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ORIGINAL PAPER

Influence of grasshopper (*Locusta Migratoria*) and mealworm (*Tenebrio Molitor*) powders on the quality characteristics of protein rich muffins: nutritional, physicochemical, textural and sensory aspects

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Abstract
Insects are the most common animal group in the world and they constitute about 80% of the animal kingdom. Today, around 1600 insect species have been consumed by humans. The aim of this study was to explore the potential use of edible insect flours for the production of protein rich muffins. Proximate composition and sensory quality of muffins were also explored. The protein and fat content of resulting muffins were effectively improved. While grasshopper powder provided 12.91 ± 0.40% protein content, mealworm powder enhancement obtained 36.56 ± 1.26% fat content compared with control ($p \leq 0.05$). Physical properties of resulting muffins were also investigated. GR-M sample presented the highest baking yield of 88.66 ± 0.58%. On the other hand, fortification with edible insect powders led to have denser structures with the lower specific volume than the control; incorporation of 15% with mealworm powder obtained the lowest specific volume (1.14 ± 0.02 cm^3/g). As regard to textural parameters, inclusion of edible insect flours also affected the textural properties; muffins fortified with grasshopper powder showed a significantly ($p \leq 0.05$) softer crumb with lower springiness, cohesiveness and chewiness while no significant differences ($p > 0.05$) in all textural properties except cohesiveness and adhesiveness between used insect types were observed. Sensory characteristics revealed that fortification of wheat flour by mealworm powder provided a muffin with liking score ranged from 6.70 to 8.70 for all attributes tested, therefore, indicating that mealworm powder could be an effective ingredient in increasing nutritional value of bakery products.

Keywords Edible insects · Fortified muffin · Sensory profile · Microstructure · Color · Texture

Introduction

The rise in the rates of obesity and other diseases has increased the awareness about healthy and balanced nutrition, also caused people to expect various benefits in addition to their nutrients from the food products they consume. However, the problem of lack of adequate nutrient sources, especially lack of protein sources, has arisen with the population increase. In many countries, protein of animal origin is more expensive than other sources and therefore difficult to access for most of the population. At the same time, the risk of high cholesterol levels, cardiovascular disease, and cancer associated with consumption of animal protein is widely emerging in an increasing number of studies, and such studies have contributed significantly to the increased interest in consuming protein-rich but non-meat-based foods. As a result, in many underdeveloped and developing countries where animal protein consumption is low and expensive, other protein sources have been used as the main protein source. Studies on the use of different products as alternative protein sources to increase the quality of the products by adding more nutrients and to prevent malnutrition problems gained significant importance [1].

The enhancement of food items has been a significant device to prevent nutritional deficiencies. Muffins are very popular over the world especially by children due to their sweet taste and smooth texture. They can also be a good vehicle for nutrient supplementation to improve the intake of nutrients because they are highly consumed at breakfast or as a snack [2, 3]. Several studies have incorporated different proteins, protein-rich powders, and flours and researched

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the quality of the resulting products. Some recent examples include legume flours [4, 5] and protein isolates [6, 7].

Edible insects with high nutritional value have emerged as an alternative protein source in recent years, and studies are increasing. Insects have been used for a very long time in different areas including animal feed, pharmaceutical, and textile industry. Edible insects have recently attracted great attention from Western societies due to their low cost with high protein content [8]. While insects constitute 2% of human food in European countries, this rate reaches approximately 30% of total food consumption in America and Africa [9]. Beetles, mealworms, wasps, and grasshoppers along with crickets and termites are some examples of eaten edible insects [10]. Among these species, industrial production of mealworm and grasshopper is very high especially for the use of animal feed formulations [11–13]. The absorption of insect proteins in the human body can range between 76 and 96%. This value is close to egg and beef which have the highest protein absorption value, but it is much higher than the plant-derived proteins. Therefore, edible insects have attracted great interest in the production of novel food products with high protein content recently due to their low cost with high protein content [14, 15]. Edible insects could represent an opportunity to manufacture healthier baked foods such as muffins, cakes, and biscuits since they are versatile and popular. Grasshopper (*Locusta Migratoria*) and mealworm (*Tenebrio Molitor*) are one of the most widely consumed insect species in the world. Both insect species provide a valuable source of proteins containing satisfactory ratios of essential amino acids and lipids with essential fatty acid content [16, 17]. These species have also been extensively used as a high protein supplement in human nutrition [18–22].

However, to our knowledge, there has been very limited information about the effect of the use of different edible insect powders on the quality characteristics of muffins. The present study, therefore, aimed to muffin to prepare muffins using different flour blends with the same levels of edible insect powder fortification and their subsequent effects on the nutritional, microstructural, textural, and sensorial properties of muffins.

Materials and methods

Raw materials

Mealworm (*T. Molitor*) and grasshopper (L. *Migratoria*) were provided as a gift by Mira Canlı Hayvan Böcek Turizm İnşaat Tarım Sanayi Co. (Antalya, Turkey). Before use, dry edible insects were ground (Custom Grind, model 80365; Hamilton Beach, Glen Allen, VA, USA) and stored in an airtight plastic container for further applications. Wheat flour, salt, sugar, sunflower oil, baking powder, whole milk, and eggs were purchased from the local grocery market (Alanya/Turkey).

Muffin preparation

Muffins were prepared according to Shevkani et al. [7] with slight modifications. Wheat flour was replaced with edible insect powders (grasshopper or mealworm) at level of 15% (w/w) and following formula was used to produce muffin samples: 130 g granulated sugar, 14 g baking powder, 1 g salt, 70 g whole egg, 160 ml whole milk, 120 ml sunflower oil and 1 g vanilla powder. Dry ingredients (wheat flour, sugar, baking powder, vanilla powder and salt) were firstly mixed and placed in the bowl of a mixer (KitchenAid Model Artisan KSM 1520, St. Joseph, MI, USA). The wet ingredients (whole milk, egg and sunflower oil) are also mixed in a separate bowl and combined with dry ingredients and all ingredients were mixed for 3 min at medium speed with a mixer (KitchenAid Model Artisan KSM 1520, St. Joseph, MI, USA). About 50 g of muffin batter was poured in silicone muffin cups and then placed into metallic muffin trays and baked at 180 °C for 25 min in a preheated baking oven (Memmert, Model ULM 400, Memmert GmbH, Germany).

Sample with 100% wheat flour was coded as control (C-M). Two samples where 15% of wheat flour was replaced with grasshopper and mealworm powders were called GR-M and MW-M, respectively. After removal from oven, cooked muffins were cooled to room temperature and used for further analysis.

Analysis of nutritional value

The samples were measured for their ash, moisture, fat, and protein content according to AACC methods [23]. The total content of carbohydrates was calculated by the difference method. The metabolizable energy of the muffin samples was calculated based on specific calorific values of each nutritional component [24].

Physical properties

To determine the height of muffins, the highest point of the muffin to the bottom part was measured using a ruler and recorded in centimeter (cm) [25].

Specific volumes were calculated as the ratio of volumes to the weights and expressing the results as cm^3/g. The volume of muffins was determined using seed rapeseed replacement method [23]. Firstly, glass container of known volume was filled uniformly with rapeseeds and bulk density of the seeds was calculated from the measured weight of the seeds and volume of the container. To determination of volume of sample, a whole muffin was placed inside a plastic 100 ml container full of seeds. The weight (g) of the seeds displaced from the container was weighed (g) and the volume (cm^3) of the muffin was assessed using the calculated density of seeds. Specific volume of the samples (cm^3/g) was calculated by dividing the volume by weight.

Baking loss (%) values were calculated as the percentage difference between batter weight and muffin weight according to equation (Eq. 1) by Heo et al. [26];

$$\text{Baking loss (\%)} = \frac{(\text{batter weight} - \text{muffin weight})\text{g}}{\text{batter weight (g)}} \times 100 \quad (1)$$

Baking yield (%) values were calculated using the equation (Eq. 2);

$$\text{Baking yield (\%)} = \frac{\text{muffin weight (g)}}{\text{batter weight (g)}} \times 100 \quad (2)$$

Image analysis of muffin cellular structure

Image analysis of cellular structures was performed on scans of muffin slices obtained using a flatbed scanner (HP Scanjet 3800, Hewlett-Packard Company, California, US). Muffin slices that were cut from the center of the muffin were scanned on one side and saved in tiff format. The digital images were investigated by ImageJ software (National Institutes of Health, imagej.nih.gov/ij/). Images were converted into 8-bit grayscale and binarized after applying a threshold. An ImageJ plugin (ImageJ/Fiji plugin) was also used to apply watershed segmentation to separate the cells for counting. A 3.8 × 3.2 cm^2 field of view of the slice center was intercepted by ImageJ software to evaluate the features as follows: total cell count, porosity (%), mean cell area (mm^2), and cell density ($cells/mm^2$) [27].

Texture profile

The texture analysis of muffins was performed out using a TA.XTplus Texture Analyzer (Stable Microsystems, Godalming) equipped with a 5-kg load cell and a cylindrical probe of a 75 mm diameter [28]. The crosshead speed was 10 mm/s and the samples were compressed to 50% of the initial height. During the test hardness, adhesiveness, gumminess, springiness, chewiness, cohesiveness, factorability, and resilience of the muffins were calculated by using the texture analyzer software.

Color evaluation

Color readings (L*, a*, b*) of the muffin crust and crumb were taken using Minolta CR-400 Colorimeter (Minolta Camera Co., Osaka, Japan,). The instrument was calibrated with a white standard plate six times. Results as the average of measurement taken from six different points were expressed in L*a*b* scale (lightness (L*) and color (a*-redness; b*-yellowness). The averages were used to calculate the total color difference (ΔE*) between the control and samples as described by Goswami et al. [29]. Browning index (BI) were also calculated according to the following equation (Eq. 3):

$$\text{BI} = 100 - \frac{(x - 0.31)}{0.17} \quad (3)$$

where x was calculated according to the following equation (Eq. 4);

$$x = \frac{(a * + 1.75L *)}{(5.645L * + a * - 3.01b *)} \quad (4)$$

Sensory evaluation

Sensory profiles were evaluated based on a 9-point hedonic rating scale to denote a degree of liking, where 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely by semi-trained 20 panelists (10 female- 10 male) aged between 18 and 40 years among students of the Department of Gastronomy and Culinary Arts (AHEP University, Antalya, Turkey). Consumers were selected based on their willingness and instructed prior to the evaluation that samples contain different edible insect flours. Each muffin was first cooled to room temperature (24 °C) for 1 h after removing from the oven, placed in a plastic cup with a random three-digit code. Panelists were asked to evaluate color, appearance, texture, sweetness, mouthfeel, flavor, odor, and overall liking of samples.

Statistical analysis

The baking experiments were repeated twice, analyses were done in triplicate and measurements were expressed as media ± standard deviation. Statistical analyses were carried out using analysis of variance (ANOVA) followed by Tukey's HSD for multiple pairwise comparisons at a significance level of $p \leq 0.05$ and correlations between variables ($p \leq 0.05$) by correlation analyses using the Pearson's linear correlation coefficient were performed by using software Minitab Statistical Software (Minitab 17.0 for Windows, Minitab, USA).

Results and discussion

Nutritional value

Enhanced nutritional values were observed when muffins were enriched with edible insect powders (Table 1). Results suggested that muffins containing edible insect powders retained more moisture as compared to control muffins. This could be due to the higher crude fiber content and protein content of edible insect powders, which were shown in our previous study [30], leading to higher water absorption capacity compared to that of wheat flour [31, 32]. A similar trend was observed in a study completed by Pauter et al. [33] in which the increase in the level of cricket powder enhanced the moisture content of the produced muffin samples. As expected, MW-M presented a higher quantity of protein, ash, fat and lower carbohydrates, with no significant difference ($p > 0.05$) with GR-M. The results of our research are in accordance with previous studies obtained by Çabuk, Yılmaz [30] in pasta, by Severini et al. [8] in snacks and by da Rosa Machado, Thys [34] in bread. Regarding fat content, results agree with a previous study where wood grasshopper flour was used in baby biscuits [35]. The richness in protein and fat content could be attributed to the higher fat and protein content of edible insect powders than wheat flour [30]. These results are consistent with those reported by Roncolini et al. [19]. The energy content of muffin samples varied between 442.54 kcal/100 g to 467.37 kcal/100 g. However, among baked muffins with insect powders, there were no significant differences ($p > 0.05$) in energy value. The values found suggest that both mealworm and grasshopper powder could be added to different foods such as soups and baked products helping them to significantly increase their energy value.

Physical properties and cell structure

Significant variations in the muffin physical quality were observed with the fortification of wheat flour with edible insect powders (Table 1). The results showed that edible

Table 1 Nutritional and energetic value, physical properties, cell characteristics and texture parameters of muffins produced with different flour blends

Parameters	C-M	MW-M	GR-M
Dry ash (%)	1.71 ± 0.02^a	1.74 ± 0.17^a	1.72 ± 0.04^a
Protein (%)	5.85 ± 0.82^b	11.70 ± 0.81^a	12.91 ± 0.40^a
Fat (%)	31.21 ± 1.66^b	36.56 ± 1.26^a	36.47 ± 0.75^a
Carbohydrate (%)	34.56 ± 4.02^a	22.07 ± 1.63^b	21.87 ± 0.58^b
Metabolizable energy (kcal/100 g)	442.54 ± 2.62^b	464.09 ± 11.28^a	467.37 ± 6.52^a
Physical properties			
Height (cm)	4.83 ± 0.12^a	4.57 ± 0.15^{ab}	4.40 ± 0.2^b
Weight (g)	57.77 ± 0.88^c	61.76 ± 0.63^b	65.82 ± 0.58^a
Specific volume (cm^3/g)	1.69 ± 0.03^a	1.14 ± 0.02^c	1.43 ± 0.08^b
Baking loss (%)	$15.25 \pm 0{,}38^a$	$13.98 \pm 0{,}34^b$	$11.34 \pm 0{,}59^c$
Baking yield (%)	84.75 ± 0.38^c	86.02 ± 0.34^b	88.66 ± 0.58^a
Cell characteristics			
Total cell count	523.33 ± 41.74^a	607.66 ± 57.14^a	617 ± 16.09^a
Average cell size (mm^2)	0.43 ± 0.06^{ab}	0.40 ± 0.00^b	0.53 ± 0.06^a
Porosity (%, cell area/total area)	25.66 ± 2.55^b	28.05 ± 2.20^b	37.26 ± 1.06^a
Mean cell area (mm^2)	0.45 ± 0.08^{ab}	0.42 ± 0.01^b	0.54 ± 0.03^a
Cell density (cells/ mm^2)	1209.89 ± 289.73^a	1464.05 ± 172.46^a	1137.47 ± 90.14^a
Texture parameters			
Hardness (g)	2638.11 ± 195.57^a	1742.90 ± 170.66^b	1657.74 ± 79.02^b
Adhesiveness (g/s)	-3.17 ± 2.79^a	-8.55 ± 2.89^a	-28.57 ± 6.35^b
Springiness	0.84 ± 0.00^a	0.77 ± 0.02^b	0.78 ± 0.01^b
Cohesiveness	0.44 ± 0.02^a	0.33 ± 0.01^c	0.37 ± 0.01^b
Gumminess	1158.54 ± 44.34^a	569.09 ± 63.55^b	613.88 ± 26.57^b
Chewiness	977.63 ± 38.18^a	435.76 ± 58.19^b	477.78 ± 28.28^b
Resilience	0.18 ± 0.01^a	0.13 ± 0.01^b	0.14 ± 0.00^b

[a,b]Different superscripts in the same row indicate significant differences ($p < 0.05$). Data are expressed as means ± SD. Control muffin (C-M):100% wheat flour; mealworm muffin (MW-M): 75% wheat flour + 15% mealworm powder; Grasshopper muffin (GR-M):75% wheat flour + 15% grasshopper powder

insect powder incorporation to formulation had a significant ($p \leq 0.05$) influence on muffins: the weight of C-M (57.77 g) was significantly lower than insect treatments. The samples' weight was positively correlated with protein and fat content ($r = 0.92$ and 0.76, $p \leq 0.05$, respectively) while negatively correlated with total carbohydrate content ($r = -0.81$, $p \leq 0.05$). Insects are a great protein and fiber source which is observed to have pronounced influences on dough properties resulting in higher water absorption [36, 37]. The water absorption capacity of flours was calculated as 0.78 g/g, 1.07 g/g and 1.50 g/g for wheat flour, grasshopper and mealworm blended ones, respectively. Therefore, this result was probably due to having greater water absorption capacity of flour blends than wheat flour.

The height and the volume of muffins are among the most studied physical properties influencing both the acceptability and quality. Results revealed that fortification of wheat flour had a negative influence on muffin height: the height of MW-M and GR-M was measured as 4.57 cm and 4.40 cm, respectively. This shows that C-M sample had better baking expansion and gas retention compared to edible insect incorporated ones. Partial fortification of wheat flour with edible insect powders affected the specific volume of muffins as well. The specific volume of baked muffins ranged from 1.14 to 1.48 cm^3/g. Fortification with mealworm powder resulted in highest (0.55 cm^3/g) decrease in specific volume values. Also, specific volume of samples was negatively correlated with the cell count ($r = -0.723$, $p \leq 0.05$). Therefore, the addition of gluten-free insect powders might have interrupted the formation of SS bonds between gluten molecules. This could cause formation of a weaker and thinner gluten network compared to control which lowers trapped air amount between three-dimensional network and as a result, lowers the specific volume [38, 39]. The height and volume loss of baked products by fortification with gluten-free flours has been commonly observed in various studies [40, 41]. Our results in the present study also agree with those previously reported by Osimani et al. [42] and García-Segovia et al. [43] suggesting that fortification with insect flours significantly lowered specific volume of baked products.

Generally, fortification with gluten-free flours create higher moisture loss during baking [29]. However, our findings showed that fortification with mealworm powder and grasshopper powder provided significantly lower baking loss and increasing the baking yield of muffins. Generally, lower specific volume led to evaporation of less water during baking which consequently decreased baking loss. However, in this study, no significant correlation ($p > 0.05$) was calculated between baking loss rate and specific volume. On the other hand, baking loss was negatively correlated with protein content ($r = -0.82$, $p \leq 0.05$); the higher the protein content, the lower the loss rate of baking. This is in-line with the finding by Indriani et al. [44] who reported a reduction in baking loss of cakes with increasing high protein content Bombay locust powder.

The top and side-view photographs of baked muffins and images of the crumb cellular structure characteristics measured using image analysis are shown in Figs. 1 and 2, respectively. In our study, muffins exhibited significant variance in the cell structure. The disruption of crumb structure, especially formation of crack was clearly observed in the images (Fig. 2). Formation of cracks may be associated with the compositional differences of insect powders compared to wheat flour which consequently altered gluten matrix which led to a change in the viscoelastic behavior of the batter formulations further causing formation of cracks during baking [45]. Therefore, more compact but crumbly texture when both mealworm and grasshopper powders were obtained in muffin formulations.

Table 1 also shows the cell characteristics of muffins produced with different flour blends. Incorporation of mealworm and grasshopper powder slightly increased the total number of air cells, however this increase was statistically insignificant ($p > 0.05$). The porosity of the muffins ranged from 25.66 to 37.26%. The wheat flour fortification mealworm powder produced muffins with similar porosity to the grasshopper fortified one, while the highest porosity was detected at the GR-M. Edible insects are rich sources of chitosan [46] and similar structural alterations were also observed by Kerch et al. [47] in the presence of chitosan forming a more porous structure in bread. Regarding cell density calculated by dividing the number of cells by the mean cell area, MW-M had the highest density (1464.05 cells/mm^2) among all samples with insignificant differences ($p > 0.05$).

Color evaluation

The crumb and crust color values of muffins as affected by flour fortification are presented in Fig. 3a and b. As flour was replaced with edible insect powders, the crumb color became darker. Muffin crust color is mainly developed during baking due to Maillard reaction taking place by the exposure of surface to high temperatures. In this study, L* value of the crust exhibited a high negative correlation with protein content ($r = -0.90$, $p \leq 0.05$) and a strong positive correlation total carbohydrate content ($r = 0.90$, $p \leq 0.05$). The lightness (L*) values of the crumb ranged between 68.02 and 50.32 with significant differences ($p \leq 0.05$) observed between muffins. The crust of both GR muffin and MW-M had around 11% lower luminosity than C-M. Darker crust color formation in both GR-M and MW-M might be attributed to the higher protein content compared to control muffin. These findings agree with those recently collected by Khuenpet et al. [48] and Indriani et al. [44] on crumb of breads and cakes produced with various species of edible insects, including

Fig. 1 Top and side view of muffin samples: **a** control muffin, **b** muffin with 15% mealworm powder, **c** muffin with 15% grasshopper powder (left line: top view images of muffins, right line: side view images of muffins)

mealworm (*T. molitor*) and Bombay locust (*Patanga succincta* L.), respectively. Red color indicated by the positive a^* value was significantly ($p \leq 0.05$) higher for the MW-M and GR-M compared to C-M, although, a very little indication of redness was evident in MW-M given the low a* value (1.08 ± 0.26 for crumb and 1.46 ± 0.22 for crust). Muffins made with grasshopper powder exhibited highest redness for both crust (3.09 ± 0.31) and crumb (4.9 ± 0.58) color. A similar study has previously shown increased the value of a* by mealworm (*T. molitor* L.) and buffalo worm (*Alphitobius diaperinus*) powders in bread [43]. Regarding b* values, differences were measured between crust and crumb of muffins. Muffin C obtained the highest crumb yellowness with the b* value of 19.44 ± 0.60 and differences in insect powders appeared to have little impact on yellowness with no significant difference ($p > 0.05$). On the other hand, there was a significant difference among crust b* of muffin samples with edible insect powders and the intensity of yellowness was the highest in GR-M. This trend for change might be attributed to the original color of insect powders. Total color differences (ΔE), representing the magnitude of the color difference between the samples and control were found to be 13.70 for MW-M and 18.80 for GR-M. This result proves that changes in muffin color were strong enough to be clearly visible by consumers. Previous studies pointed out that color difference is visually noticeable when $\Delta E > 3.0$ [49, 50]. This indicates that the alteration of color that results from the use of the additive is. Such a significant difference in color can result in a reduction of the attractiveness to consumers.

The browning index (BI) values of both crust and crumb of different muffin samples are presented in Fig. 3c. C-M

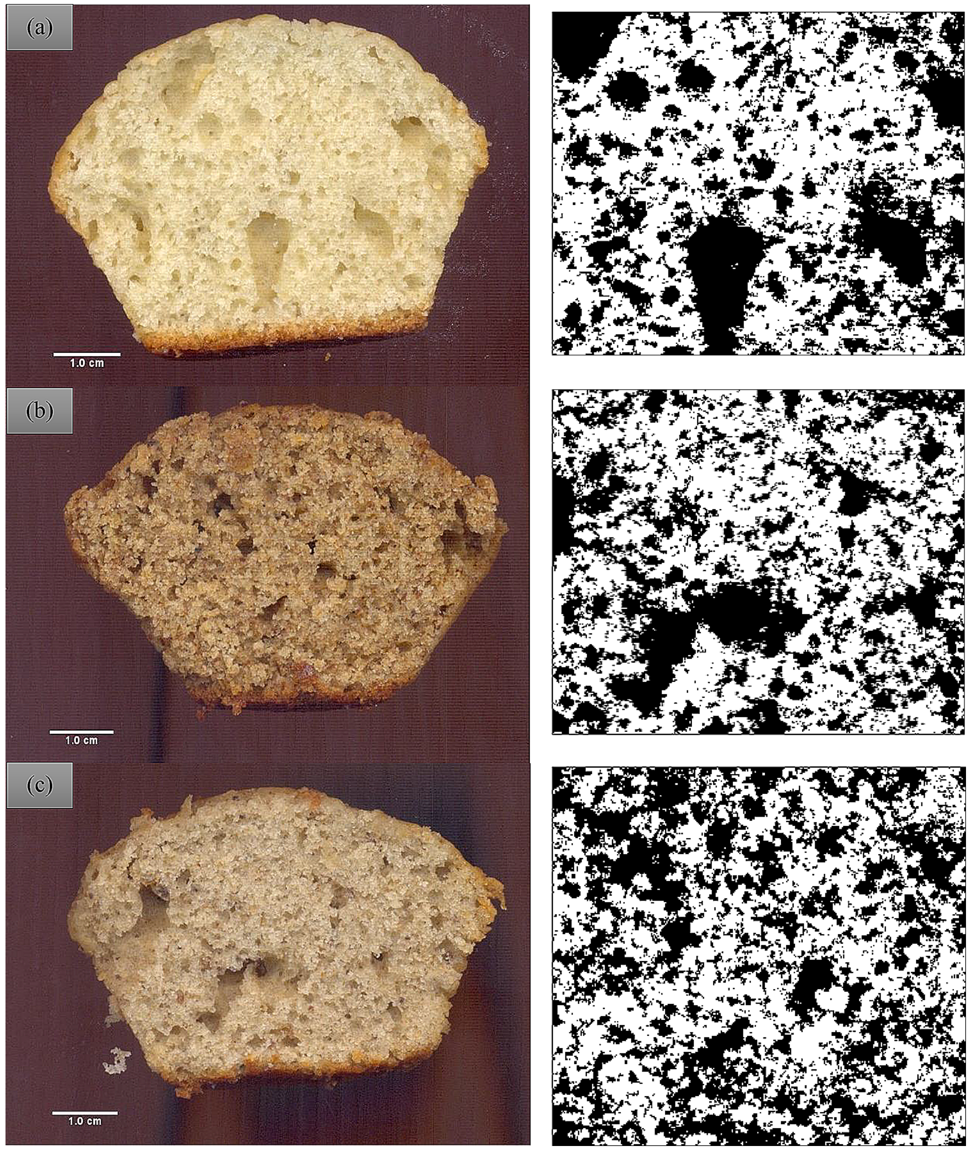


Fig. 2 Muffins profiles and their corresponding thresholding images of cell structure: **a** control muffin, **b** muffin with 15% mealworm powder, **c** muffin with 15% grasshopper powder

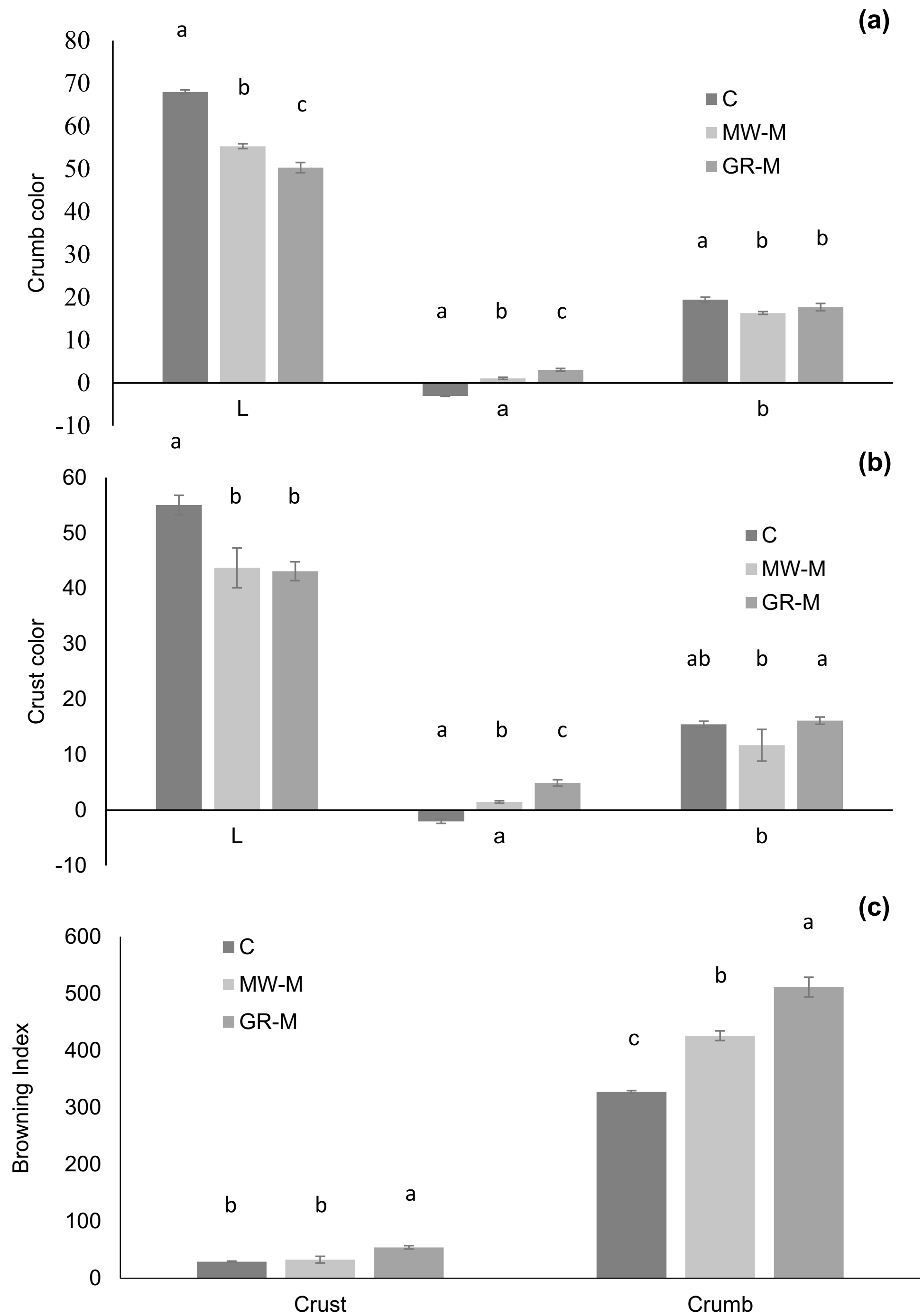
sample showed the lowest values of BI (29.23 for crust and 327.71 for crumb) while for grasshopper muffins the values were the highest (54.34 for crust and 511.35 for crumb). In general, the edible insect powders were darker compared to wheat flour which is also confirmed by the higher browning index values.

Sensory evaluation

Sensory properties of edible powder fortified muffins were evaluated and presented as likeness score, in comparison with the C-M (Fig. 4). The C-M obtained the highest likeness score ($p \leq 0.05$) for all sensory attributes tested. G-M sample scored significantly lower ($p \leq 0.05$) than C-M and MW-M samples for all tested sensory attributes. However, the acceptability for all attributes except odor was above 5. Pearson's correlation analysis between sensory characteristics and color values of samples revealed that porous muffins obtained lower scores of texture attribute with a negative correlation between porosity and texture ($r = -0.83$, $p \leq 0.05$). Interestingly, color and appearance attributes were not significantly correlated with L* values of both crumb and crust ($p \leq 0.05$). In terms of nutritional composition, protein content was observed to significantly negatively correlate with texture, appearance, flavor and overall liking ($p \leq 0.05$), whereas fat content displayed no significant correlations with all sensory attributes ($p > 0.05$).

All panelists stated that muffins with mealworm powder had a very rich nutty smell and therefore average score of the odor was slightly higher than C-M. Similarly, ground mealworms contributed to nutty flavor development in a model system studied by Wendin et al. [20]. Meanwhile, the grasshopper powder resulted in a very strong unpleasant smell in baked muffins which negatively impacted the score

Fig. 3 Color properties of control and edible insect powder fortified muffins. Different superscript letters indicate significant differences (p < 0.05)



of odor attribute. This was also confirmed with the positive correlation between odor and overall liking scores ($r = 0.76$, $p \leq 0.059$). A similar impact of grasshopper on odor attribute was also observed by Haber et al. [38] where a decreasing trend in overall preference was observed with increasing grasshopper powder in bread samples. MW-M had similar likeness score on odor, color, texture, and sweetness to the C-M ($p > 0.05$). Moreover, there was a negative trend towards GR-M showing the lowest acceptability score of 5.6. In terms of overall acceptability, both L* and a* values of crust and crumb showed positive ($r = 0.67$ and $r = 0.83$, $p \leq 0.05$, respectively) and strong negative ($r = -0.86$ and $r = -0.84$, $p \leq 0.05$, respectively) correlation with overall liking.

Overall, the results indicated the fortification of edible insect powders, especially grasshopper powder had adverse effects on sensory attributes. Lower acceptability scores might be related to the darker color, distinct smell, denser

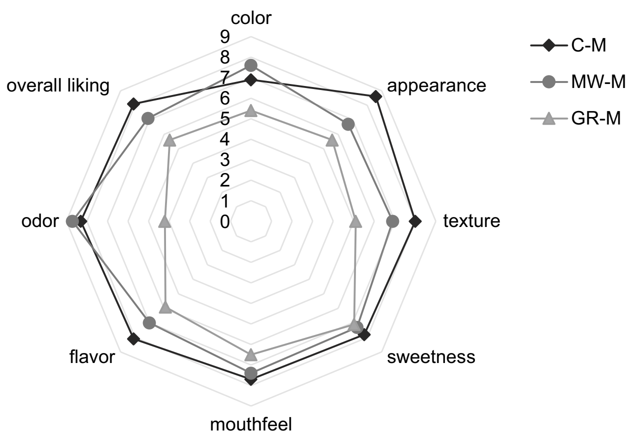


Fig. 4 Spider web chart of the sensory properties of fortified and unfortified bread

structure and lower specific volume of edible insect fortified muffins. But, in our study, mealworm powder fortified muffin obtained an average score above 7, indicating that it was liked moderately.

Texture analysis

Significant differences were observed among the hardness values of muffins (Table 1). Hardness for the C-M was 2638.11 g and with the incorporation of mealworm powder, hardness value decreased down to 1742.90 g and further to 1657.74 g when grasshopper powder was used. Pearson's test demonstrated that the hardness of muffin samples was negatively correlated with fat ($r = -0.92$, $p \leq 0.05$) and moisture ($r = -0.68$, $p \leq 0.05$) content. Similar observations were also reported by both Mohamad et al. [51] and Abera et al. [52] where decreased firmness of baked products were calculated with increased moisture content. Moreover, cell characteristics were observed to affect the firmness of bakery products [53, 54]. In this study, results show that the total cell count affected muffin hardness in negative correlations ($r = -0.76$, $p \leq 0.05$). These associations may have been a result of increased fat content and increased gas retention of muffins [43, 44]. This trend is similar to that reported by Kowalczewski et al. [55] in which gluten-free bread with cricket powder showed decreasing hardness with increasing cricket powder. The springiness value is the ability of the samples to return to its undeformed original condition after the deformation is removed [56]. While both edible insect powders added muffins were significantly less springy than C-M which can be related to the non-uniformity with a crumby matrix of muffins and there were no significant differences ($p > 0.05$) were observed between GR-M and MW-M. Additionally, statistical analysis revealed a significant negative correlation ($r = -0.77$, $p \leq 0.05$) between springiness and moisture content of samples.

The gumminess values of muffins were in the range of 1158.54–569.09 g and C-M showed the highest gumminess value. Like hardness, springiness and gumminess, muffins with edible insect powders had significantly lower cohesiveness values than C-M. The lower cohesiveness agrees with the low springiness that also reflects the low internal cohesion within the crumb. MW-M samples obtained significantly lower ($p \leq 0.05$) cohesiveness (0.33) than GR-M ones (0.37) and cohesiveness were positively correlated with specific volume ($r = 0.94$, $p \leq 0.05$) indicating that interactions among gluten and non-gluten ingredients in MW-M were weaker resulting in less gas retain and the lower volume [45]. Similar observations were also reported by González et al. [18] in a similar research that studied the use of *A. domestica* and *T. molitor* flours in bread making. There were also highly significant positive correlations between the specific volume, springiness ($r = 0.87$, $p \leq 0.05$) and gumminess ($r = 0.86$, $p \leq 0.05$). As a result of the decreased gumminess and springiness, muffins with edible insect powders were found to be significantly lower in chewiness from those of the C-M sample indicating that lower energy is needed to disintegrate muffins. MW-M samples showed similar adhesiveness values with the C-M. On the other hand, both GR-M and MW-M obtained lower resilience values (0.13 and 0.14 for MW-M and GR-M, respectively). Moreover, resilience of samples showed positive correlations with muffin specific volume ($r = 0.90$, $p \leq 0.05$). Both of these results imply that when edible insect flours were blended, the crumb matrix becomes denser the samples lose the ability to spring back, returning to their original shape when subjected to a compressing force. Similar observations were also noted by other authors when wheat flour was replaced with gluten-free flours [57–60].

Conclusions

In this study, the effect of fortification of wheat flour with mealworm and grasshopper powder on nutritional values, textural properties, and structural changes was investigated. Results collected in this study confirmed that wheat flour fortification (15%, w/w) by edible insect powders resulted in significant nutritional changes, such as increased protein and fat content and decreased carbohydrate content. When edible insect powders were added to the formulations, resulting muffins exhibited decreased specific volume with softer texture than the C-M. Moreover, addition of grasshopper powder significantly lowered the sensory ratings of muffin sample for all sensory attributes due to its unpleasant smell and dark color, while mealworm muffins received good acceptability scores in sensory tests. However, this research also showed that mealworm powder could be used successfully with small modifications to replace wheat flour and produce high protein muffins with acceptable quality and sensory attributes.

In summary, this paper is significant as it provides basic data that can be used as a reference in the development of new bakery products with alternative protein sources.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with animals performed by any of the authors.

References

1. A. Pihlanto, P. Mattila, S. Mäkinen et al., Food Funct. **8**(10), 3443–3458 (2017)
2. T. Sanz, A. Salvador, R. Baixauli et al., Eur. Food Res. Technol. **229**(2), 197–204 (2009)
3. M.U. Rosales-Soto, J.R. Powers, J.R. Alldredge, J. Sci. Food Agric. **92**(7), 1511–1518 (2012)
4. D. Jeong, J.S. Hong, Q. Liu et al., Cereal Chem. **98**, 392–404 (2021)
5. K.T. Kaczmarska, M.V. Chandra-Hioe, D. Frank et al., LWT **96**, 205–214 (2018)
6. S. Jisha, G. Padmaja, Food Bioprocess Technol. **4**(1), 92–101 (2011)
7. K. Shevkani, A. Kaur, S. Kumar et al., LWT-Food Sci Technol. **63**(2), 927–933 (2015)
8. C. Severini, D. Azzollini, M. Albenzio et al., Food Res. Int. **106**, 666–676 (2018)
9. D. Raheem, C. Carrascosa, O.B. Oluwole et al., Crit. Rev. Food Sci. Nutr. **59**(14), 2169–2188 (2019)
10. S. Kelemu, S. Niassy, B. Torto et al., J. Insects Food Feed **1**(2), 103–119 (2015)
11. E. Zielińska, B. Baraniak, M. Karaś et al., Food Res. Int. **77**, 460–466 (2015)
12. T. Spranghers, M. Ottoboni, C. Klootwijk et al., J. Sci. Food Agric. **97**(8), 2594–2600 (2017)
13. J.R.-E. Blásquez, J.M.P. Moreno, V.H.M. Camacho, Food Nutr. Sci. **3**(02), 164 (2012)
14. A. Banjo, O. Lawal, E. Songonuga, Afr. J. Biotechnol. **5**(3), 298–301 (2006)
15. J. De Prins, Adv. Entomol. **2**, 47–48 (2014)
16. B. Purschke, H. Tanzmeister, P. Meinlschmidt et al., Food Res. Int. **106**, 271–279 (2018)
17. J. Stoops, S. Crauwels, M. Waud et al., Food Microbiol. **53**, 122–127 (2016)
18. C.M. González, R. Garzón, C.M. Rosell et al., Innov. Food Sci. Emerg. Technol. **51**, 205–210 (2019)
19. A. Roncolini, V. Milanović, F. Cardinali et al., PLoS ONE **14**(2), e0211747 (2019)
20. K. Wendin, V. Olsson, M. Langton, Foods **8**(8), 319 (2019)
21. C. Clarkson, M. Mirosa, J. Birch, Insects **9**(1), 20 (2018)
22. J. Van Itterbeeck, I.N. Rakotomalala Andrianavalona, F.I. Rajemison et al., Foods **8**(12), 666 (2019)
23. AACC International, 10th edn. (St. Paul, Minessota, 2000)
24. M. Pojić, T. Dapčević Hadnađev, M. Hadnađev et al., J. Food Qual. **38**(6), 431–440 (2015)
25. N. Arifin, S.N. Izyan, N. Huda-Faujan, J. Food Sci. (2019). https://doi.org/10.26656/fr.2017.3(6).090
26. Y. Heo, M.J. Kim, J.W. Lee et al., Food Sci. Nutr. **7**(5), 1778–1785 (2019)
27. M.I. Palacio, A.I. Etcheverría, G.D. Manrique, J. Food Sci. Technol. **55**(8), 2955–2962 (2018)
28. S. Martínez-Cervera, A. Salvador, T. Sanz, LWT-Food Sci. Technol. **63**(2), 1083–1090 (2015)
29. D. Goswami, R.K. Gupta, D. Mridula et al., LWT-Food Sci. Technol. **64**(1), 374–380 (2015)
30. B. Çabuk, B. Yılmaz, J. Food Sci. Technol. **57**(7), 2750–2757 (2020)
31. P.M.G. Ishida, C.J. Steel, Food Sci. Technol. **34**(4), 746–754 (2014)
32. M.S. Soares Júnior, P.Z. Bassinello, M. Caliari et al., Food Sci. Technol. **29**(3), 636–641 (2009)
33. P. Pauter, M. Różańska, P. Wiza et al., Acta Sci. Pol. Technol. Aliment **17**(3), 227 (2018)
34. C. da Rosamachado, R.C.S. Thys, Innov. Food Sci. Emerg. Technol. **56**, 102180 (2019)
35. T. Dewi, A. Vidiarti, D. Fitranti et al., Food Res. **4**(3), 114–122 (2020)
36. B. Biró, R. Fodor, I. Szedljak et al., LWT-Food Sci Technol. **116**, 108542 (2019)
37. A. Cappelli, N. Oliva, G. Bonaccorsi et al., LWT-Food Sci. Technol. **118**, 108867 (2020)
38. M. Haber, M. Mishyna, J.J.I. Martinez et al., LWT-Food Sci. Technol. **115**, 108395 (2019)
39. C.B.J. Villarino, V. Jayasena, R. Coorey et al., Crit. Rev. Food Sci. Nutr. **56**(5), 835–857 (2016)
40. K. Ng, S. Bhaduri, R. Ghatak et al., J. Acad. Nutr. Diet **112**(9), A58 (2012)
41. M. Valcarcel, R. Ghatak, S. Bhaduri et al., J. Acad. Nutr. Diet **112**(9), A58 (2012)
42. A. Osimani, V. Milanović, F. Cardinali et al., Innov. Food Sci. Emerg. Technol. **48**, 150–163 (2018)
43. P. García-Segovia, M. Igual, J. Martínez-Monzó, Foods **9**(7), 933 (2020)
44. S. Indriani, M.S. Bin Ab Karim, S. Nalinanon et al., LWT-Food Sci. Technol. **119**, 108876 (2020)
45. M. Premi, H.K. Sharma, J. Food Meas. Charact. **12**(1), 11–21 (2018)
46. G. Melgar-Lalanne, A.-J. Hernández-Álvarez, A. Salinas-Castro, Compr. Rev. Food Sci. Food Saf. **18**(4), 1166–1191 (2019)
47. G. Kerch, F. Rustichelli, P. Ausili et al., Eur. Food Res. Technol. **226**(6), 1459–1464 (2008)
48. K. Khuenpet, C. Pakasap, S. Vatthanakul et al., Int. J. Agric. **16**(2), 283–296 (2020)
49. A.N. Bellary, A.R. Indiramma, M. Prakash et al., Innov. Food Sci. Emerg. Technol. **33**, 554–562 (2016)
50. W. Mokrzycki, M. Tatol, Mach. Graph. Vis. **20**(4), 383–411 (2011)
51. R.A. Mohamad, F. Taip, S. Mazlina et al., J. Appl. Sci. Agric. **10**(5), 63–68 (2015)
52. G. Abera, W.K. Solomon, G. Bultosa, Food Sci. Nutr. **5**(3), 653–661 (2017)
53. N.C. Pa, N.L. Chin, Y.A. Yusof et al., J. Food Agric. Environ. **11**(2), 48–55 (2013)

54. C.B.J. Villarino, V. Jayasena, R. Coorey et al., LWT-Food Sci. Technol. **60**(1), 435–443 (2015)
55. P.Ł Kowalczewski, K. Walkowiak, Ł Masewicz et al., Foods **8**(7), 240 (2019)
56. R. Kaur, M. Kaur, LWT-Food Sci. Technol. **91**, 278–285 (2018)
57. M.E. Matos, T. Sanz, C.M. Rosell, Food Hydrocoll. **35**, 150–158 (2014)
58. B. Herranz, W. Canet, M.J. Jiménez et al., Int. J. Food Sci. Technol. **51**(5), 1087–1098 (2016)
59. M.D. Alvarez, B. Herranz, M.J. Jiménez et al., J. Texture Stud. **48**(6), 550–561 (2017)
60. M. Bala, T.V. Arun Kumar, S. Tushir et al., J. Food Sci. Technol. **56**(2), 713–723 (2019)