Zhang and Li
Food Production, Processing and Nutrition (2024) 6:44
https://doi.org/10.1186/s43014-024-00225-9

Food Production, Processing and Nutrition

RESEARCH Open Access

Impact of melon seed oil cake with different particle sizes on bread quality

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Abstract

Melon seed oil cake (MSOC), as the secondary by-product from melon seed oil pressing process, has high potential nutritional value. The aim of this study was to assess the effect of incorporating MSOC as wheat flour substitute and its particle size on bread quality; three particle size fractions of MSOC (coarse, medium, and fine) and two substitution levels (3 and 6%, w/w) were employed. Functional properties and colour of different particle sizes of MSOC were assessed, and the physical properties of bread made with MSOC were explored and compared to control bread (100% wheat flour). Results showed that bread made with 3% MSOC had relatively satisfactory quality in terms of specific volume (2.64–2.86 mL/g), hardness (14.31–15.04 N) compared to the control bread (specific volume 2.79 mL/g and hardness 13.87 N). Bread made with fine particle size of MSOC (2.64 mL/g and 15.04 N at 3% substitution level; 2.44 mL/g and 16.03 N at 6% substitution level) had lower specific volume and higher hardness values than the bread made with medium (2.80 mL/g and 14.31 N at 3% substitution level; 2.50 mL/g and 15.50 N at 6% substitution level) and coarse (2.86 mL/g and 14.72 N at 3% substitution level; 2.52 mL/g and 15.12 N at 6% substitution level) particle sizes of MSOC. These results indicate that using 3% MSOC with larger particle size could be more suitable for making bread with relatively satisfactory quality. Overall, MSOC could be re-introduced into food chain as ingredient for bread production, which offers possibilities to develop novel sustainable foods. Future work will be conducted on sensory quality and consumer acceptance to provide a desirable quality of bread.

Keywords Melon seed, By-product of oil extraction, Oil cake, Composite bread, Sustainable food, Valorisation

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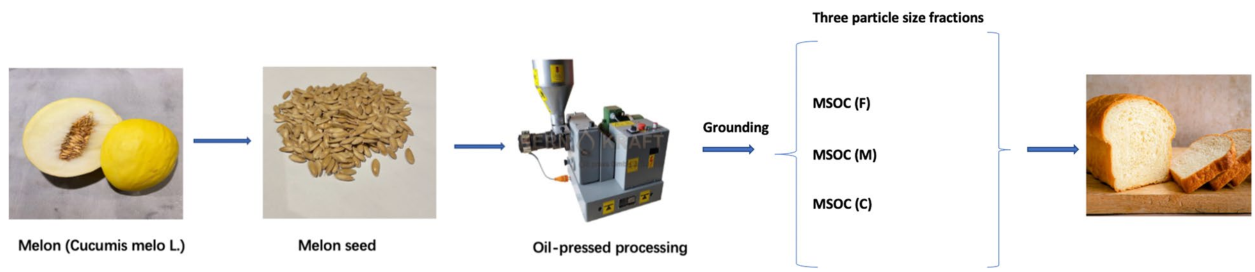
Graphical Abstract



Introduction

Melon (*Cucumis melo L.*) is one of the most commercial type of fruits, the world production about 28 million tons in 2021 (FAOSTAT 2021). Melon seed (about 5–10% of total melon weight), a major by-product in melon supply chain, is reported to contain high potential value (e.g. protein, oil, and fibre) that could be recovered and converted into high added products (Petkova & Antova 2015; Sahin et al. 2022). Due to high oil content (30–45% w/w) and rich in unsaturated fatty acid (74–86%), melon seed has received attention and current valorisation focus on oil extraction (Rabadán et al. 2020; Sahin et al. 2022). Melon seed oil cake (MSOC), as a major by-product following oil extraction, also contain considerable level of nutritional value, such as protein (~34% w/w) and fibre (~35% w/w), but it is underutilised (Zhang et al. 2023). Oil cake is reported to consider as an excellent functional ingredient that could be re-incorporated into food chain for food product development (Mirpoor et al. 2021; Purić et al. 2020). Consequently, MSOC could be considered as ingredient in developing healthy and sustainable food, on the other hand, maximising value from the food side-streams can reduce food waste, and then promote sustainable food development and production (Mirpoor et al. 2021).

Bread is one of the most important staple foods in the world, it is a significant contributor to daily dietary nutrient intake. Most breads are made using refined wheat flour, which has some limitations in terms of nutritional profile, such as dietary fibre, minerals, and phytochemical compounds (Villarino et al. 2015; Xin et al. 2022). Many studies in the literature indicated incorporation of food by-products in bread production is a feasible method to improve bread nutritional quality and manufacture healthier bakery products (Coțovanu et al. 2022; Dziki et al. 2021; Lau et al. 2022; Wang et al. 2023). However, utilising by-products in bread formulation as wheat flour replacement is a challenge without compromising bread characteristic and quality. In our previous study, MSOC as wheat flour substitution has been incorporated in bread formulation at 5 and 10% replacing levels; MSOC addition comprehensively improved bread nutritional quality, especially in fibre and protein content, but caused negative effect on bread volume and texture (Zhang et al. 2023) Particle size is known as one of the important factors to influence bakery product's quality (Albasir et al. 2022; Noort et al. 2010; Sun et al. 2023). In bakery applications, Lin et al. (2022) found that the bread made with super fine wheat bran (11.3 µm) produced a firmer texture compared to the one made with coarse fraction (363.2 µm) at 20% wheat flour substitution level. On the other hand, Wu and Shiau (2015) reported that steamed bread with large particle size of pineapple peel fibre (250–420 µm) had significantly higher specific volume than bread made with small particle size of pineapple peel fibre (104–250 µm). Previous studies in literature showed that ingredients with appropriate particle size could improve final bakery product quality (Feng et al. 2022; Xin et al. 2022; Xu et al. 2022). However, to date, no studies are currently available on incorporating different particle size of MSOC on bread production. Therefore, the aim of this study was to investigate and assess the effect of incorporating MSOC with different particle sizes on bread quality. This data could contribute to develop the added value of MSOC, help its further application in bread production to produce high quality bread, and promote sustainable food development.

Materials and methods

Material preparation

Honeydew melon seeds were collected manually from fresh honeydew melons (region, Brazil; purchased from Sainsbury's, Reading, UK). Other ingredients used for bread production were strong wheat flour (composition from manufacturer; protein 13.5 g/100 g, fibre 1.6 g/100 g, fat 0.6 g/100 g Marks & Spencer, Reading, UK), baking fat (Marks & Spencer, Reading, UK), instant dried yeast

(Borwick's, UK), and salt (Sainsbury's table salt, Sainsbury's, Reading, UK).

Methods

Production of melon seed oil cake (MSOC)

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 (Wolverine proctor, USA) for 24 h. Dried seeds were pressed using a cold-pressed oil machine (KK 20F SPEZ, oil press GmbH & Co, KG, Germany) for oil and melon seed oil cake (MSOC). The proximate composition of MSOC was determined in previous study (protein 34.1 g/100 g, fat 16.4 g/100 g, fibre 35.1 g/100 g, and ash 4.4 g/100 g) (Zhang et al. 2023). Following Albasir et al. (2022) description with slight modifications to obtain the different particle size fractions of MSOC. Briefly, melon seed oil cake was separated into three portions. Each portion was milled using a food grinder (Caterlite CK686, Bristol, UK) and/or laboratory mill 3100 (Petern, Warrington, UK), and sieved through distinct sieves (1000 µm, 850 µm, and 600 µm) to obtain different particle sizes of melon seed oil cake, namely Coarse melon seed oil cake (passed through 1000 µm of sieve), Medium melon seed oil cake (passed through 850 µm of sieve), and Fine melon seed oil cake (passed through 600 µm of sieve).

Water/oil holding capacity (WHC/OHC)

Water/oil holding capacity were measured according to Guerra-Oliveira et al. (2022) with slight modifications. Briefly, 100 mg of MSOC sample (as Wi) was added 1 mL of distilled water/corn oil (purchased from Sainsbury's, Reading, UK) and vortexed using vortex mixer (SciQuip, UK) for 1 min, and then was left for 30 min. Afterwards, mixtures were centrifuged (Mini Spin, Eppendorf, Germany) at 3000 rpm for 15 min. The supernatant was removed and weighted residue (Wr). Analysis was performed in triplicate. The WHC/OHC was calculated following the formula:

$$\mathrm{WHC/OHC}\left(\mathrm{g/g}\right) = (\mathrm{Wr} - \mathrm{Wi})/\mathrm{Wi},$$

Where, Wr = residue weight (g), Wi = sample weight (g).

Bread preparation and baking procedure

Wheat flour was substituted by three particle size fractions of MSOC (coarse, medium, and fine) at 3 and 6% w/w, resulting in a total of 7 formulations, as presenting in Table 1. Control was 100% wheat flour bread.

A procedure of bread baking was followed previously Zhang et al. (2023) description. Briefly, the bread dough was prepared using a Z-blade mixer (Morton Mixers, UK). All ingredients were mixed for 130 s at low speed (48 rpm), and then were mixed at high speed (111 rpm) for 100 s. Afterwards, each dough was separated into three pieces of 460 g each, and then transferred into a loaf tin with specific dimension, then was placed into a proofing oven (ARM/93 proof oven, Salva, 129 Lezo, Spain) for 10 min at 40 °C as the initial proving period. After initial proving period, each dough was moulded in a mono mini moulder (Mono Equipment, Swansea, UK) and proved for another 20 min, then was baked in a deck oven (3STA4676, Polin Stratos, Verona, Italy) at 210 °C for 20 min. After baking, the loaf was left to reach to room temperature, and then was sealed in polypropylene bags for further analysis. Three breads were obtained in each replicate and the bread baking procedure for each bread formulation was carried out in duplicate, totally 6 breads were produced.

Physical characteristics

Weight loss (WL; %) of bread during baking was calculated according to Rodríguez-García et al. (2013) methodology. The bread specific volume (mL/g) was determined by using Volscan Profiler (VSP 600C, Stable Micro Systems, UK). Moisture content (%) was determined using a moisture analyser (Sartorius Lab Instruments, Germany). Water activity (aw) was determined using a HygroLab balance (Rotronic instruments, UK).

Table 1 Bread formulations

Ingredient (g)	Control	3%MSOC (F)	3%MSOC (M)	3%MSOC (C)	6%MSOC (F)	6%MSOC (M)	6%MSOC (C)
Wheat Flour	1000	970	970	970	940	940	940
Bakery fat	7	7	7	7	7	7	7
Salt	18	18	18	18	18	18	18
Dry yeast	12	12	12	12	12	12	12
Water	600	600	600	600	600	600	600
MSOC	0	30	30	30	60	60	60
Ascorbic acid	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Control - 100% wheat flour; *MSOC (F)* fine melon seed oil cake, *MSOC (M)* medium melon seed oil cake, *MSOC (C)* coarse melon seed oil cake, 3 and 6% represent replacing level of wheat flour by melon seed oil cake (MSOC)

Measurements were performed in the three breads loafs produced per batch ($n = 6$).

Texture properties analysis

The texture properties of bread were determined by using a Texture Analyser (TA-XT2, Stable Micro Systems, Surrey, UK) with a 5 kg load cell, and analysed following Zhang et al. (2023) description with slight modifications. Briefly, the bread samples were sliced into 15 mm thick slices. The two middle bread slices were used for texture analysis. A two-cycle crumb compression test was performed using a 40 mm diameter probe (p/40) at a pre-test speed of 3.0 mm/s, 1.7 mm/s test speed, 40% strain, and trigger force of 5 g. Hardness (N), springiness, cohesiveness, and chewiness (N) were determined. Measurements were performed in triplicate in the two breads loafs produced per batch ($n = 4$).

Colour measurement

Colour of melon seed oil cake samples were measured according to Tufaro et al. (2022) description with using a colorimeter (Chroma meter CR400, Konica Minolta). The bread of colour measurement was determined according to Lau et al. (2022) description. The bread crumble and crust were measured using a colorimeter (Chroma meter CR400, Konica Minolta). Briefly, the bread crust was measured on the three points of bread crust surface. The bread crumb was measured on the three points of central part of bread slice. Measurements were performed in the three breads loafs produced per batch ($n = 6$). The parameters (L*, a*, and b*) were determined. The total colour difference (ΔE*) 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.

Bread crumb characteristics

Cell crumb characteristics 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, Hewlette-Packard, United States). Afterwards, the image was analysed using Image J software (National Institutes 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 average cell size (mm^2) were determined. Two slices per bread was analysed ($n = 6$).

Statistical analysis

The results are given as mean and standard deviation (SD). One-way analysis of variance (ANOVA) was performed using Minitab (version 20, State 180 College, USA) software. Turkey's HSD test was used to compare the mean values ($p < 0.05$) among samples.

Results and discussion

Functional properties and colour of MSOC

Functional properties of seed flour are essential, which relate to the final product quality including texture, flavour, and mouthfeel (Gupta et al. 2018; Tiencheu et al. 2021). Functional properties of melon seed oil cake (MSOC) with different particle sizes are shown in Table 2. In terms of water holding capacity (WHC), the WHC of MSOC had a reducing tendency when the particle size of MSOC decreased. This result is similar to Rumler et al. (2021) study on sorghum flour with different particle sizes. The possible reason could be explained by the presence of higher porosity in coarser particle size of MSOC; the greater surface area was exposed to water thereby increasing water absorption (Dayakar Rao et al. 2016; Rumler et al. 2021). In terms of oil holding capacity (OHC), no significant difference ($p > 0.05$) was observed among three particle size fractions of MSOC. However, Zhang et al. (2021) reported that the WHC and

Table 2 Functional properties and colour parameter of different particle size fractions of melon seed oil cake (MSOC)

Sample	Moisture (%)	WHC (g/g)	OHC (g/g)	L*	a*	b*
MSOC (F)	9.23% ± 0.16[a]	2.37 ± 0.03[b]	1.36 ± 0.04[a]	71.36 ± 0.49[a]	4.44 ± 0.10[a]	26.31 ± 0.18[a]
MSOC (M)	9.39% ± 0.15[a]	2.43 ± 0.02[b]	1.23 ± 0.22[a]	70.00 ± 0.44[b]	4.65 ± 0.19[a]	25.33 ± 0.51[b]
MSOC (C)	9.56% ± 0.13[a]	2.51 ± 0.02[a]	1.31 ± 0.22[a]	69.93 ± 0.32[b]	4.69 ± 0.11[a]	25.07 ± 0.27[b]
Wheat flour	13.1% ± 0.45	0.70 ± 0.03	0.75 ± 0.05	–	–	–

Mean ± SD ($n = 3$) in the same column with different letters are significantly difference ($p < 0.05$) according to the Tukey's HSD Test. *WHC* Water holding capacity, *OHC* oil holding capacity, *MSOC (F)* fine melon seed oil cake, *MSOC (M)* medium melon seed oil cake, *MSOC (C)* coarse melon seed oil cake

OHC of tobacco leaf powders decreased with decreasing particle size. In contrast, Zhao et al. (2020) found that the WHC and OHC of ginger stem powders increased with decreasing particle size. The different changing trends in WHC and OHC could be related to the chemical compositions of ingredients used, milling conditions, and molecular structure change during milling (Zhang et al. 2021; Zhao et al. 2020).

Regarding the colour parameters of MSOC (in Table 2), the lightness (L*) and yellowness (b*) values were increased with the reduction of particle size of MSOC, whereas fine MSOC showed a significant difference ($p < 0.05$) compared to medium and coarse MSOC. No significant difference ($p > 0.05$) was observed in redness (a*) value among three particle size fractions of MSOC. The increase in lightness (L*) in finer particle size of MSOC could be attributed to increase in reflected surface area, allowing for more reflection of light. In addition, the finding in yellowness (b*) change is in line with Grob et al. (2021) and Hwang (2011), who found that the yellowness (b*) of cocoa pod endocarp powders and persimmon peel powders increased with decreasing particle size. The increase in yellowness (b*) of finer particle sizes could be attributed to the increased release of colored pigments after exposure to heat during milling (Chaireh et al. 2019). On the other hand, according to Liu et al. (2018), the reduction of particle size increased the surface area, exposing the internal structure of cellulose and hemicellulose, resulting in colour changes. Other studies also have been reported that material colour characteristics were susceptible to particle size (Ahmed et al. 2019; Li et al. 2020; Moreira et al. 2015).

Physical parameters

The physical parameters of all bread samples are shown in Table 3. No significant differences ($p > 0.05$) were observed on moisture content and weight loss (WL) value between control bread and all MSOC breads. In terms of water activity, all MSOC breads were significantly higher ($p < 0.05$) than control bread. This could be attributed to the difference in water holding capacity (WHC) of ingredients; adding high in fibre and protein ingredients could have higher water retention capacity during baking process (Korese et al. 2021; Yang et al. 2022). As shown in Table 2, MSOC (2.37–2.51 g/g) had a three-fold higher WHC than wheat flour (0.70 g/g). Besides, the wheat flour in this study contained approximately 13% moisture, while the three particle sizes of MSOC contained 9.2–9.6% moisture (Table 2). The lower moisture content of MSOC could explain our results on WL and moisture content of breads and their discrepancy with the water activity results.

In terms of specific volume, there was no significant difference ($p > 0.05$) between control bread and 3%MSOC breads, while specific volume significantly decreased ($p < 0.05$) as amount of MSOC addition further increased to 6% (Table 3 and Fig. 1). In addition, regarding the effect of particle size, a tendency of decrease in bread specific volume was observed when the particle size of MSOC was reduced. This finding is in line with Protonotariou et al. (2020) and Wu and Shiau (2015), who used different particle sizes of whole wheat flour and pineapple peel fibre in bread production and noticed that bread volume decreased with decreasing particle size of whole wheat flour and pineapple peel fibre. With the addition of MSOC, MSOC penetrated into gluten network and acted weakness point to interfere with gluten network formation; in addition, fine MSOC particle was easier to fill into gluten network as compared to coarse MSOC, thus, could interfered with gluten network formation in a greater extent and result in a lower volume (Feng et al. 2022; Gómez & Martinez 2018; Lin et al. 2022; Noort et al. 2010). To this end, bread containing 3% medium

Table 3 Physical parameters of breads

Parameters	WL (%)	Specific volume (mL/g)	Moisture (%)	Water activity (a_w)
Control	7.74 ± 0.38^{a}	2.79 ± 0.06^{ab}	35.94 ± 0.34^{a}	0.964 ± 0.005^{b}
3%MSOC (F)	7.46 ± 0.33^{a}	2.64 ± 0.12^{bc}	36.20 ± 0.35^{a}	0.977 ± 0.005^{a}
3%MSOC (M)	7.35 ± 0.44^{a}	2.80 ± 0.08^{ab}	36.59 ± 0.35^{a}	0.984 ± 0.002^{a}
3%MSOC (C)	8.03 ± 0.16^{a}	2.86 ± 0.07^{a}	36.47 ± 0.46^{a}	0.983 ± 0.003^{a}
6%MSOC (F)	8.06 ± 0.48^{a}	2.44 ± 0.07^{d}	35.87 ± 0.23^{a}	0.978 ± 0.003^{a}
6%MSOC (M)	7.97 ± 0.26^{a}	2.50 ± 0.02^{cd}	36.13 ± 0.18^{a}	0.978 ± 0.005^{a}
6%MSOC (C)	8.10 ± 0.39^{a}	2.52 ± 0.02^{cd}	36.23 ± 0.19^{a}	0.980 ± 0.005^{a}

Mean ± SD ($n = 6$) in the same column with different letters are significantly difference ($p < 0.05$) according to the Tukey's HSD Test. WL - weight loss during baking. Control - 100% wheat flour; *MSOC (F)* fine melon seed oil cake, *MSOC (M)* medium melon seed oil cake, *MSOC (C)* coarse melon seed oil cake, 3 and 6% represent replacing level of wheat flour by melon seed oil cake (MSOC)

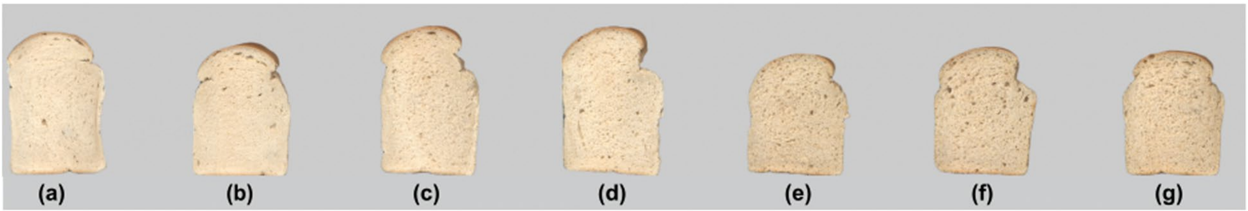


Fig. 1 Scanned images of bread slices. The order from left to right is (**a**) control bread (**b**) 3%MSOC (F), (**c**) 3%MSOC (M), (**d**) 3%MSOC (C), (**e**) 6%MSOC (F), (**f**) 6%MSOC (M), (**g**) 6%MSOC (C)

Table 4 Texture properties of breads

Sample	Hardness (N)	Chewiness (N)	Springiness	Cohesiveness
Control	13.87 ± 0.95^{b}	8.10 ± 0.30^{ab}	0.84 ± 0.02^{a}	0.69 ± 0.04^{a}
3%MSOC (F)	15.04 ± 0.66^{ab}	7.34 ± 0.25^{b}	0.82 ± 0.04^{a}	0.62 ± 0.03^{a}
3%MSOC (M)	14.31 ± 0.88^{b}	7.51 ± 0.95^{b}	0.84 ± 0.03^{a}	0.63 ± 0.01^{a}
3%MSOC (C)	14.72 ± 0.55^{ab}	7.92 ± 0.67^{ab}	0.84 ± 0.01^{a}	0.64 ± 0.03^{a}
6%MSOC (F)	16.03 ± 1.06^{a}	8.99 ± 0.63^{a}	0.82 ± 0.04^{a}	0.64 ± 0.06^{a}
6%MSOC (M)	15.50 ± 0.51^{ab}	8.40 ± 0.69^{ab}	0.83 ± 0.03^{a}	0.66 ± 0.02^{a}
6%MSOC (C)	15.12 ± 0.34^{ab}	8.44 ± 0.41^{ab}	0.84 ± 0.04^{a}	0.66 ± 0.02^{a}

Mean ± SD ($n = 4$) in the same column with different letters are significantly difference ($p < 0.05$) according to the Tukey's HSD Test. Control - 100% wheat flour; *MSOC (F)* fine melon seed oil cake, *MSOC (M)* medium melon seed oil cake, *MSOC (C)* coarse melon seed oil cake, 3 and 6% represent replacing level of wheat flour by melon seed oil cake (MSOC)

or coarse MSOC were satisfactory compared to control bread in terms of bread volume.

Texture properties

Texture properties of all bread samples are shown in Table 4. Hardness is the most important indicator in bread texture properties (Ni et al. 2020). Compared to the control bread, all MSOC breads showed an increase in hardness, but only 6% fine MSOC bread showed significantly higher ($p < 0.05$) hardness value than control bread. In addition, bread with using coarse and medium particle size of MSOC showed lower hardness value as compared to bread with using fine particle size of MSOC. Similar results have been reported and shown that addition by-products and oil cake rich in fibre might have contributed to the increase in bread hardness, depending on substitution level (Coțovanu et al. 2022; da Costa Borges et al. 2021; Zarzycki et al. 2022); meantime, fine particles, with high surface area, may interact to a greater extent with the gluten network, resulting a more compact structure than coarse particles (Gómez & Martinez 2018). Besides, Dziki et al. (2021) and Xin et al. (2022) reported that bread volume relates to bread hardness and has a strong negative correlation, a decrease in bread volume generally increases hardness of bread. Our bread specific volume results (Table 3) and hardness change trend (Table 4) could help to explain the harder texture of fine MSOC breads compared to medium and coarse MSOC breads. In contrast, control bread and all MSOC breads were similar in terms of springiness and cohesiveness. Chewiness indicates the extent of difficultly in food mastication before swallowing, which is calculated as hardness multiplied by springiness and cohesiveness (González et al. 2018; Sun et al. 2015). In terms of chewiness, similar change trend as in the hardness were observed.

Bread crumb characteristics

The mouthfeel of bread is influenced by bread crumb characteristics; fewer/larger gas cells indicate a coarser structure (Albasir et al. 2022; Wang et al. 2017). Figure 2 shows the crumb characteristics of bread samples in terms of cell number and average cell size. As the MSOC addition increased, the cell number decreased and the average cell size increased. In terms of particle size, with a decrease in particle size of MSOC, the cell number increased while the average cell size decreased; especially at the 6% replacing level, fine MSOC bread showed significant difference ($p < 0.05$) as compared to medium and coarse MSOC breads. These results indicated that MSOC addition made a coarser bread crumb structure but decreasing MSOC particle size can reduce this adverse effect to provide a finer crumb structure, which are line with other studies (Albasir et al. 2022; Wang et al. 2023).

Colour of bread crust and crumb

The crust and crumb colour of all bread samples shows in Table 5 and Fig. 1. In terms of bread crust colour, although no significant differences ($p > 0.05$) were observed in lightness (L*), redness (a*), and yellowness (b*) values between control bread and all MSOC breads, the total colour differences (ΔE*) were 1.18 to 2.37, indicating that they still had minor colour difference on crust, which could be appreciated by the human eye. The colour change in bread crust is mainly caused by Maillard

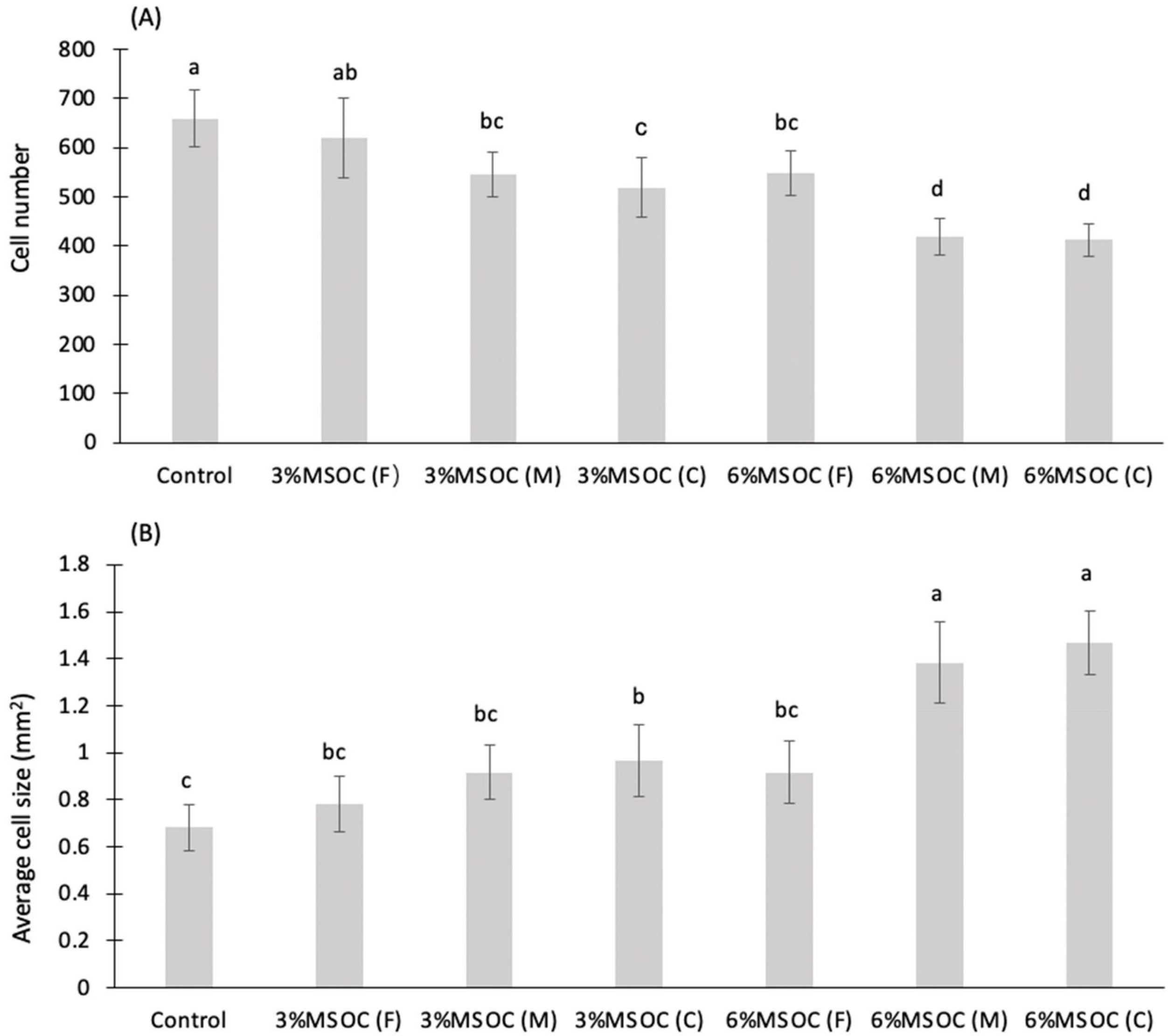


Fig. 2 Crumb characteristics of breads. **A** Cell number; (**B**) Average cell size. Error bars represent mean ± SD ($n = 6$), where different letters express significant difference ($p < 0.05$) according to Turkey's HSD test. Control - 100% wheat flour; MSOC (F) - fine melon seed oil cake; MSOC (M) - medium melon seed oil cake; MSOC (C) - coarse melon seed oil cake; 3 and 6% represent replacing level of wheat flour by melon seed oil cake (MSOC)

reaction and is less affected by the colour of ingredients used; in addition, the intensity of the Maillard reaction is mainly related to several factors such as baking time and temperature and chemical composition of ingredients used (Gómez et al. 2003; Kowalski et al. 2022; Lin et al. 2022).

Regarding bread crumb colour, lightness (L*) value reduced significantly ($p < 0.05$) while yellowness (b*) value increased significantly ($p < 0.05$) when increasing MSOC addition. Except for 3%MSOC breads, 6%MSOC breads showed less greenness (−a*) than control bread. In addition, the total colour difference (ΔE*) for crumb in all MSOC breads were higher than 3 as compared to control bread, indicating the difference in crumb colour between control bread and MSOC breads were obviously by human eye. This result could be associated with colour of MSOC used when considering the colour of MSOC (L* 69.93–71.36, a* 4.44–4.69, and b* 25.07–26.31) in Table 2 and the colour of wheat flour (L* 94.02, a* -0.59, b* 9.93) reported in previous study (Zhang et al. 2023). Besides, Purić et al. (2020) and Pycia et al. (2020) used apple seed oil cake and walnut oil cake in bread production and noticed changes in bread crumb colour, suggesting that crumb colour changes could be mainly attributed to the originally colour of ingredient used. During baking, due to high moisture content, Maillard and caramelization

Table 5 Crust and crumb colour parameters of breads

	L*	a*	b*	ΔE*
Crust				
Control	63.86 ± 1.37[ab]	10.69 ± 0.85[a]	32.53 ± 0.29[a]	–
3%MSOC (F)	63.90 ± 1.77[ab]	10.35 ± 0.78[a]	32.65 ± 0.42[a]	1.18
3%MSOC (M)	66.04 ± 1.07[a]	8.82 ± 0.51[b]	31.57 ± 0.98[ab]	1.77
3%MSOC (C)	61.98 ± 1.37[b]	10.17 ± 1.29[ab]	31.48 ± 1.22[ab]	2.37
6%MSOC (F)	62.87 ± 1.54[b]	10.46 ± 0.82[a]	32.35 ± 0.47[ab]	1.64
6%MSOC (M)	62.51 ± 1.16[b]	10.02 ± 0.54[ab]	32.20 ± 0.35[ab]	1.63
6%MSOC (C)	62.94 ± 0.93[b]	9.50 ± 0.43[ab]	31.25 ± 0.58[b]	1.61
Crumb				
Control	80.30 ± 0.87[a]	−1.24 ± 0.07[d]	14.10 ± 0.38[c]	–
3%MSOC (F)	75.05 ± 1.35[b]	−0.87 ± 0.10[abc]	15.96 ± 0.26[b]	5.58
3%MSOC (M)	75.27 ± 1.20[b]	− 0.97 ± 0.12[bcd]	15.18 ± 0.37[b]	5.15
3%MSOC (C)	73.89 ± 1.19[bc]	−1.16 ± 0.09[cd]	15.31 ± 0.39[b]	6.52
6%MSOC (F)	72.82 ± 1.48[cd]	−0.66 ± 0.37[ab]	17.61 ± 0.72[a]	8.28
6%MSOC (M)	71.79 ± 0.40[d]	−0.62 ± 0.20[a]	17.49 ± 0.26[a]	9.18
6%MSOC (C)	71.05 ± 0.62[d]	−0.83 ± 0.11[ab]	16.92 ± 0.53[a]	9.68

Mean ± SD (n = 6) in the same column with different letters are significantly difference (p < 0.05) according to the Tukey's HSD Test. Control - 100% wheat flour; *MSOC (F)* fine melon seed oil cake, *MSOC (M)* medium melon seed oil cake, *MSOC (C)* coarse melon seed oil cake, 3 and 6% represent replacing level of wheat flour by melon seed oil cake (MSOC)

reactions are slower progress in bread inside as compared to bread crust, therefore, it could not significantly modify the bread crumb colour (de la Hera et al. 2013; Tabibloghmany et al. 2022). Besides, at the same replacing level, the lightness (L*) and yellowness (b*) values of MSOC bread crumb trend to increase with decreasing particle size of MSOC from coarse to fine, and no change trend was observed in greenness (−a*) value; this is in line with our finding in colour of different particle sizes of MOSC (Table 2). Overall, final bread crumb colour was affected by MSOC addition and particle size.

Conclusions

Substitution of MSOC to wheat flour is feasible in bread production. Bread containing 3% MSOC was satisfactory and exhibited similar quality to control bread on bread volume and texture. In terms of particle size, the reduction of MSOC particle size could result in reduced bread volume and firmer texture but with an improved crumb structure. Therefore, medium size of MSOC was most suitable for making bread when all were taken into consideration. Overall, this work could be regarded as a basis to further develop MSOC enriched bread with satisfactory quality. Future work will be conducted on sensory quality (e.g. mouthfeel and flavour) and consumer acceptance.

Acknowledgements
Authors would thank BSc student Xiaoxuan Yao for her help in bread baking process.

Authors' contributions
GZ: Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing. ZL: Methodology, Investigation, Writing – original draft, Writing – review & editing.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Availability of data and materials
All data generated and analyzed during the current study are included in this published article.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing or interests.

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Received: 16 October 2023 Accepted: 2 January 2024
Published online: 08 June 2024

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