse-flour crackers had a $\delta E > 3$, exhibiting a visible colour deviation compared to the control, with those baked at 31 min having significantly higher δE values than those baked at 21 min.

Texture

Dough hardness was reduced by 40% substitution of pulse flours, but results were not significant (results not shown). There were no differences observed in dough cohesiveness or adhesiveness as a result of pulse flour substitution.

The hardness of the crackers, i.e. the force in Newtons required to break or snap the cracker, indicates quality and freshness to the consumer (Peleg, 2015). As expected, longer baking time significantly increased the hardness of all pulse-flour crackers (Table 4) and was negatively correlated with moisture content (r^2 = -0.798). When baked for 31 min, crackers formulated with broad-bean flour were the hardest which may be attributed to the higher total dietary fibre and protein contents observed in this cracker (Park *et al.*, 2015); a positive correlation was revealed between hardness and total fibre (r^2 = 0.753). A significant two-way interaction effect was observed between flour type and baking time, whereby at 21 min baking time yellow-pea crackers were the hardest, whereas at 31 min baking time broad-bean crackers were the hardest. The texture characteristics of the crackers did not change over the testing period.

Water activity

The a_w of the cracker samples baked for 21 min were significantly higher than those baked for 31 min. For both microbiological safety and sensory acceptability, dry snack products such as crackers require and a_w of below 0.5 (Smith *et al.*, 2004). Crackers baked at 31 min were ≤ 0.5 while crackers baked at 21 min were > 0.5 (Table 4). No change was revealed over a 28-day testing period indicating stable products.

Sensory evaluation

The objective of sensory evaluation in this study was to establish consumer preferences with respect to appearance and eating quality of crackers formulated with wheat-pulse flour blends, and to correlate where possible, consumer preferences with product characteristics. Results for consumer preferences as recorded on a 9-point hedonic scale are represented in Fig. 1. Consumer liking of colour and overall appearance varied significantly with flour type ($p < 0.001$), but not with baking time. The colour of a product acts as a visual queue to the consumer indicating quality, freshness, potential flavours and even possible ingredients (Barham *et al.*, 2010). The colour of crackers containing broad-bean and yellow-pea flour was significantly more preferred than the control, with mean scores of 6.7, 6.8 and 4.7 respectively. Both of these crackers also had the highest $a*$ (red hue) and $b*$ values (yellow hue) and a positive correlation was observed between colour acceptability and $a*$ values (r^2 = 0.496). For overall appearance, for which panellists were asked to consider size, shape and surface appearance, over 60% of panellists scored ≥7 for broad-bean and yellow-pea crackers. A significant positive correlation was found for colour and overall appearance scores (r^2 = 0.752), indicating the importance of colour in consumer acceptance. Several panellists specifically commented on the visible green colour of the crackers containing green-pea flour, which some found unacceptable. These crackers had significantly lower $a*$ and $b*$ values than other pulse-flour crackers. A similar relationship was observed by Han *et al*. (2010) who reported lower $a*$ values in samples with crackers substituted green-lentil flour, compared with yellow-pea and bean flours. Similarly, these samples also scored lower in consumer testing for colour and overall appearance, indicating that such low $a*$ values may be a possible hindrance to product acceptance.

Texture attributes, such as hardness and mouthfeel, are also indicators of freshness and eating quality in baked goods. In dry snack products such as crackers, where moisture content is low, consumers expect a certain hardness and crispiness, an attribute which can be lost if the moisture content is compromised, causing the product to be rejected by the consumer (Carter *et al.*, 2015). The eating texture of all pulse-flour crackers were preferred at 31 min baking, with broad-bean and yellow-pea crackers scoring averages of 7.1 and 6.6 respectively on the 9-point scale. No significant effect was noted due to flour type alone; however there was a two-way interaction effect of pulse flour and baking time ($p < 0.05$). At the 21 min baking time, green-pea crackers scored the highest, whereas at 31 min baking broad-bean cackers scored the highest.

Consumers were asked to rate the mouthfeel of the crackers which encompasses the structural and mechanical changes that occur during consumption i.e. the chewing and eventual swallowing of the product, as a result of the intrinsic characteristics and composition of the food (Barham *et al.*, 2010). Longer baking time increased the liking scores for mouthfeel with mean scores of 6.3, 6.2 and 5.6 for broad-bean, yellow-pea and green-pea crackers respectively. Mouthfeel and acceptance of texture is believed to be strongly correlated with water activity in dry snack products such as biscuits and crackers (Carter *et al.*, 2015). Table 4 shows that the a_w values for the crackers baked for 21 min were all above 0.6, exceeding the critical value as suggested by Katz and Labuza, (1981). Crackers with the highest scores for mouthfeel, broad-bean and yellow-pea crackers, had a_w values of 0.367 and 0.364 respectively.

Antioxidant activity

Total phenolic content

As well as being a rich source of fibre and protein, pulses have been reported to contain a variety of polyphenolic compounds, particularly phenolic acids, flavonoids and proanthocyanidins (Carbonaro, 2011). Such compounds have demonstrated the potential to play a protective role in human health through their antioxidant, antiradical and anti-inflammatory properties (Šibul *et al.*, 2016; Wang *et al.*, 2011). Total phenolic content (TPC) of the baked crackers was increased following substitution of wheat flour with pulse flours ($p < 0.001$) (Table 2). Broad-bean crackers had significantly higher TPC than all other crackers, irrespective of baking time. TPC has been reported to be higher in broad-bean extracts than yellow-pea extract, particularly phenolic acids and flavonoids (Šibul *et al.*, 2016). Interestingly, it was found that longer baking times produced crackers with increased TPC which may be attributed to the depolymerisation of fibres during mechanical mixing and baking, releasing fibre-associated phenolic compounds (Collar *et al.*, 2014).

DPPH• scavenging activity

The ability to scavenge free radicals is one of many properties exhibited by polyphenolic compounds which contribute to their therapeutic effects (Wang *et al.*, 2011). Due to the high TPC measured in the pulse-flour crackers, good antioxidant activity was expected and achieved (Table 2). Extracts from broad-bean and yellow-pea crackers had significantly higher radical scavenging activity (109.30 and 73.22 mg AAE/100g DM respectively) than the control crackers (38.80 mg AAE/100g DM). These results are in agreement with those reported by Šibul *et al.*, (2016), who observed the highest antioxidant activity in broad-bean extracts compared with 6 other pulse vegetable extracts, including yellow-pea. Longer baking times increased antioxidant activity in all crackers but results were not significant. Increased antioxidant activity during baking has been reported by Vogrinčič *et al.* (2010), who attributed this to the production of antioxidant compounds during baking via Maillard reactions.

Conclusions

Wheat-pulse flour crackers were produced using broad-bean, yellow-pea and green-pea flours with enhanced nutritional characteristics and high sensory acceptability. Substitution of wheat flour with pulse flours (40%) significantly increased the protein and TDF content by up to 55%. Broad-bean crackers had the highest protein content while yellow-pea crackers had the highest TDF, IDF and SDF. Phenolic content and antioxidant activity were significantly increased following addition of yellow-pea and broad-bean flours. These results indicate the potential of pulse flours to enhance the nutritional quality of wheat based snacks. They also offer an opportunity to increase the consumption of beneficial plant compounds in the diet.

Addition of pulse flours resulted in a darker and more golden colour, a characteristic which was preferred by the consumers in comparison to the control cracker which was lighter. Consumer preference studies showed that addition of pulse flours had no negative effect on appearance, colour, hardness or mouthfeel. Broad-bean and yellow-pea flours significantly increased consumer liking compared with wheat-only crackers.

Further studies will investigate the protein quality and amino acid profile of pulse-wheat flour blends as well as glycaemic index and *in vitro* digestibility. Flavour profiles of pulse flours and pulse-flour crackers will also be investigated to establish consumer preferences.

Acknowledgements

The authors would like to thank Emily Crofton for her assistance with the sensory study. This research was funded by the Teagasc Walsh Fellowship Scheme.

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Table 1

Formulations used for crackers containing wheat flour and the pulse flours used in this study

Ingredients	Control formula (parts)	Pulse-supplemented formula (parts)
Soft wheat flour	100	60
Pulse flour[a]	0	40
Water	45	45
Fat	10	10
Sugar	2	2
Salt	1	1
Sodium bicarbonate	0.6	0.6
Dough conditioning agent (SSL)	0.5	0.5
Baking time 21 min	No	Yes
Baking time 31 min	Yes	Yes

[a] Broad-bean flour, yellow-pea flour or green-pea flour

Table 2

Effects of flour type and baking time on the chemical composition and antioxidant activity of crackers formulated from wheat flour and wheat-pulse flour blends.

	Moisture content g/100g	Protein[A] g/100g DM	TDF g/100g DM	SDF g/100g DM	IDF g/100g DM	TPC (mg GAE/100g DM)	AOX (mg AAE/100g DM)
31 min baking time							
Control	18.25 ± 1.12[ab]	18.36 ± 0.35[d]	17.92 ± 0.81[c]	4.74 ± 0.09[b]	3.19 ± 0.71[b]	108.26 ± 19.41[c]	138.80 ± 7.91[c]
BB	16.61 ± 0.63[b]	13.02 ± 0.23[a]	10.70 ± 0.23[ab]	5.84 ± 0.62[ab]	4.86 ± 0.40[a]	283.98 ± 39.99[a]	109.30 ± 9.44[a]
YP	15.85 ± 1.80[b]	12.46 ± 0.26[ab]	12.33 ± 0.82[a]	7.18 ± 0.91[a]	5.15 ± 0.08[a]	196.33 ± 35.56[b]	173.22 ± 19.78[b]
GP	16.15 ± 2.85[b]	11.50 ± 0.46[bc]	11.08 ± 0.01[ab]	6.35 ± 0.35[ab]	4.73 ± 0.33[ab]	160.03 ± 29.44[bc]	164.38 ± 5.94[bc]
21 min baking time							
BB	15.68 ± 2.40[a]	10.98 ± 0.14[bc]	19.61 ± 0.18[bc]	4.58 ± 0.12[b]	4.89 ± 0.09[a]	280.96 ± 29.12[a]	103.93 ± 11.33[a]
YP	10.58 ± 4.01[ab]	11.33 ± 0.57[ab]	10.34 ± 0.05[ab]	5.28 ± 0.12[ab]	5.07 ± 0.17[a]	157.56 ± 17.39[bc]	154.87 ± 23.23[bc]
GP	12.68 ± 1.66[ab]	10.20 ± 0.12[c]	19.77 ± 0.44[bc]	4.91 ± 0.30[b]	4.87 ± 0.13[a]	135.65 ± 13.32[c]	146.02 ± 7.58[c]

TPC: Total phenolic content; AOX: Antioxidant activity as measured by DPPH radical scavenging assay. Control: wheat only crackers, BB: wheat-broad bean crackers, YP: wheat-yellow pea crackers, GP: wheat-green pea crackers.

[A] Results adjusted for moisture content and reported as g/100g dry matter (DM).

[a - e] Values with the same letter denote homogenous subsets within each parameter.

Table 3

The effect of flour type on physical dimensions of crackers prepared from wheat only and wheat-pulse flour blends at 40% substitution.

(a) Contrast analysis of crackers made with wheat flour only and those made with wheat-pulse blends.

	Control BB	YP	GP
Diameter (mm)	-0.20**	-0.12*	-0.11
Thickness (mm)	-0.03	-0.10*	-0.09*
Spread ratio	-0.50	-2.73**	-2.35**
Volume (cm^3)	-1.05	-1.91**	-1.67**
Weight (g)	-0.74*	-1.19**	-0.96**
Density (g/cm^3)	-0.19	-0.01	-0.42

*Significant effect observed ($p < 0.05$). **Significant effect observed ($p < 0.01$)

(b) Effect of flour type on volume and weight of crackers prepared from wheat only and wheat-pulse flour blends.

	Control	BB	WP	GP
Volume (cm^3)	8.26 ± 0.50^{a}	7.21 ± 0.72^{ab}	6.35 ± 0.62^{b}	6.59 ± 0.84^{b}
Weight (g)	5.26 ± 0.08^{a}	4.52 ± 0.43^{b}	4.07 ± 0.41^{b}	4.31 ± 0.46^{b}

All attributes were measured on day 1 of testing, post-baking. Control: wheat only crackers, BB: wheat-broad bean crackers, YP: wheat-yellow pea crackers, GP: wheat-green pea crackers.

[a,b] Values with the same letter denote homogenous subsets within each parameter.

Table 4

Effects of flour type and baking time on the colour and texture attributes of crackers formulated from wheat flour and wheat-pulse flour blends.

	$L*$	$a*$	$b*$	$C*_{ab}$	δE	Hardness (N)	a_w
31 min baking time							
Control	76.59 ± 0.67^{a}	11.90 ± 0.13^{de}	25.19 ± 0.37^{d}	25.26 ± 0.38^{d}	-	38.45 ± 3.26^{ab}	0.508 ± 0.073^{bcd}
BB	64.84 ± 1.64^{bc}	11.24 ± 1.74^{ab}	39.19 ± 1.39^{a}	40.80 ± 1.75^{a}	20.58 ± 3.04^{ab}	43.33 ± 6.18^{a}	0.367 ± 0.040^{d}
YP	62.39 ± 3.08^{c}	14.07 ± 1.44^{a}	41.06 ± 1.20^{a}	43.44 ± 1.08^{a}	24.83 ± 1.53^{a}	27.65 ± 2.54^{bc}	0.364 ± 0.090^{d}
GP	62.78 ± 0.20^{c}	17.14 ± 1.25^{bc}	38.72 ± 0.57^{ab}	39.40 ± 0.60^{a}	20.11 ± 3.91^{ab}	30.37 ± 3.09^{bc}	0.405 ± 0.100^{cd}
21 min baking time							
BB	70.97 ± 3.08^{b}	13.23 ± 1.41^{cd}	30.77 ± 1.77^{c}	30.96 ± 1.92^{c}	18.44 ± 1.98^{c}	18.58 ± 9.55^{c}	0.754 ± 0.047^{a}
YP	71.03 ± 3.66^{b}	16.88 ± 3.73^{bc}	37.59 ± 2.99^{ab}	38.30 ± 3.69^{ab}	14.66 ± 4.94^{bc}	24.36 ± 5.61^{bc}	0.629 ± 0.159^{abc}
GP	70.11 ± 0.85^{b}	-0.29 ± 0.99^{e}	34.86 ± 0.79^{bc}	33.70 ± 1.50^{bc}	12.37 ± 1.78^{c}	17.56 ± 1.39^{c}	0.704 ± 0.024^{ab}

All attributes were measured on day 1 of testing, post-baking. Control: wheat only crackers, BB: wheat-broad bean crackers, YP: wheat-yellow pea crackers, GP: wheat-green pea crackers. Colour measured using the $L*a*b*$ colour scale, Colour difference (δE) was measured with respect to the wheat flour crackers (those with a $\delta E > 3$ exhibit a colour difference from the wheat cracker which is visible to the eye).

$^{a-d}$ Values with the same letter denote homogenous subsets within each parameter.