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Effect of defatted melon seed residue on dough development and bread quality

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ABSTRACT

The aim of this study was to investigate the effect of replacing wheat flour with defatted melon seed (*Cucumis melo* L.) residue (DMSR) on the dough properties and bread nutritional quality and physical characteristics. Adding DMSR did not affect the water absorption of dough, but it made the dough weaker and less extensible. Considering the physical characteristics of breads, DMSR decreased the bread specific volume and the cell number in the crumb, whereas the average cell size increased resulting in a heterogeneous and compact cell crumb structure. Compared with the control bread, DMSR breads exhibited a darker crust, a yellowish crumb, and a firmer texture. DMSR improved the nutritional quality of bread; the protein, lipid, fibre, and ash contents increased, whereas the starch content decreased. At 10% wheat flour replacement with DMSR, the fibre content increased more than five-fold compared to control bread. Overall, although DMSR had a negative impact on dough rheology and on certain physical characteristics of bread, overall, it exhibited considerable potential to fortify bread and improving it nutritional quality.

1. Introduction

Bread is one of the popular daily staple foods in many countries, with refined wheat flour commonly used in most white bread formulations. However, especially in terms of fibre content, this makes white bread a high glycaemic index (GI) food, which is associated with health issues including diabetes and obesity (Lal et al., 2021; Zhu, 2019). Nowadays, with increasing health consciousness, consumers generally tend to purchase high nutritional value foods (Dhen et al., 2018; Hsieh et al., 2017). This trend is also reflected in the bakery market, where products containing ingredients that have beneficial effects on health are attracting consumers' attention (Sajdakowska et al., 2021). In the UK, nearly 11 million loaves are sold each day and they are significant contributors to UK nutrients intake, which provides 11%–12% of energy, 10%–12% of protein, and 17%–21% of fibre (Lockyer & Spiro, 2020; Steer et al., 2008). Consequently, bread is an important vehicle for nutrients and a key part of a healthy and balanced diet.

Melon (*Cucumis melo* L.) production was over 28 million tonnes in 2020 in the world (FAOSTAT, 2021). Melon seed is a by-product from melon supply chain, and can represent up to 10% of the total melon weight. Previous studies showed that melon seeds are good source of protein (22%–39% w/w), lipid (30%–45% w/w), fibre (19%–34% w/w), and minerals (rich in potassium) (Mallek-Ayadi et al., 2018; Mian-Hao & Yansong, 2007; Wang et al., 2019). Research on melon seed valorisation has primarily focused on oil extraction, due to its high linoleic acid content (Mallek-Ayadi et al., 2018; Wang et al., 2019). After oil extraction, defatted melon seed residue (DMSR) is produced as a by-product, consisting of a high amounts of protein and fibre. Consequently, considering its high fibre and protein content, DMSR could be used as an ingredient for developing fortified foods. Previous studies have shown that vegetable or fruit by-products have great potential for being re-utilised as functional ingredients to increase the nutritional value of bakery products (Ahmad et al., 2018; Chareonthaikij et al., 2016; Sardabi et al., 2021; Zarzycki et al., 2022). In addition, from a sustainable development perspective, re-introducing food by-products into the food chain as ingredients can improve the resource utilisation efficiency and reduce waste, which are key for transitioning to more sustainable consumption and production patterns (Difonzo et al., 2022). da Cunha et al. (2020) demonstrated the possibility of using melon seed flour in cake production and indicated that 10% wheat flour replacement with melon seed flour was the most acceptable level for consumers in terms of sensory perception. However, to date, there is insufficient information in the literature about the utilisation of DMSR and its application for bread production. Therefore, the aim of this study was to

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investigate the effect of DMSR on dough properties and bread quality, to evaluate the possibility of utilising DMSR into bread production. These data could provide useful information to achieve a complete valorisation of melon seeds, reduce food waste, and develop nutritionally fortified bread.

2. Materials and methods

2.1. Materials

Honeydew melons (*Cucumis melo* L.; produced in Brazil) were purchased from Sainsbury (Reading, UK). The seeds were collected manually from the fresh melons. All collected seeds were washed with tap water to remove any flesh attached on the seeds' surface and then dried at 50 °C in a tray dryer (APEX Construction LTD, England) for 24 h. Dried melon seeds were pressed using a cold-pressed oil machine (KK 20F SPEZ, oil press GmbH & Co, KG, Germany) to extract the oil. The defatted melon residue (DMSR) was collected and grounded with a food grinder (Caterlite, CK686, Bristol, UK) for 30 s, sieved through 1000 μm mesh sieves, and then stored at −20 °C until further use. The composition of DMSR was evaluated through preliminary work following by AOAC methods (AOAC, 2005): moisture 9.60 g/100 g, protein 34.13 g/100 g, fat 16.44 g/100 g, fibre 35.13 g/100 g, and ash 4.41 g/100 g. Other ingredients used for bread production were strong wheat flour (Marks & Spencer, Reading, UK; moisture 13.8 g/100 g, protein 13.5 g/100 g, fibre 1.6 g/100 g, fat 0.6 g/100 g, salt 0.03 g/100 g), instant dried yeast (Borwick's, UK), salt (Sainsbury's table salt, Sainsburys, Reading, UK) and baking fat (Marks & Spencer, Reading, UK; 75 g/100g vegetable fat; fat 75 g/100 g of which 28 g are saturated, salt 1.38 g/100 g).

2.2. Dough development characteristics

2.2.1. Farinographic analysis

Wheat flour was used to produce the control dough whereas two more doughs were formulated by replacing wheat flour with DMSR at different percentages: 5% and 10% (DMSR5 and DMSR10, respectively). A farinograph (Brabender Farinograph® FA/R-2 810105, Duisburg, Germany) with a 300 g bowl was used to determine the effect of DMSR flour on the dough development. The AACC 54–21.01 constant dough weight procedure was followed (AACC International, 2010). Results including flour water absorption to yield dough consistency of 500 Brabender Units (BU) (WA; %), dough development time (time needed for the curve to reach maximum dough consistency which is usually the highest point on the curve when the curve is centered on the 500 B.U. line, DDT; min), dough stability time (time that dough consistency remains at 500 BU,DST; min), and mixing tolerance index (consistency difference between height at peak and that after 5 min, MTI; FU) were calculated. Each dough was assessed in triplicate.

2.2.2. Dough uniaxial extensibility

The extensibility of bread dough was determined using a Kieffer extensibility rig assembled on a Texture Analyser (TA-XT2, Stable Micro Systems, Surrey, UK) with a 5 kg load cell. The dough samples were each prepared using a 300 g mixing bowl of farinograph (Brabender Farinograph® FA/R-2 810105, Duisburg, Germany). 300 g of wheat flour (control) or composite flour (DMSR5: 95% wheat flour and 5% DMSR; DMSR10: 90% wheat flour and 10% DMSR) were added to the mixing bowl. Water addition varied depending on the water absorption results for each dough sample (Table 1) from the farinographic analysis (section 2.2.1): control (187.7 g), DMSR5 (190.0 g), and DMSR10 (188.3 g). From the dough formed in the farinograph, 20 g were moulded into a cylinder and placed in a press lubricated with parafin oil, and then was compressed for 40 min. The press was sealed to reduce the moisture emission of the sample. Two dough strips were used for each dough replicate. The test conditions were as followed: pre-test speed at 2.0 mm/s, test speed at 3.3 mm/s, post-test speed of 10.0 mm/s, distance at 75 mm, and trigger force of 0.05 N. The resistance to extension (R/E; N) and extensibility (E; mm) were determined.

Table 1
Mixing properties and uniaxial extensibility of the different dough samples.

Dough	Mixing properties				Unaxial extension	
	WA (%)	DDT (min)	DST (min)	MTI (FU)	R/E (N)	E (mm)
Control	62.57 ± 0.32 ^{a}	3.57 ± 0.11 ^{b}	9.17 ± 0.29 ^{a}	16.33 ± 1.53 ^{c}	0.45 ± 0.02 ^{a}	70.27 ± 2.45 ^{a}
DMSR5	63.33 ± 0.35 ^{a}	4.27 ± 0.25 ^{a}	5.57 ± 0.21 ^{b}	27.67 ± 2.08 ^{b}	0.16 ± 0.01 ^{b}	40.35 ± 4.94 ^{b}
DMSR10	62.77 ± 0.25 ^{a}	4.57 ± 0.11 ^{a}	2.33 ± 0.15 ^{c}	123.67 ± 4.04 ^{a}	0.08 ± 0.02 ^{c}	18.25 ± 1.86 ^{c}

Mean ± SD values in the same column with different superscript letters are significantly different ($p < 0.05$) according to the Tukey's HSD Test; WA-water absorption; DDT-dough development time; DST-dough stability time; MTI-Mixing tolerance index; R/E − resistance to extension; E − extensibility. Control - 100% wheat flour, DMSR5 - 5% wheat flour replaced by defatted melon seed residue, DMSR10 - 10% wheat flour replaced by defatted melon seed residue.

2.3. Bread baking procedure

The formulation of breads was as followed: 1000 g flour (control: 100% wheat flour; DMSR5: 95% wheat flour and 5% DMSR; DMSR10: 90% wheat flour and 10% DMSR), 7 g bakery fat, 15 g salt, 14 g dry yeast, 0.2 g ascorbic acid, and 600 mL water. The water content was constant in all the samples. Bread dough was prepared using the Z-blade mixer (Morton Mixers, UK). All ingredients were mixed at 48 rpm for 130 s at low speed, and then mixed high speed, i.e. at 111 rpm for 100 s. Afterwards, the dough was hand-moulded into three 460 g pieces and placed on a baking tray for an initial proving period (proofing oven ARM/93 proof oven, Salva, Lezo, Spain) at 40 °C for 10 min. Then, the dough pieces were moulded in a mono mini moulder (Mono Equipment, Swansea, UK) and transferred into a baking tin (17 × 7.5 × 8 cm). Doughs were proved for another 20 min, and then baked in a deck oven (3STA 4676, Polin Stratos, Verona, Italy) at 230 °C for 20 min. After baking, the loaves were removed from the tins, left to cool down to room temperature, and then sealed in polypropylene bags. Three bread loaves per replicate were obtained. Analyses were carried out during the following 24 h. Each bread formulation was prepared in triplicate.

2.4. Proximate composition analysis of bread

The moisture, protein (conversion factor x 6.25), lipid, fibre, and ash of control bread and DMSR breads were determined by the AOAC method (AOAC, 2005). Starch was determined using the Total Starch Assay Kit (Megazyme, Ireland). Samples were analysed in triplicate.

2.5. Bread physical characteristics

Weight loss (WL; %) of bread during baking was calculated according to Rodríguez-García et al. (2013) methodology. The bread specific volume was determined by using Volscan Profiler (VSP 600C, Stable Micro Systems, UK). Cell crumb structure of bread was determined according to Lau et al. (2022) methodology with minor modifications. Briefly, the image of bread slice was scanned using a flatbed scan (HP Scanjet G2710, Hewlett-Packard, United States). Afterwards, the image was analysed using Image J software (National Institute of Health, USA). The image was cropped at the centre of the slice to produce a 5 cm × 4.5 cm crumb image, and then was split into colour channel, and blue was selected. The image was binarized; the number of cells and the area of the air cells were measured. Two slices per bread sample were measured.

2.6. Bread texture profile analysis

The texture properties of bread were determined using a Texture Analyser (TAX-Plus, Stable Micro Systems, Surrey, UK) with a 5 kg load cell, and analysed following Dhen et al. (2018) description with some modifications. Briefly, bread samples were sliced into 15 mm thick slices. The two middle bread slices of each bread were used for texture analysis. A two-cycle crumb compression test was performed using a 20 mm diameter cylindrical prob (p/20); samples were compressed 40% of their original height at a speed of 1.7 mm/s with 5 s waiting time between the two cycles. The results of hardness (N), springiness, cohesiveness, and chewiness (N) were calculated by the software Exponent (Version 6.1.18.0, Stable Micro Systems, Surrey, UK). Three measurements per replicate were performed, in each of the three loaves obtained.

2.7. Colour measurement of crumb and crust

A chroma meter (CR-400, Minolta, Japan) was used to measure the colour of the bread crust and crumb. The colour of the crust was measured in three points in the centre of the loaf. The colour of the crumb was measured at three points in the central part of a slice. Measurements were performed in the three breads loafs produced per batch. The results were expressed in accordance with the CIELAB system (illuminant C and 10° viewing angle). The measurements were made with an 8 mm diameter diaphragm inset with optical glass. The parameters measured were L* (L* = 0 [black], L* = 100 [white]), a* (–a* = greenness and +a* = red) and b* (–b* = blueness and +b* = yellow). The total colour difference (ΔE*) between the control sample and each of the breads containing DMSR was calculated as follows (Francis & Clydesdale, 1975):

$$\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$$

The values used to determine whether the total colour difference was visually obvious were the following (Bodart et al., 2008): $\Delta E^* < 1$ colour differences are not obvious for the human eye; $1 < \Delta E^* < 3$ minor colour differences could be appreciated by the human eye depending of the hue; $\Delta E^* > 3$ colour differences are obvious for the human eye.

2.8. Statistical analysis

One-way analysis of variance (ANOVA) was performed using Minitab (version 20, State College, USA) software package. Turkey's HSD test was used to compare the mean values ($p < 0.05$) among samples.

3. Results and discussion

3.1. Dough mixing properties

The dough mixing properties are presented in Table 1. Dough water absorption (WA) was not significantly different ($p > 0.05$) between doughs when wheat flour was replaced by DMSR. Adding DMSR significantly increased ($p < 0.05$) dough development time (DDT), but no difference ($p > 0.05$) was observed between 5% and 10% enrichment. DDT increase could be due to the fibre content increasing in DMSR dough (DMSR proximate composition in section 2.1.). Fibre in DMSR competes for water with wheat flour components hindering the hydration of gluten proteins, thereby more time is required to develop the gluten network, increasing the DDT (Gökşen & Ekiz, 2016; Wirkijowska et al., 2020). Dough stability time (DST) and mixing tolerance index (MTI) indicate dough strength and tolerance to mixing; a strong dough is characteristed by a high DST and low MTI values (Chisenga et al., 2020; Guardianelli et al., 2021). Adding DMSR significantly decreased DST and increased MTI ($p < 0.05$), indicating that the replacement of wheat flour with DMSR resulted in a weaker and less stable dough. These results could be attributed to gluten dilution and increased fibre content which induces greater disruption of the gluten network (Chisenga et al., 2020; Pasqualone et al., 2017). Similar results were observed in previous works, in which Moldavian dragonhead seed residue or Flaxseed addition resulted in softer bread doughs (Wirkijowska et al., 2020; Zarzycki et al., 2022).

3.2. Dough uniaxial extensibility

Extensibility reflects the expansion capacity of dough and relates to bread final volume (Burešová et al., 2014; Coțovanu & Mironeasa, 2021). Dough extensibility properties are presented in Table 1. The resistance to extension (R/E) and extensibility (E) of dough decreased significantly ($p < 0.05$) when DMSR proportion increased, indicating that the DMSR dough became weaker and softer. A specific ratio of gliadin (determines dough extensibility) to glutenin (determines the dough elasticity and strength) fractions is important for dough extensibility (Barak et al., 2013; Lu et al., 2018). The presence of non-gluten proteins from DMSR could have reduced the possibility of gliadins and glutenins interacting, thereby reducing dough extensibility.

3.3. Proximate compositions of bread

The proximate composition of breads is presented in Table 2. The moisture content decreased as DMSR content increased in breads; DMSR10 had a significantly lower moisture content ($p < 0.05$) than control bread. This could be attributed to the initial moisture content difference between wheat flour (13.8 g/100 g) and DMSR (9.60 g/100 g). DMSR breads had significantly higher ($p < 0.05$) lipid, protein, and fibre content than control bread. Especially, the fibre content in DMSR10 bread (3.41 g/100 g) was more than 5-fold higher compared to the control bread (0.57 g/100 g). According to the European regulation for nutrition and health claims on foods, products that claim to be 'source of fibre' and 'high fibre' should contain at least 3 g fibre and 6 g fibre per 100 g product, respectively (The Council of European Union, 2007). Therefore, DMSR10 bread could be labelled as 'source of fibre'. In contrast, DMSR breads contained lower starch content as compared to control bread. Luo and Zhang (2018) indicated that increasing fibre or decreasing starch content is essential to develop low-Glycaemic index (GI) bread, which might have potential health benefits for preventing hyperglycemia related diseases. In terms of ash content, a significant increase ($p < 0.05$) was observed in DMSR10 bread as compared to control bread. Previous studies reported that melon seed is rich in potassium (1148–2082 mg/100 g) (Mallek-Ayadi et al., 2018; Morais et al., 2017); thus, DMSR10 bread could contribute to an increased dietary intake of potassium.

3.4. Physical characteristics of bread

Table 3 shows the physical characteristics of control bread and

Table 2
Proximate composition (g/100 g) of bread samples.

Sample	Moisture	Lipid	Protein	Ash	Starch	Fibre
Control	38.07 ± 0.30 ^{a}	0.42 ± 0.04 ^{c}	9.71 ± 0.12 ^{c}	1.69 ± 0.03 ^{b}	49.37 ± 0.43 ^{a}	0.56 ± 0.15 ^{c}
DMSR5	37.71 ± 0.12 ^{ab}	0.71 ± 0.06 ^{b}	9.96 ± 0.03 ^{b}	1.69 ± 0.01 ^{b}	48.05 ± 0.29 ^{b}	1.71 ± 0.10 ^{b}
DMSR10	37.23 ± 0.24 ^{b}	1.02 ± 0.04 ^{a}	10.29 ± 0.03 ^{a}	1.79 ± 0.05 ^{a}	44.93 ± 0.30 ^{c}	3.41 ± 0.38 ^{a}

Mean ± SD values in the same column with different superscript letters are significantly different ($p < 0.05$) according to the Tukey's HSD Test. Control - 100% wheat flour; DMSR5 - 5% wheat flour replaced by defatted melon seed residue; DMSR10 - 10% wheat flour replaced by defatted melon seed residue.

Table 3
Physical characteristics of bread samples.

Sample	WL (%)	Specific volume (ml/g)	Number of cells	Average cell size (mm^2)
Control	8.72 ± 0.33^{a}	3.02 ± 0.08^{a}	1017.0 ± 54.29^{a}	0.77 ± 0.15^{c}
DMSR5	8.80 ± 0.41^{a}	2.67 ± 0.04^{b}	742.33 ± 11.15^{b}	1.17 ± 0.06^{b}
DMSR10	8.80 ± 0.16^{a}	2.48 ± 0.04^{c}	535.67 ± 42.36^{c}	1.93 ± 0.06^{a}

Mean ± SD values in the same column with different superscript letters are significantly different ($p < 0.05$) according to the Tukey's HSD Test. WL – weight loss; Control - 100% wheat flour; DMSR5 - 5% wheat flour replaced by defatted melon seed residue; DMSR10 - 10% wheat flour replaced by defatted melon seed residue.

DMSR breads. Weight loss (WL) values were not significantly different ($p > 0.05$) among the three bread formulations. However, as mentioned in section 3.3 (Table 1) DMSR breads had lower moisture content than the control. These results could be due to the lower moisture content of DMSR (9.6 g/100 g) over wheat flour (13.8 g/100 g). The decreasing or increasing effects on WL may depend on the substitution ingredient used due to their different chemical compositions and molecular structures (Alinovi et al., 2022; Lazou et al., 2022; Sardabi et al., 2021). Specific volume is an important parameter as it relates with the total gas phase retained in the final bread. As expected, a significant decrease in bread specific volume ($p < 0.05$) was observed with increasing DMSR (Table 3 and Fig. 1). The addition of DMSR reduced the dough uniaxial extensibility (Table 1), thus decreasing the expansion capacity of dough during fermentation and baking and resulting in a lower volume of bread. The addition of DMSR reduced the dough uniaxial extensibility (Table 1), thus decreasing the expansion capacity of dough during fermentation and baking and resulting in a lower volume of bread.

In terms of crumb structure, the number of cells decreased with increasing amount of DMSR (Table 3). In contrast, the average cell size increased when the DMSR ratio increased. These findings could be explained by the dough mixing properties discussed in section 3.1. As the DMSR proportion increased, the dough strength decreased, giving place to a dough in which gas phase destabilization phenomena, such as flocculation and coalescence of bubbles, took place, resulting in bigger cells and less cells numbers. These results are in agreement with other studies, where it is reported that addition of high fibre ingredients reduced the strength of gluten network and the stability of gas cell walls; this resulted in broken gas cell walls and coalescence of cells into larger ones (Bigne et al., 2018; Han et al., 2019; Ni et al., 2020; Saka et al., 2022).

3.5. Texture properties of bread

Texture properties of all formulation breads are presented in Table 4. The hardness of bread increased significantly ($p < 0.05$) with increasing the DMSR ratio. As it was discussed in the previous section, breads with higher DMSR content presented lower volumes and a more compact cell crumb structure, thus giving place to firmer crumbs; this is supported by the PCA plot (Figure s1), where DMSR breads were positively associated with hardness and average cell size, but were negatively associated with volume and cell number. This was attributed to the increased level of fibre leading to a weaker and less extensible dough, with lower gas retention ability during fermentation and baking, thereby resulting in a compact structure (Ahmad et al., 2018; Dhen et al., 2018; Ma et al., 2019). These results were in line with previous studies, where fruit or vegetable by-products were added into bread formulations to increase dietary fibre (Ahmad et al., 2018; Ni et al., 2020; Zarzycki et al., 2022). Moreover, the lower moisture content in DMSR breads may have also been another factor to the increased hardness value. Water is the most common plasticizer in bread, which is related to hardness, thus, a lower moisture content could result in a firmer structure (Alinovi et al., 2022; Das et al., 2015; Mastromatteo et al., 2013). Additionally, a significant increase in chewiness ($p < 0.05$) was observed when increasing the percentage of DMSR in bread formulation. Chewiness reflects the extent of difficulty in food mastication before swallowing, and harder foods having higher chewiness (Xin et al., 2022).

Springiness and cohesiveness reflect the elasticity of bread and the resistance of its internal structure, respectively (Dhen et al., 2018; Ulziijargal et al., 2013). The springiness and cohesiveness values of both of DMSR breads were significantly lower ($P < 0.05$) than control bread, indicating that DMSR breads were less elastic and with a weaker cell crumb structure than control bread. These results could be attributed to the dilution of the gluten content. As mentioned before, when wheat flour was replaced by DMSR the inter-molecular interaction between gluten proteins for the formation of the network were disrupted, which led to a less elastic and fragile crumb structure in DMSR breads. Previous

Table 4
Texture properties of bread samples.

Sample	Hardness (N)	Springiness	Cohesiveness	Chewiness (N)
Control	13.66 ± 0.52^{c}	0.91 ± 0.01^{a}	0.71 ± 0.02^{a}	8.43 ± 0.15^{c}
DMSR5	19.76 ± 0.40^{b}	0.83 ± 0.02^{b}	0.61 ± 0.02^{b}	9.51 ± 0.24^{b}
DMSR10	22.69 ± 0.41^{a}	0.81 ± 0.01^{b}	0.55 ± 0.01^{c}	10.51 ± 0.18^{a}

Mean ± SD values in the same column with different superscript letters are significantly different ($p < 0.05$) according to the Tukey's HSD Test. Control - 100% wheat flour; DMSR5 - 5% wheat flour replaced by defatted melon seed residue; DMSR10 - 10% wheat flour replaced by defatted melon seed residue.

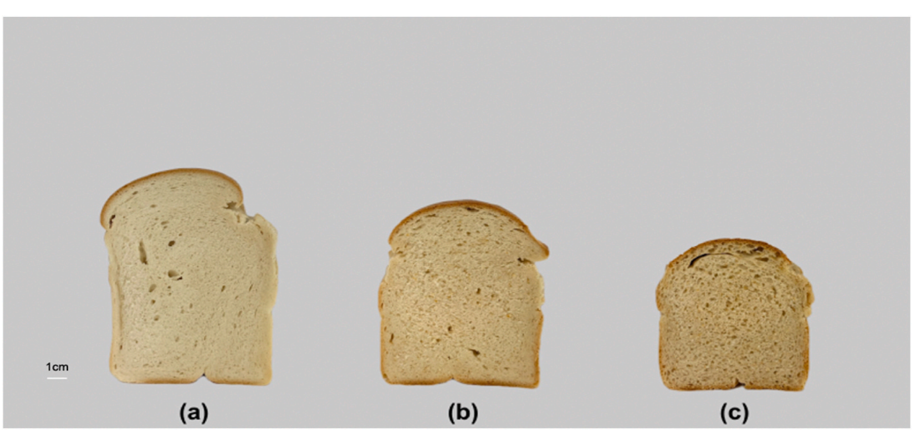

Fig. 1. Scanned images of bread slices; (a) Control bread - 100% wheat flour; (b) DMSR5 - 5% replacing level of wheat flour; (c) DMSR10 - 10% replacing level of wheat flour.

studies in bread, in which wheat flour was replaced by wheat by-products and broad bean hull also observed that substituted breads presented the characteristics of lower springiness and cohesiveness (Ni et al., 2020; Pasqualone et al., 2017).

3.6. Colour of bread crust and crumb

The crust and crumb colour of all formulation breads are presented in Table 5 and in Fig. 1. Bread crust became significantly ($p < 0.05$) darker (lower L*) when DMSR ratio increased in bread. This result could be associated with the dark colour of DMSR. Previous studies reported similar results when dark colour ingredients were used in bread production (Alinovi et al., 2022; Mikulec et al., 2019). In addition, the DSMR bread crusts colour presented lower values of the red component (a*) and yellow component (b*) than the control bread crust. These colour changes in the crust could be attributed to Maillard reaction due to higher protein content in DMSR than wheat (34.13 g/100 g and 13.5 g/100 g, respectively). These results are in line with previous studies in which a* and b* values decreased when wheat flour substitution by roasted flaxseed flour/defatted hemp flour increased in bread (Lazou et al., 2022; Marpalle et al., 2014).

In terms of bread crumb colour, similar trends as in the crusts were observed. The lightness (L*) of the crumb decreased significantly ($p < 0.05$) with increasing DMSR. In contrast, a significant increase in b* (yellowness) and decrease in a* (greenness) ($p < 0.05$) were observed in the breads with increasing DMSR. Crumb colour changes could be mainly attributed to the originally colour of DMSR, rather than to chemical reactions. During baking, the centre of the crumb cannot reach temperature above 100 °C. In addition, due to its higher moisture content, Maillard and caramelization reactions do not take place or are slower in comparison to the crumb, thereby they could not produce a significant impact on crumb colour (Lau et al., 2022; Purić et al., 2020).

The total colour differences (ΔE*) for crust and crumb in all DMSR breads were higher than 3 as compared to control bread, indicating that the differences in colour between DMSR breads and control bread were obvious to the human eye.

Table 5
Crust and crumb colour parameters of bread samples.

Crust	L*	a*	b*	ΔE*
Control	59.76 ± 1.78 [a]	13.79 ± 0.58 [a]	36.77 ± 0.64 [a]	0
DMSR5	53.56 ± 1.35 [b]	12.24 ± 0.22 [b]	23.14 ± 0.95 [b]	15.14
DMSR10	47.13 ± 0.73 [c]	12.29 ± 0.21 [b]	20.07 ± 0.16 [c]	21.02
Crumb				
Control	77.11 ± 1.01 [a]	−1.60 ± 0.06 [c]	12.60 ± 0.29 [c]	0
DMSR5	72.16 ± 0.61 [b]	−1.24 ± 0.09 [b]	14.98 ± 0.11 [b]	3.83
DMSR10	66.02 ± 0.25 [c]	−0.58 ± 0.08 [a]	16.17 ± 0.34 [a]	11.70
Ingredient				
WF	94.02 ± 0.20	−0.59 ± 0.04	9.93 ± 0.14	–
DMSR	69.96 ± 0.19	4.98 ± 0.17	26.62 ± 0.60	–

Mean ± SD values in the same column with different superscript letters are significantly different ($p < 0.05$) according to the Tukey's HSD Test; WF - wheat flour. Control - 100% wheat flour; DMSR5 - 5% wheat flour replaced by defatted melon seed residue; DMSR10 - 10% wheat flour replaced by defatted melon seed residue.

4. Conclusions

Replacement of 10% of wheat flour by DMSR resulted in a bread that could be considered 'source of fibre'. Moreover, DMSR addition enhanced protein and lipid content, improving bread nutritional quality. The reduction of starch content and the increase of fibre in DMSR breads could lead to a lower glycaemic index (GI) food than control bread. To this end, further work to evaluate the starch digestibility, blood glucose response and sensory profiling of DMSR breads should be carried out. DMSR addition reduced dough strength and extensibility, and had a negative effect in bread volume, hardness and springiness. Future work to reduce the negative effect of DMSR on bread physical properties will be carried out by using processing technologies to modify the technological properties of DMSR, such as thermal treatment, micro-milling, and fermentation. Overall, in the present work, DMSR was re-introduced into the food chain and incorporated into bread production as a complementary ingredient to wheat flour, helping in reducing food waste and contributing to a more sustainable food system.

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CRediT authorship contribution statement

Guoqiang Zhang: Conceptualization, Methodology, ValidationValidation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Afroditi Chatzifragkou:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision. **Dimitris Charalampopoulos:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Project administration. **Julia Rodriguez-Garcia:** Conceptualization, Methodology, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no competing or interests.

Data availability

The data presented in this study are openly available in the University of Reading Research Data Archive at https://doi.org/10.17864/1947.000439 (02/12/2022)

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2023.114892.

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