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Development of a gluten free bread enriched with faba bean husk as a fibre supplement

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ABSTRACT

Faba bean husks (FBH) are a high-fibre waste product of faba beans and are primarily used as animal feed with the potential of becoming a fibre supplement. In this study, different levels and particle sizes of FBH flour were used to enhance the fibre content of gluten free bread. Bread properties were evaluated by measuring specific volume, colour (crust and crumb), and crumb texture. The sensory characteristics of breads were assessed by a group of untrained panellists ($n = 66$) on appearance, aroma, flavour, texture, aftertaste, willingness to buy, and overall acceptability using a nine-point hedonic scale. Volume of bread was affected by the level and particle size of FBH added. Texture analysis showed the importance of level of FBH, and of its particle size in establishing hardness, gumminess, and chewiness ($p < 0.05$). The added FBH influenced the colour of the crust and crumb. Two formulations of FBH-enriched gluten free bread (particle sizes of 212–300 μm at 5% wheat flour weight substitution, and particle sizes of smaller than 212 μm at 15% wheat four weight substitution) increased the fibre content of the bread, while had no negative impact on sensory evaluation in comparison to control treatment ($p < 0.05$).

1. Introduction

Coeliac disease (CD) is an autoimmune disease triggered by gluten ingestion in genetically predisposed individuals (Altobelli, Paduano, Petrocelli, & Di Orio, 2014). Ingestion of gluten in these individuals damages the villi of the small intestine and can cause further problems if not treated – e.g. colon cancer. The only treatment for this chronic illness is to commit to a lifelong gluten-free (GF) diet. CD is one of the most common genetic diseases in the modern day with a global prevalence of 1.4% (Singh et al., 2018). Apart from CD-diagnosed individuals, an additional percentage of population has non-celiac wheat/gluten sensitivity, making them experiencing symptoms similar to CD after consuming gluten-containing food products (Sabença et al., 2021). For this population group, exclusion of wheat/gluten from their diet is also generally recommended (Sergi, Villanacci, & Carroccio, 2021).

Consumers of gluten free food are the diagnosed (and undiagnosed) of the above groups as well as their family, friends, and cohabitant/household members. Topper (2014) reported that 82% of consumers of GF foods are those not diagnosed with CD, with 44% doing so for reasons other than gluten sensitivity and 38% doing so as they believe it is better for one's overall health, despite existing scientific evidence that from nutritional point of view GF products are in many aspects worse than gluten-containing products (Miranda, Lasa, Bustamante, Churruca, & Simon, 2014; Pellegrini & Agostoni, 2015; Taetzsch et al., 2018). With this misconception, it is unsurprising that this market has gained significant growth over the past number of years (Chris, 2014).

As previously mentioned, within the food product ranges, GF formulations have been reported to be inferior in nutrition value to gluten-containing counterparts (Taetzsch et al., 2018). Extensive resources on the development of GF bread have been invested in an attempt to make GF bread comparable to gluten-containing bread, in terms of product's characteristics and sensory properties (Masure, Fierens, & Delcour, 2016; Melini, Melini, Luziatelli, & Ruzzi, 2017). Apart from the challenge in production technicality, low content of dietary fibre (DF) is one of the main shortfalls in GF products (Pellegrini & Agostoni, 2015). Lee, Ng, Dave, Ciaccio, and Green (2009) determined that the nutritional profile, including the intake of DF, of a GF diet can be significantly improved using "alternative" grains (such as oats, high fibre GF bread,

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and quinoa). Hager, Axel, and Arendt (2011) analysed the ingredients of several market-available GF breads and reported that many labels are enriched with fibre (from sugar beet, psyllium husk, citrus, pea fibre, insulin).

Although DF-fortified GF products are commercially-available, studies on nutritional status of individuals with CD have showed they have a low DF intake compared to the recommended level (Kinsey, Burden, & Bannerman, 2008; Öhlund, Olsson, Hernell, & Öhlund, 2010). In a recent meta-analysis on the nutrient intakes of adults with CD following a GF diet with control subjects eating a gluten-containing diet showed that consuming a GF diet resulted in significantly lower DF intake and CD patients would still need to consume more fibre to reach the RDA (Taetzsch et al., 2018).

Different sources of fibre, such as cereals (wheat, maize, oat, and barley (Sabanis, D., Lebesi, & Tzia, 2009);), rice bran (Phimolsiripol, Mukprasirt, & Schoenlechner, 2012), psyllium (Mariotti, Lucisano, Pagani, & Ng, 2009) have been studied to produce DF-enriched GF bread. To the best of our knowledge, no one has used faba bean husks (FBH) as a source of fibre and this research aimed to understand the effect that the use of FBH as a source of fibre has on quality parameters of GF bread.

Faba beans are one of the oldest cultivated plants known and are often used as a break crop for arable growers (Karkanis et al., 2018). The beans themselves are harvested for human and animal consumption however the husks tend to be discarded in spite of the fibre content being close to 50% (Ni et al., 2020). Valorisation of the fibre-rich FBH could promote circular economy and tackle food waste, a problem which has become a global challenge (Scherhaufer, Moates, Hartikainen, Waldron, & Obersteiner, 2018). This project aimed to evaluate the suitability of FBH as a fibre supplement to enrich gluten free bread, which is generally low in fibre, without compromising its consumer acceptability. This project explored more valuable ways of using FBH other than animal feed. It is expected that this research will provide a better understanding towards the use of food by-products as food supplements. Additionally, it will help to understand if fibre-enriched GFB would make people willing to buy GFB irrespectively of coeliac disease status.

2. Materials and methods

2.1. Particle size reduction of faba bean husks

FBH from 'fuego' variety supplied from Askew & Barrett (Pulses) Ltd, Smeeth Road, Marshland St James, Wisbech, Cambs (UK) were milled in a laboratory mill (Retsch Centrifugal Mill ZM1, Germany) using 2 stainless steel sieves with trapezoid holes in 2 sizes – 500 μm and 250 μm. The resulting flour was shaken through an industrial sieve shaker (Fritsch Analysett, Brackley, UK) using 4 stacked sieves as described by Rocha Parra, Ribotta, and Ferrero (2015). Samples were loaded onto the top mesh sieve and the coarse (300-212 μm) and fine (below 212 μm) target fractions were collected from the 212 μm and bottom sieves in the stack respectively (de la Hera, Martinez, & Gómez, 2013).

2.2. Bread making

An experimental design of 3 factors and 2 levels was used, resulting in 8 combinations. The factors included (1) water level (WL; 103% and 110% flour weight based), (2) FBH level (FBHL; 5% and 15% flour mix substitute), and (3) FBH particle size (PS; 212–300 μm and smaller than 212 μm). A GF control loaf, containing a WL of 103% and a FBHL of 0%, was included (Table 1, Formulation 0). A procedure of bread making was adapted from that described by Miñarro, Albanell, Aguilar, Guamis, and Capellas (2012). Briefly, all the dry ingredients were weighed and mixed before adding water and vegetable oil. Samples were mixed 1 min at low speed (Setting 1) and a further minute at high speed (Setting 3) using a Kenwood Electric Hand Whisk HM220.

After homogenisation, each sample (480 ± 5 g) was transferred into a greased metal loaf tin (500 g; 16 × 10.5 × 7.4 cm), then proofed at room temperature for 45 min. The loaves were baked in the centre of a fan assisted electric oven equipped with an internal temperature control probe (Belling Choice 60, UK) at 180 °C for 25 min. To promote the development of a good crust (Nunes, Moore, Ryan, & Arendt, 2009), the oven was pre-injected with steam by filling a preheated metal tray (in the bottom of the oven) with cold water (250 ml) just before the samples were placed in the oven. Breads were cooled at room temperature for at least 2 h before being instrumentally analysed. Samples were prepared in triplicates.

Table 1
Bread formulations.

Formulation*	Ingredients				
	Water	FBH	Corn Starch	Soya Flour	Chickpea Flour
0 (Control; 103% water [a])	226.3	N/A	203	8	8
1 (103% water, 5% coarse FBH[b])	226.3	10.9	192.9	7.6	7.6
2 (103% water, 15% coarse FBH)	226.3	32.8	172.6	6.8	6.8
3 (103% water, 5% fine FBH)	226.3	10.9	192.9	7.6	7.6
4 (103% water, 15% fine FBH)	226.3	32.8	172.6	6.8	6.8
5 (110% water, 5% coarse FBH)	240.9	10.9	192.9	7.6	7.6
6 (110% water, 15% coarse FBH)	240.9	32.8	172.6	6.8	6.8
7 (110% water, 5% fine FBH)	240.9	10.9	192.9	7.6	7.6
8 (110% water, 15% fine FBH)	240.9	32.8	172.6	6.8	6.8

*Apart from those listed in the Table, all bread formulations also included fixed ingredients as follows: 12 g of sugar, 11 g of shortening, 5 g of dried yeast, 4 g of xanthan gum, 3 g of baking powder, and 3 g of salt.

[a] Percentage based on flour weight.

[b] Percentage based on flour mix substitution.

2.3. Specific volume

Each bread loaf was weighed to determine its mass (g). The volume (cm^3) was determined by rapeseed displacement Method 10–05. 01 (AACC, 1998). Specific volume (cm^3/g) of the loaves was calculated by dividing the loaf volume by its weight.

2.4. Crumb texture

Texture profile analysis (TPA) was performed by a texture analyser (TX Plus Stable Microsystems, Surrey, UK). Loaves were sliced into equal thickness slices (25 mm) using an adjustable bread-slicer. A P/36 R cylinder probe (36 mm diameter) and a 5 kg load cell were used to measure the force (g) in compression. Relevant parameters measured were hardness, springiness, chewiness, cohesiveness, gumminess and resilience. Test results were obtained from three central bread slices of each formulation.

2.5. Crust colour

Crust and crumb colour were measured using a Colour Meter (CSM 5 PCE, UK) as described by (Rocha Parra et al., 2015). Hunter scale parameters L^*, a^*, b^* were measured in triplicate for each version of the bread loaf for the crumb, the top crust, and side crust. The L*, a* and b* values of the reference (standard white plate) where the following respectively L* 72.27, a* 0.18 and b* 0.98.

2.6. Sensory evaluation

Based on the results of the abovementioned physical characteristic tests (2.3–2.6) – two formulations of the FBH-enriched bread samples, showing significant alteration on physical attributes by the effects of FBH addition (Formulations 4 and 5), were chosen for further sensory evaluation. The GF control bread sample was used as a comparison. The sensory panel consisting of 66 untrained panellists (33 males, 33 females) who were students and staff of Abertay University, UK, were recruited. The participants included those with confirmed coeliac disease, gluten sensitivity, gluten tolerant, and those who did not consume gluten for other personal reasons. The participants were asked to rate their opinion regarding consuming/purchasing gluten-free products (from 1 'Strongly Disagree' to 9 'Strongly Agree') before evaluating the two selected gluten-free breads and control. Each panellist evaluated ½ slice of each bread formulation. A random 3-digit code was assigned for each sample. The three bread samples were presented at the same time in a balanced presentation order. The questionnaire comprised three main areas: Demographics (age, gender, education, gluten free consumption). Panellists were asked to rate the appearance, aroma, flavour, texture, aftertaste, willingness to buy and overall acceptability of the samples provided. A horizontal 9-point hedonic scale was used to measure the degree of liking (from 1 'Dislike Extremely' to 9 'Like Extremely').

2.7. Proximate analysis

The two chosen formulations and control were subjected to proximate analysis. Analysis of fibre was carried out according the AOAC method no. 991.43 (AOAC, 1995). Protein content was determined following the Dumas method following the AOAC method no. 990.03 and multiplying the total nitrogen for 6.25 (AOAC, 2006). Crude fat and ash were determined by the AOAC method no. 920.85 (AOAC, 2014) and 942.05 (AOAC, 2005), accordingly. Total carbohydrate was determined by difference. All the proximate analysis were carried out by UKAS accredited lab Huson and Hardwick, a division of Alex Stewart Agriculture LTD, Liverpool (UK).

2.8. Statistical analysis

SPSS Statistics for Windows, version 23 (SPSS Inc., Chicago, Ill., USA) was used for statistical analysis. The following tests were used to analyse statistically significant results at the 95% significance level (p-value <0.05). The specific volume, crust colour, and texture profile analysis were analysed by one-way ANOVA with Bonferroni post-hoc tests. Independent samples Kruskall-Wallis was used for the Crumb porosity. For sensory evaluation, Mann-Whitney U and Kruskall-Wallis test was used.

3. Results and discussion

3.1. Physical attributes

3.1.1. Specific volume

Specific volumes of the bread samples are illustrated in Fig. 1. Statistical analysis showed specific volume was affected by FBHL ($p < 0.05$). Water level had no effect on specific volume between all treatments ($p \geq 0.05$). In term of particle size, the specific volumes of FBH-enriched bread formulations statistically differed from control treatment ($p < 0.05$). Nevertheless, no difference in specific volume was observed between FBH-enriched with coarse and fine PS ($p \geq 0.05$). The effects of FBHL on specific volume can be observed clearly between 0% (control), 5% and 15% addition. The results showed that the higher concentration of FBH added, the lower specific volume of bread was obtained.

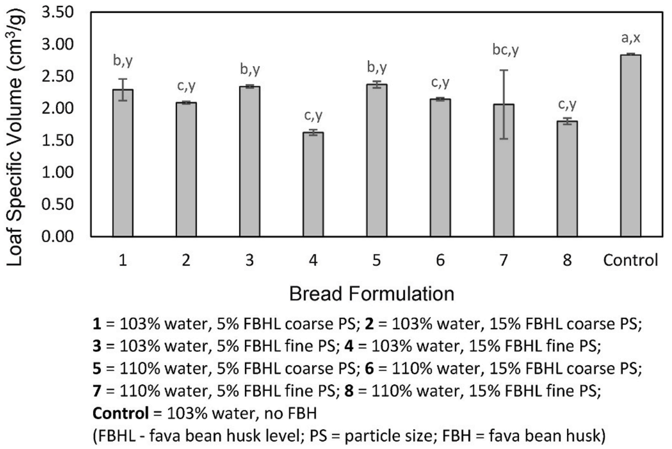


Fig. 1. Average specific volume of GF breads. Bars with different letters indicate statistical different ($p < 0.05$) between treatments (a, b, c for the effect of FBHL, and x, y for the effect of PS).

3.1.2. Colour

For the crust (top and side) and crumb colour, ΔL^*, Δa^* and Δb^* scores were calculated using (L^* sample - L^* standard). For each value, the L^*, a^* and b^* of the control sample were used as the standard measurement and those of the FBH-enriched bread samples (Formulations 1–8, Table 1) as a sample measurement. The results are shown in Fig. 2.

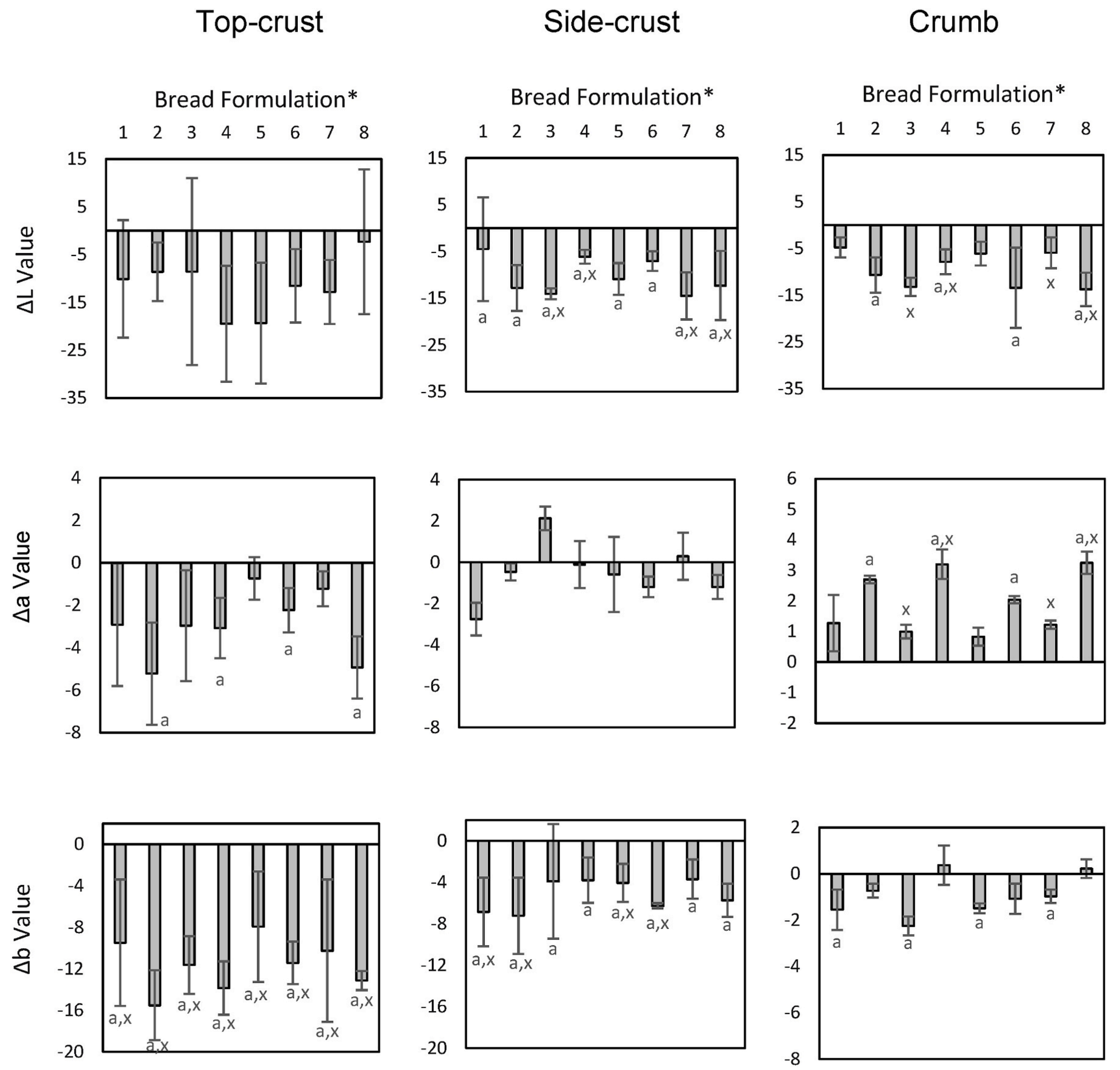
The mean ΔL^*, Δa^* and Δb^* scores for the crust (both top and side) were of negative values in most cases (with a couple exceptions of the Δa^* values of the side-crust colour of Formulations 3 and 7). This suggests that inclusion of FBH causes the bread to yield darker crust colour upon baking. Statistical analysis of the L^*, a^*, and b^* values of all samples indicated that, in comparison to the control recipe, WL did not affect colour of the finished products, while FBHL and PS did to a certain extent.

With regards to the colour of the bread's top crust, when higher amount of FBH was added into the bread dough, it significantly reduced the values of the a^* and b^* colour space ($p < 0.05$), while having no effect on the L* value. Addition of the smaller particle sizes of FBH also led to lowering the b^* values ($p < 0.05$). Concerning the colour of the bread's side crust, addition of FBH affected mostly the L^* and b^* values. The effects of FBH addition was also observed in the colour of the bread crumb. The results showed the higher amount and smaller particle size of FBH added, the lower L^* values and higher a^* and b^* values of the finished products were obtained ($p < 0.05$). Examples of colour of some of the samples upon baking are shown in Fig. 3.

3.1.3. Crumb texture

Characteristics data for all the bread loaves showed that addition of FBH altered the texture of the crumb considerably (Fig. 4). Statistical analysis ($p < 0.05$) showed that WL did not have effect on the crumb texture, while FBHL and PS did. The control yielded the lowest values of hardness (most soft), gumminess and chewiness (easiest to manipulate in the mouth; $p < 0.05$). Inclusion of FBH of smaller particle sizes at a higher concentration made the bread became harder and stickier (highest values in hardness, gumminess, chewiness, and cohesiveness; $p < 0.05$). The presence of FBH, however, did not have effect on springiness and resilience of the final product ($p \geq 0.05$).

Overall, for physical characteristics, PS and FBHL appear to be important. Addition of fine PS of FBHL led to changes in the physical properties of the finished product. Nevertheless, although breads formulated with 5% and 15% FBHL altered some physical attributes, PS seemed to have a direct effect, especially on specific volume and crumb texture. Based on these results, the formulations 4 (103% WL, 15% FBHL, fine PS) and 5 (110% WL, 5% FBHL, coarse PS) were regarded as



*Bread Formulation:
1 = 103% water, 5% FBHL coarse PS; **2** = 103% water, 15% FBHL coarse PS; **3** = 103% water, 5% FBHL fine PS;
4 = 103% water, 15% FBHL fine PS; **5** = 110% water, 5% FBHL coarse PS; **6** = 110% water, 15% FBHL coarse PS;
7 = 110% water, 5% FBHL fine PS; **8** = 110% water, 15% FBHL fine PS; **Control** = 103% water, no FBH

Fig. 2. Mean ΔL^*, Δa^* and Δb^* values for the bread crust (top and side) and bread crumb. The values shown are means ± SD of three replicates. Bars with different letters indicate statistical difference ($p < 0.05$) between the respective treatment and control (a for the effect of FBHL, and x for the effect of PS).

samples representing the effects of FBH addition and hence selected for the subsequent experiments.

3.2. Sensory evaluation/acceptability

A simplified gluten-free status group ($n = 66$) was created, which included those with diagnosed CD (18%), self-diagnosed gluten sensitivity (4%), those with a negative test result for CD but with gluten sensitivity (11%), those who live with one of the above (14%), and gluten tolerant (53%). Fig. 5(a) and (b) show the responses of the participants regarding their opinion on consuming/purchasing gluten-free products and evaluation of the 3 gluten-free breads (the two formulations selected from the previous step and control).

The results shown in Fig. 5(a) indicated that, in general, the participants enjoyed trying new bread products (Q.4) and were inclined to buy nutrient-enriched breads (Q.3). About one quarter of the participants thought that they had inadequate intake of dietary fibre (Q.5). Approximately 35% of the responses indicated that they buy/consume gluten-free products regularly while approximately 30% followed gluten-containing product range (Q.1). More than half of the group preferred gluten-containing products over gluten-free equivalents (Q.2).

With regards to the results of sensory evaluation, the FBH-enriched formulations were rated on sensory attributes similar to those of control – except for texture ($p < 0.05$; Fig. 5(b)), which sample formulation 4 (103% WL, 15% FBHL, fine PS) received higher score than control and sample formulation 5 (110% WL, 5% FBHL, coarse PS). In general, all bread samples received scores between 5 (Neither like nor dislike) and 7 (Like moderately). The panellists accepted the appearance and aroma of the tested samples better than other attributes. With regards to willingness to buy, the panellists indicated they were slightly (scale 5) to

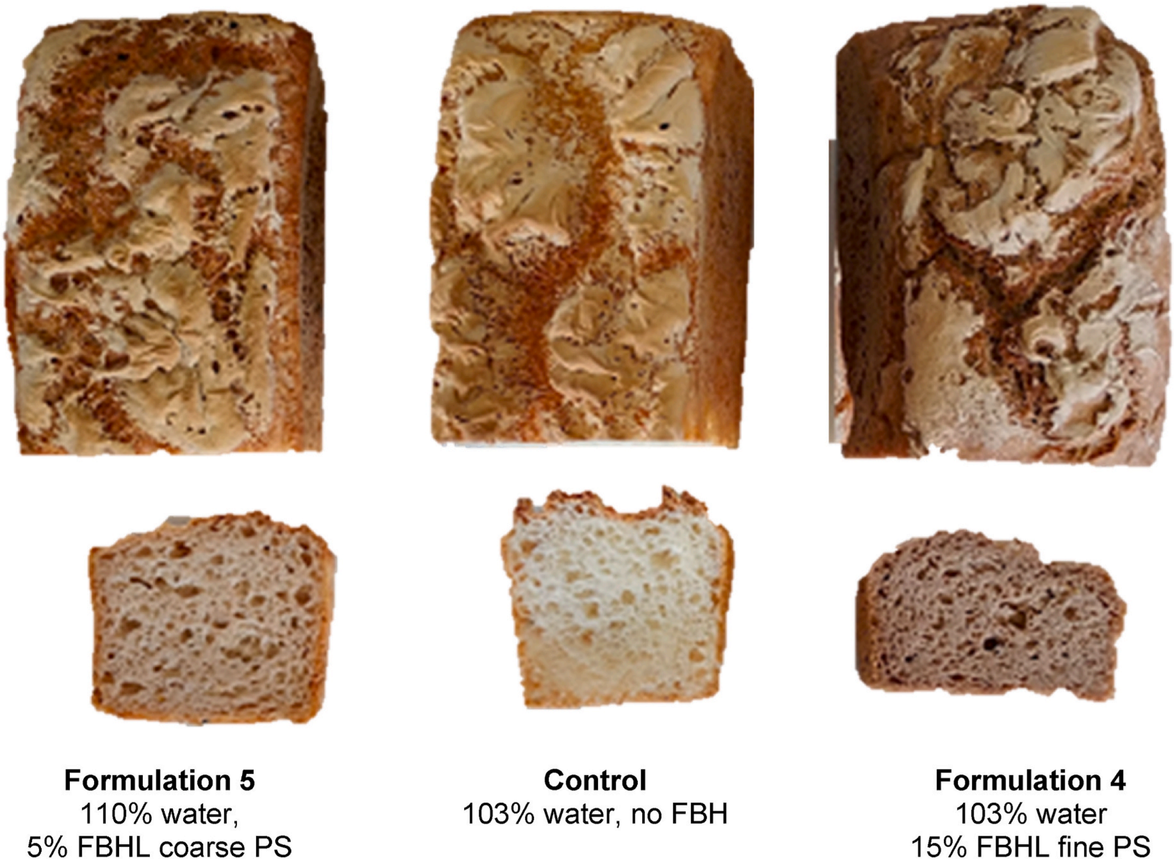


Fig. 3. Examples of the baked GF bread samples.

moderately (scale 6) likely to do so for all three samples.

3.3. Nutritional analysis

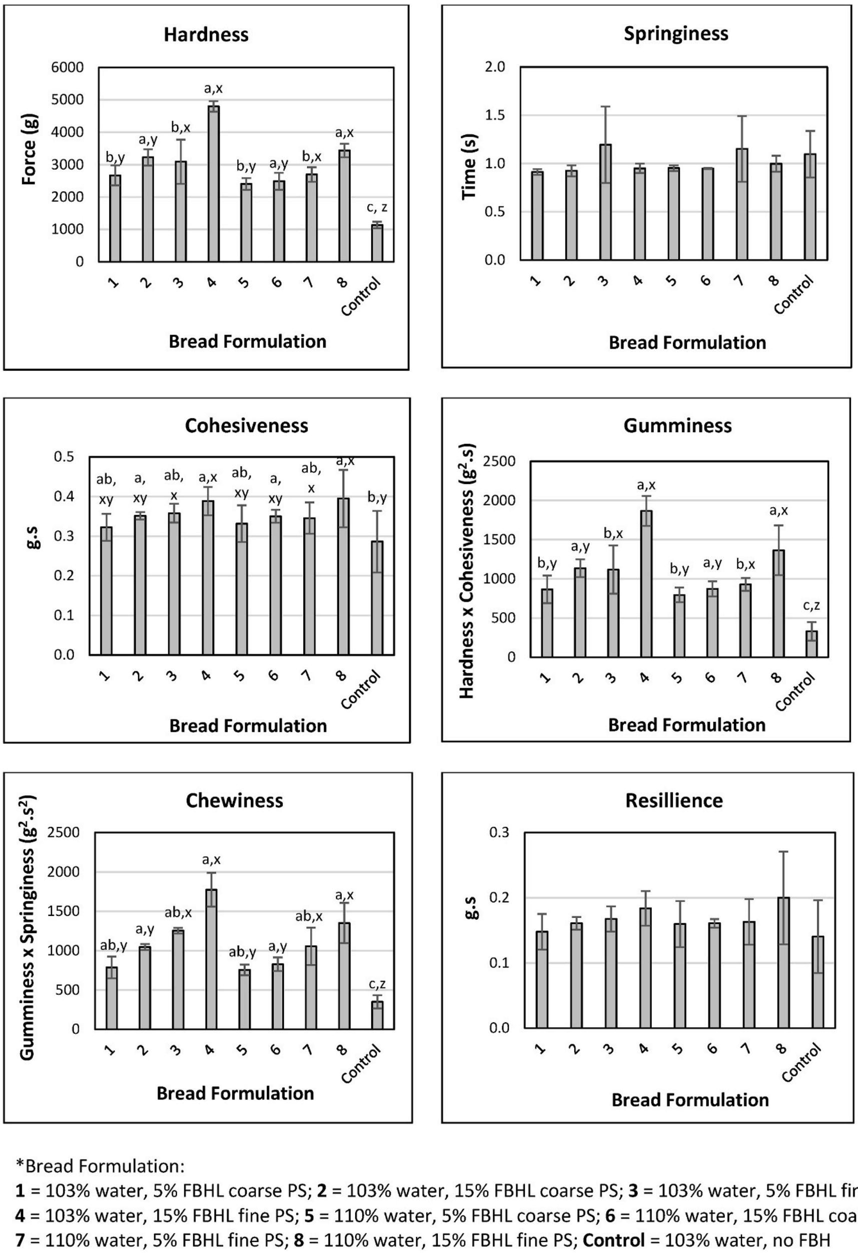
The substitution of a fraction of starch flour with FBH flour resulted in a sharp increase in the fibre content of the FBH-enriched formulations (Table 2).

Chemical compositions of the two FBH-enriched breads showed that the dietary fibre content of the products was twice (Formulation 5; 110% WL, 5% FBHL, coarse PS) and four times (Formulation 4; 103% WL, 15% FBHL, fine PS) higher than that of the control treatment. Increase on protein content in FBH-enriched formulations, 18% for Formulation 5 and 69% for Formulation 4, in comparison to control, was also observed. The bread formulation 4 contained 4.3 g/100 g fibre, exceeding the amount of fibre required by Regulation (EC) 1924/2006' (Valero, Ruiz, del Pozo, Ávila, & Varela-Moreiras, 2013) on nutrition claims made on food and therefore the claim "SOURCE OF FIBRE" could be made for such bread.

4. Discussion

The specific volume of bread seemed to be affected predominantly by the amount of FBH added. It was observed that the 5% FBHL yielded a loaf with a higher specific volume than that of the 15% FBHL, regardless of WL or PS. In wheat bread model, the inverse variation between specific volume and the amount of insoluble fibre added has long been reported (Dalgetty & Baik, 2006; Gómez, Ronda, Blanco, Caballero, & Apesteguía, 2003; Park, Seib, & Chung, 1997; Wang, Rosell, & de Barber, 2002). With regards to studies specific on fibre addition in GF bread, the results showed the effect of fibre on specific volume is highly influenced by the amount and types of fibre added. The work of Rocha Parra et al. (2015) demonstrated that the balance between the amount of fibre added and water was crucial to specific volume of the finished product. The authors concluded that increasing the level of apple pomace fibre content decreased specific volume of GF bread. Sabanis, Lebesi, and Tzia (2009a, 2009b) observed that, up to a certain limit, addition of maize fibre (less than 5%) improved the volume of GF breads. However, the authors concluded that extreme levels of fibre (8%) and water (110%) decreased the specific volume. Other types of fibre (from maize, oats, and barley) yielded the same results, but not wheat fibre (Sabanis, Dimitrios, Lebesi, & Tzia, 2009).

Apart from fibre, specific volume of GF bread also depends on the amount and type of proteins present in the formulation. Horstmann, Foschia, and Arendt (2017) concluded that the presence of higher protein and insoluble fibre content decrease dough rise rate, leading to denser bread structure. With regards to the chemical composition of fava bean pods, it was reported that total fibre accounts for 90%, of which 94% was water insoluble (Fendri et al., 2016). Its fibre content is composed of lignin, hemicellulose, and cellulose (approximately 50%, 25% and 25% respectively) (Vallejo et al., 2021);). Another study extracted glucan from fava bean pods and recovered 30–45% crude glucan, of which approximately one-third was the soluble fraction (Fazio, La Torre, Dalena, & Plastina, 2020). The insoluble-fibre-rich nature of FBH could be the reason of the decrease in the bread's specific volume, especially when FVBH was added at a higher concentration. A study by Martínez, Díaz, and Gómez (2014) demonstrated that while soluble fibres favour dough rise and gas retention in GF bread, insoluble fibres exert the opposite effect. The mechanism could be because of fibre-starch interaction. Soluble fibres are able to create a mesh network stabilising and retaining the gas produced, while insoluble fibres promote points of rapture causing the gas to escape and leading to structural collapse through a decrease in gas retention capacity (Horstmann, Belz, Heitmann, Zannini, & Arendt, 2016; Sabanis, Dimitrios, Lebesi, & Tzia, 2009).

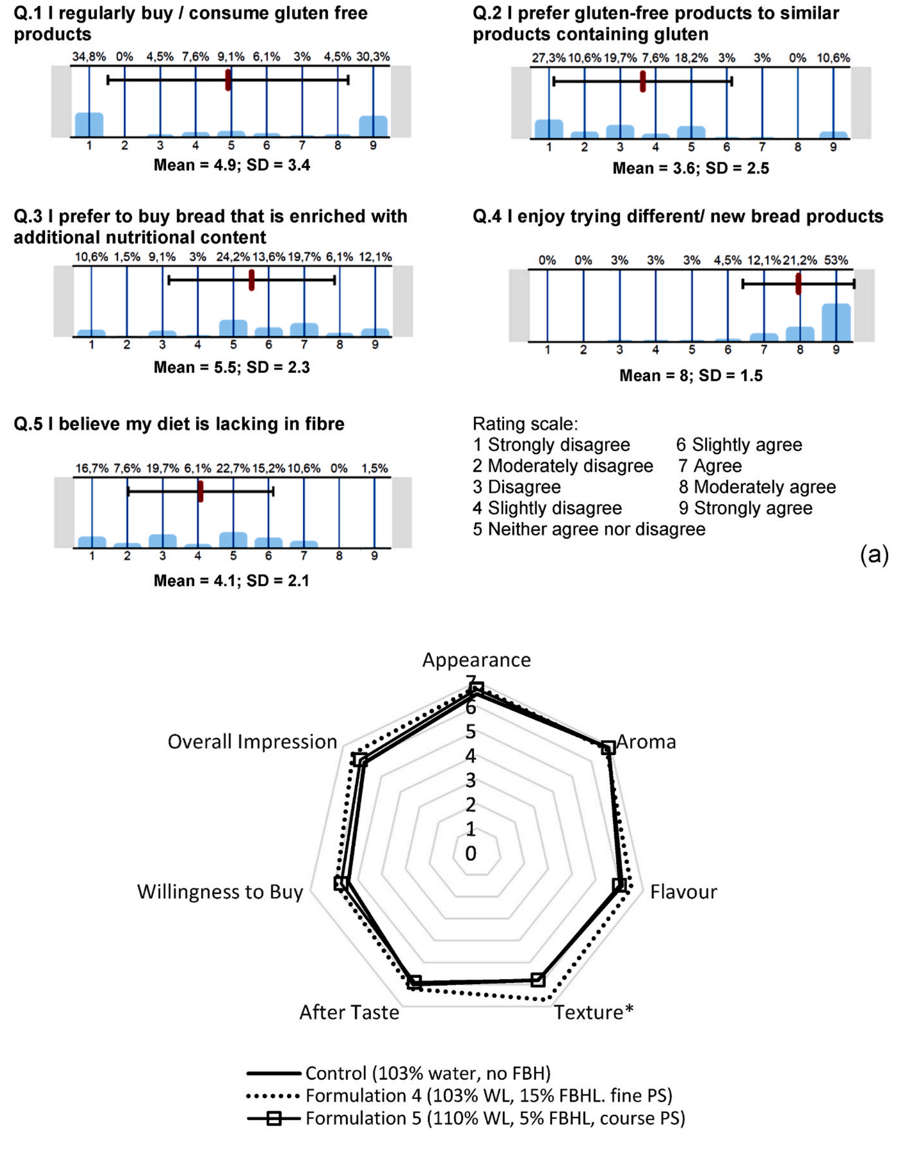


*Bread Formulation:
1 = 103% water, 5% FBHL coarse PS; **2** = 103% water, 15% FBHL coarse PS; **3** = 103% water, 5% FBHL fine PS;
4 = 103% water, 15% FBHL fine PS; **5** = 110% water, 5% FBHL coarse PS; **6** = 110% water, 15% FBHL coarse PS;
7 = 110% water, 5% FBHL fine PS; **8** = 110% water, 15% FBHL fine PS; **Control** = 103% water, no FBH

Fig. 4. Texture analysis of the GF bread crumb. The value shown are mean ± SD of three replicates. Bars with different letters indicate statistical different ($p < 0.05$) between treatments (a-c for the effect of FBHL, and x-z for the effect of PS).

With regards to the level of hydration and particle size, a study on the particle size of rice flour on the volume of GF bread reported that the smaller particle size of the flour and the lower water level led to poorer specific volume (De La Hera, Rosell, & Gomez, 2014). In general, a higher amount of water is required when a higher concentration of fibre is incorporated in the bread formulation in order to obtain a workable dough (Mariotti et al., 2009). However, reduction in specific volume is not necessarily correspondent to the particle size of the fibre added as demonstrated by Rinaldi, Littardi, Paciulli, Caligiani, and Chiavaro (2020). The authors studied three ranges of particle size of cocoa bean shell powder (1.00–1.99 mm, 0.50–0.99 mm, and 0.355–0.49 mm) and found that the highest decrease in specific volume was observed on the bread fortified with fibre with mid-range of particle size (0.5–0.99 mm). In the present work, there was no evidence showing that specific volume of the final products was affected by these two factors, within the ranges of WL and PS studied.

In terms of texture, particle size significantly affected hardness, gumminess and chewiness, with a fine PS increasing those three characteristics ($p < 0.05$). Addition of FBH increased cohesiveness in comparison to control regardless of the amount added and particle size used. The results suggested more effort in needed to process FBH-enriched bread in the mouth in comparison to control, especially when smaller particle size and higher amount of FBH was added. The decrease in specific volume (Fig. 1) of the loaves corresponded to the increase in crumb hardness (Fig. 4). This inverse relationship between specific volume and hardness of GF bread observed in this present work was in agreement with reports previously published (Gallagher, Gormley, & Arendt, 2003; Sabanis, Dimitrios, Lebesi, & Tzia, 2009). This could be because insoluble fibres exert a negative effect on resistance to dough deformation and cohesiveness (Martínez et al., 2014), causing structural collapse and therefore a denser finished product. Similar effect of fibre addition on texture of bread was also evident when different types of fibres were used. In the work of Cappa, Lucisano, and Mariotti (2013), the authors reported that psyllium and sugar beet fibre increased the



* Significant difference ($p < 0.05$).

Fig. 5. Taste panel opinion on GF bread consumption (a), and sensory quality of three GF bread formulations (b).

Table 2

Chemical composition of three gluten-free bread formulations.

Chemical composition (%)	Bread formulation 4 (103% WL, 15% FBHL, fine PS)	Bread formulation 5 (110% WL, 5% FBHL, coarse PS)	Control (103% WL, no FBH)
Moisture	51.6	53.6	52.4
Protein	2.7	1.9	1.6
Fat	3	3	2.9
Dietary fibre	4.3	2.1	1

hardness of bread when more fibre was added, and water kept constant. This pattern was also observed in another study using cocoa pod husk (0.12 mm) to fortify bread (Amir, Hanida, & Syafiq, 2013). With regards to the effect of particle size of fibres on the texture of GF bread, Rinaldi et al. (2020), illustrated that particle size did not affect hardness, cohesiveness, resilience, and chewiness of the bread crumb when fibre from cocoa shell was added at 4 g/100 g mixture. In this study it was found that smaller PS increased hardness, gumminess and chewiness of the baked products. The contrast in the observations between our and the previously reported work could be due to the differences in the ranges of parameters studied, i.e. type of fibres (fava bean husk *vs* cocoa bean pod), ranges of particle size (0.2–0.3 mm *vs* 0.3-1000 mm) and amount of fibre addition (5–15% *vs* 4%).

Unsurprisingly our study found that FBH influenced colour parameters of the baked products, by lowering L* and influencing a* and b* depending on the level of addition, as well the particle size used (Fig. 2). Many studies using different types of fibres also found that increasing the fibre content results in a decrease in the L* values for both crumb and crust, for example whole chia (Sandri, Santos, Fratelli, & Capriles, 2017), carob fibre (Różyło et al., 2017; Tsatsaragkou et al., 2012), maize and barley (Sabanis, Dimitrios, Lebesi, & Tzia, 2009), and apple, date, and pear fibre (Bchir, Rabetafika, Paquot, & Blecker, 2014). In the present work, the level of FBH addition seemed to be more pronounced on the colour of the baked products more than the particle size. The change of bread crust and crumb colour upon fibre addition can be due to different reasons. In most cases, the fibres used, especially from by-products, are not colour-neutral and can contribute to the colour of the baked goods. Mechanisms explaining colour change, especially on the crust, involve Maillard reaction and caramelisation which take place during the baking. The colour of bread crust is influenced by the chemical composition of the dough and baking conditions (Zanoni, Peri, & Bruno, 1995). Unrefined fibres from lignocellulosic material (such as fava bean husk in this study) contain some proteins and polysaccharides which might be broken down into smaller oligomers during processing thereby increasing the rate of the reactions.

The addition of FBH had no negative impact on sensory evaluation and resulted in a rise of fibre including the ability to make a source of fibre claim. Overall fine particle size seemed to produce the most desirable results for texture, which is an important quality determining consumer acceptance (Cauvain, 2016). The inclusion of faba bean husk did not appear to affect porosity although, positively, it did increase fibre and the sensory panellists stated that they preferred to eat bread with additional nutritional content. This may be an area of commercial potential that could be explored further.

Consumers relate bread freshness with texture of breadcrumb (Ahlborn, Pike, Hendrix, Hess, & Huber, 2005). In the study of Horstmann and others (2016) reported that specific volume, and area of cells per total influence the breadcrumb hardness and the rates of staling. In the present work, during the study, sensory testing participants expressed concerns over the staling of GF breads. An informal observation during this work was that some of the loaves appeared to stale faster than others. It would therefore be worthwhile examining the anti-staling effect that the addition of fibre from FBH may have on the shelf life of breads, similarly to the effect reported by Sciarini et al. (2017).

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5. Conclusion

Fava bean husks can serve as a low-cost, excellent source of fibre. Reintegration of this by-product into gluten-free bread would help optimising the use of resources, and concurrently, improving the nutritional quality of the bread. In this study, while adding FBH (of different particle sizes and at different levels) into GF bread formulation improved the level of dietary fire, it also affected the physico-chemical of the baked product. Nonetheless, the results from sensory evaluation showed the acceptability of FBH-fortified GF breads were not differ from that of control GF formulation. In conclusion, the overall result has shown that fava bean husk is a good source to fortify the dietary fibre in gluten free bread without compromising quality characteristics.

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CRediT authorship contribution statement

Suwimol Chockchaisawasdee: Data curation, Validation, Writing – review & editing, Visualization. **Manuel Cifredo Mendoza:** Investigation, Formal analysis, Writing – original draft, Writing, Visualization, Resources. **Caroline A. Beecroft:** Investigation, Writing – review & editing. **Audrey C. Kerr:** Investigation, Writing – review & editing. **Constantinos E. Stathopoulos:** Conceptualization, Supervision, Writing – review & editing. **Alberto Fiore:** Conceptualization, Supervision, Funding acquisition, Writing – review & editing, Project administration.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2022.114362.

Abbreviations

Faba Bean Husk (FBH), Coeliac Disease (CD), Gluten Free Bread (GFB).

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