PHYSICOCHEMICAL AND SENSORY PROPERTIES OF SAVORY CRACKERS INCORPORATING GREEN GRAM FLOUR TO PARTIALLY OR WHOLLY REPLACE WHEAT FLOUR

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ABSTRACT

Green gram flour (GGF) has numerous health benefits and it is an excellent raw material for baking. However, knowledge of its use as a baking material is limited. The present study was aimed to develop savory crackers using GGF. The crackers were prepared at various ratios of wheat flour (WF) to green gram flour (GGF) (T1 100:0; T2 80:20; T3 60:40; T4 40:60; T5 20:80; T6 0:100). The physicochemical and ultrastructural properties, antioxidant activities, and sensory attributes of savory crackers were studied. Weight, height, thickness, moisture, a_w (water activity) and texture tended to increase with GGF application in the enriched crackers (T4-T6). Similarly, the proximate composition of crackers was improved by GGF. The color characteristics were excellent with a high content of WF because GGF content increased a^* and ΔE* color coordinates and decreased the color coordinates of L^* and b^*. The antioxidant potential was higher in the GGF enriched crackers. In terms of ultrastructure, the GGF enriched crackers had smoother surfaces. The GGF enriched crackers showed various improvements and a high content of WF gave better sensory scores, while consumer acceptability of the GGF enriched crackers suffered slightly.

Keywords: green gram flour, crackers, nutrition, antioxidant ability, ultrastructure, sensory attributes

1. INTRODUCTION

Novel functional snack foods, especially bakery products from the food industry (with potential health benefits) are in high demand by consumers. Numerous studies have assessed the production of bakery products (bread, biscuits, cookies and crackers) with health promoting ingredients, such as pulses, grains, and tubers (JULIANTI *et al.*, 2017; AHMED and ABOZED, 2015; DOKIĆ *et al.*, 2015; SEDEJ *et al.*, 2011). In Thailand, the baked snack food market value was estimated to be 7 million Euro in 2012, accounting for about 4% of the total snack sales. The baked snack products include cookies, crackers, and biscuits. Crackers are a versatile thin and crispy food that can appeal to a variety of consumer expectations. They serve as a quick snack with low contents of moisture, sugar, and fat. Crackers can be divided into three broad categories, namely; soda crackers, snack crackers, and savory crackers (AHMED and ABOZED, 2015). Snack crackers with sugar and/or desiccated coconut sprinkled on top are widely sold in Thailand. The main ingredient in crackers is wheat flour, whose consumption may trigger celiac disease in a significant fraction (1:100-1:200) of the global population. Gluten is the major component in wheat flour that generates this inflammatory disease response. Therefore, the need for food manufacturers to provide alternative gluten-free bakery products. While gluten free alternatives for bakery products such as bread, cakes, and biscuits are widely available, alternatives to crackers are not common, especially in Thailand. Additionally, only a few studies have been done on gluten-free crackers from alternative flours, such as pulse flour and buckwheat flour (SEDEJ *et al.*, 2011).
The flour used as raw materials play a crucial role in the bakery industry, and these are obtained from a wide range of plants. Flours from legumes have been put to diverse use in the bakery industries and can be used in bread, tortillas, chips, doughnuts, spreads and extruded snacks (GRAHAM and VANCE, 2003). Green gram (*Vigna radiata* (L.) Wilczek) is a legume widely grown and consumed in South East Asia. It is an excellent source of digestible protein, with a higher lysine content than any other legume, and is free from factors that cause flatulence. Normally, green gram seeds are consumed as whole or split grains, sprouts, immature seeds, or as flour (ADSULE *et al.*, 1986). Green gram flour is used in various Thai desserts. CHANDRA *et al.* (2015) demonstrated that composite flours containing green gram have excellent functional and rheological properties. Moreover, green gram flour is gluten free. Despite these positive aspects, only a few scientific studies have addressed the production of crackers with green gram flour and to the best of our knowledge, bakery products prepared from mixed wheat flour (WF) and whole green gram flour (GGF) do not currently exist. Therefore, the present study aimed at producing savory crackers with various fractions of green gram flour in mixtures with wheat flour, and evaluate their physicochemical and sensory characteristics.

2. MATERIALS AND METHODS

2.1. Materials

Commercially available raw materials such as flours (refined wheat flour (WF) and whole green gram flour (GGF), sugar, vegetable oil, chemical leavening agent, honey and fresh garlic for savory flavor were purchased from the local supermarkets in Muang, Surat and Thani in Thailand. Then, prior to processing, the flours were blended in the following WF:GGF (dry weight) ratios: 100:0 (T1), 80:20 (T2), 60:40 (T3), 40:60 (T4), 20:80 (T5) and 0:100 (T6). The flour blends were stored separately in airtight containers, in darkness at room temperature until further use. All the chemicals and reagents used in this study were of analytical grade.

2.2. Cracker preparation

Crackers made from WF, GGF and the actual mixtures of WF and GGF, were produced on a laboratory scale by a straight dough process, using a commercial cracker recipe with slight modifications. The ingredients, namely flour/blend, sugar (2%), salt (2%), chemical leavening agent (sodium bicarbonate, 2%), vegetable oil (10%) and water (15%) were thoroughly mixed together to form a cohesive dough using an electric mixer (RBSFOODMIXERPRO, Cuizimate, Thailand) at low (80 rpm, 1 min) and moderate speeds (100 rpm, 10 min). The dough was wrapped in polyethylene film and was allowed to sit for 10 min under refrigerated temperature and then for 20 min at room temperature. After leaving to sit, the dough was sheeted to 5 mm thickness using a pasta roller, and cut into 4 cm squares with a mold. These molded crackers were baked in a double deck infrared conventional oven at 180ºC for 11min and were pulled out of the oven to apply the flavoring agent. For savory flavor, finely chopped garlic was mixed with honey and brushed on the crackers, after which the baking continued for another 4 min at 180ºC, before cooling down to room temperature. Whole baked crackers were subjected to physical, ultrastructural and sensorial analyses, while coarsely crushed crackers were used in chemical and antioxidant analyses.

2.3. Quality analyses of crackers

2.3.1. Physical characteristics

Physical characteristics such as color, texture, stack weight and thickness were determined for the crackers (15 replicate crackers per experimental point). The color coordinates L^*, a^* and b^* were observed with a colorimeter (MiniScan EZ 4000S, HunterLab, Reston, Virginia). The total color difference (ΔE^*) to the baseline case T1, was measured as reported by AHMED and ABOZED (2015). The texture was analyzed by the peak force (N) test using a texture machine (CT3 Texture Analyzer, Brookfield, Stuttgart, Germany) equipped with a blade probe. Stack weight was measured using an electronic weighing balance and the results are expressed in grams (g). Cracker thickness was measured using the Vernier caliper, while crackers were stacked on top of each other, and an average value was recorded.

2.3.2. Chemical analyses

The crackers were analyzed for proximate composition in terms of moisture, fiber, fat, ash, and protein, using methods 934.01, 985.29, 983.23, 945.38, and 920.87, respectively (AOAC, 2000). A protein conversion factor of 5.7 was applied to determine the presence of protein in the samples. Carbohydrate content in the crackers was estimated by the subtraction of other components. The mineral contents of K, Ca, Mg, Fe, and Zn were measured using an individually coupled plasma optical emission spectrophotometer (ICP-OES, Vista Pro, Varian Inc., Mulgrave VIC, Australia). The pH of the crackers was measured using a handheld digital pH meter (pH30 Tester, CLEAN, Shanghai, China). Water activity (a_w) of crackers was measured using an a_w analyzer (Series 4TEV, Aqua Lab, WA, USA).

2.3.3. Antioxidant activities

Extracts from crackers for determining antioxidant properties were prepared using 10 g samples mixed with acidified methanol (50 mL) in an amber reagent bottle. The suspension was mixed thoroughly and placed in a water bath with an electric shaker, for 8 hr of extraction at 30 ºC. Thereafter, the extracted samples were centrifuged at 7800 x *g* for 15 min, after which the supernatant was collected and stored in a dark container at -4°C until analysis. The antioxidant properties were measured as follows. The total chlorophyll content (TCC) of the crackers was measured with method 940.03 (AOAC, 2000). The results are represented as mg chlorophyll/g. Total phenolic content (TPC) was measured with the method of SINGLETON *et al.* (1999). The results are shown as mg equivalents of gallic acid/g (mg Eq GA/g). Total flavonoid content (TFC) in the samples was determined with the method of ZHISHEN *et al.* (1999). The results are expressed as mg equivalents of catechin/g (mg Eq CE/g). The radical scavenging capacity of the crackers for DPPH (2, 2-diphenyl-1-picrylhydrazyl) radicals and DPPH-RSC, were determined using the method of SÁNCHEZ-MORENO *et al.* (1999). The results are expressed as percentages. The ferric reducing antioxidant power (FRAP) of crackers was measured according to the method of BENZIE and STRAIN (1996). The results are expressed as percentages. The metal chelating activities (MCA) of the crackers were measured according to the method of AKTUMSEK *et al.* (2013). The results are expressed as mg equivalents of EDTA/g (mg Eq EDTA/g).

2.3.4. Ultrastructural properties

Crackers were broken into tiny pieces to observe the surface ultrastructure. The pieces were mounted on aluminium stubs with adhesive tape, sputter coated with gold-palladium to render them thermo electrically conductive, and then observed with a JSM 5800 LV scanning electron microscope (JEOL, Akishima, Japan).

2.3.5. Sensory analysis

Sensory attributes of the crackers, namely color, taste, crispness, odor, appearance and overall acceptability, were determined by a panel of sixty consumers (18-60 years of age; equal proportions of males and females). Candidate panelists were screened for their frequency of cracker snack consumption, accepting to be among the panelist for those consuming the cracker snack at least once a month. Each panelist evaluated the various formulations of savory green gram crackers using a 9-point hedonic scale, in which the lowest value (1) stands for extreme dislike and the highest value (9) represents an extreme liking. During the sensory evaluation, crackers of each experimental type were placed separately on plastic plates that were labelled randomly with three-digit codes. Prior to each tasting a sample, lemon water was served to the panelists to neutralize their mouth feel, in order to maintain comparable testing over a sequence of samples.

2.4. Statistical analyses

All the experiments were conducted with six replications, except for the physical quality determinations that had 15 replications, and the data are expressed as a mean±standard deviation. The significance of differences between the cases was determined by analysis of variance (ANOVA) with significance threshold $P<0.05$. The means were compared by Duncan's multiple range test. Statistical analysis was performed using SPSS for Windows (version 8, SPSS Inc., Chicago, IL, USA).

3. RESULTS AND DISCUSSIONS

The physical characteristics of the composite crackers made of WF:GGF blends are shown in Table 1. The stack weight ranged from 69.45 to 87.90 g. The crackers with high GGF content were slightly heavier than those having more WF. The thickness of crackers did not differ much between the experimental cases ($P<0.05$), but as might be expected from cracker height of the WF rich crackers, these were slightly thicker than those with high GGF content. The moisture content differed significantly between the samples, ranging from 4.46 to 6.59%. The crackers with highest GGF levels (T4-T6) had higher moisture contents than the rest (T1-T3), but samples in the middle (T2-T5) did not show any significant differences. Moisture plays a very vital role in baked products affecting their texture, crispness and shelf life in storage. Generally, moisture tends to degrade the finished product's functionality. However, the crackers in the present study had significantly lower moisture levels than composite crackers in various prior studies (AHMED and ABOZED, 2015; DOKIĆ *et al.*, 2015; SEDEJ *et al.*, 2011). Similarly, the water activity (a_w) was comparatively high in the crackers with a high proportion of GGF, ranging from 0.39 to 0.48. In addition, the tested crackers were slightly alkaline in this study, with the pH varying from 7.20 to 7.96 ($P<0.05$). While the GGF rich crackers tended to have slightly decreased pH relative to others. The texture of crackers was significantly affected by the WF:GGF blends proportions. High WF level in the crackers gave a crispier structure, while the GGF rich crackers had a slightly hardened texture.

The color parameters of crackers are shown in Fig. 1A-D. Lightness (L^*) was significantly affected by the mixture proportions of WF:GGF. Increased level of WF in the crackers caused a considerably lighter surface (Fig. 1A). This could be due to the effects of chlorophyll reducing lightness on the cracker surface. The redness (a^*) was significantly affected in this study, with GGF in the crackers increasing a^* value*; this* coordinate indicates the level of browning in a baked product and should be high for brown surfaces (Fig. 1B). This suggests that GGF in the crackers could increase protein availability to Maillard reactions during baking. On the other hand, yellowness (b^*) was not significantly affected and slightly decreased with GGF content (Fig. 1C). The total color difference (ΔE^*) to T1 baseline crackers was significantly affected (Fig. 1D) in a consistent pattern that correlates with the L^* values. AHMED and ABOZED (2015) reported that changes in ΔE^* represented the darkness/lightness variation in crackers, matching well this present study despite the fact that the raw materials are different.

The proximate composition of crackers made of WF:GGF blends are shown in Fig. 2A. It was observed that GG has higher protein and mineral contents than wheat. SEDEJ *et al.* (2011) reported similar results for buckwheat crackers when compared to wheat crackers. The fat content of crackers was unaffected, as the natural fat content in WF and GGF is very similar. The total dietary fiber content did not vary significantly, because its trend decreased with GGF content. Previous studies have reported reduced levels of dietary fiber in novel crackers (AHMED and ABOZED, 2015; SEDEJ *et al.*, 2011). The ash content in the crackers increased with GGF level. The contents of protein, carbohydrate, fat and fiber contents were converted to food energy using a water general factor system according to FAO recommendations (AHMED and ABOZED, 2015; FAO, 2003). The estimated energy of crackers was not significantly different in all the treatments. On the other hand, the contents of K, Ca, Mg (Fig. 2B), Fe and Zn (Fig. 2C) minerals slightly increased with the proportion of GGF in the crackers. Based on these results, the use of GGF in crackers may provide a nutritional benefit to the consumers.

Table 1. Characteristics of savory crackers made with various blend proportions of WF and GGF.

End product characterization	Flour blend					
	T1	T2	T3	T4	T5	T6
Stack Weight (g)*	69.45±0.48[c]	73.65±0.23[c]	79.95±0.40[b]	85.20±0.44[ab]	87.30±0.43[a]	87.90±0.66[a]
Thickness (mm)**	6.94±0.12[a]	6.83±0.22[b]	6.60±0.18[c]	6.39±0.27[d]	6.38±0.14[d]	6.34±0.09[d]
Moisture (%)	4.46±0.40[c]	5.98±0.11[b]	6.01±0.01[b]	6.06±0.24[b]	6.13±0.22[b]	6.59±0.21[a]
Water activity (a_w)	0.393±0.01[f]	0.406±0.00[e]	0.415±0.00[d]	0.436±0.00[c]	0.452±0.00[b]	0.482±0.01[a]
pH	7.96±0.02[a]	7.62±0.07[b]	7.48±0.02[c]	7.45±0.02[c]	7.33±0.03[d]	7.20±0.02[e]
Texture (g)	2742.33±259.76[c]	2790.83±360.05[bc]	3113.75±649.25[b]	3483.75±462.53[a]	3493.67±282.60[a]	3798.50±171.92[a]

T1, T2, T3, T4, T5 and T6 represent WF:GGF flour's different blend ratios for making crackers (100:0, 80:20, 60:40, 40:60, 20:80 and 0:100).
Note: The data shown in mean±SD.
Different letters in the same row indicate significant differences ($P \leq 0.05$) among samples.
*Stack of 15 crackers
**Average value in a stack of 15 crackers

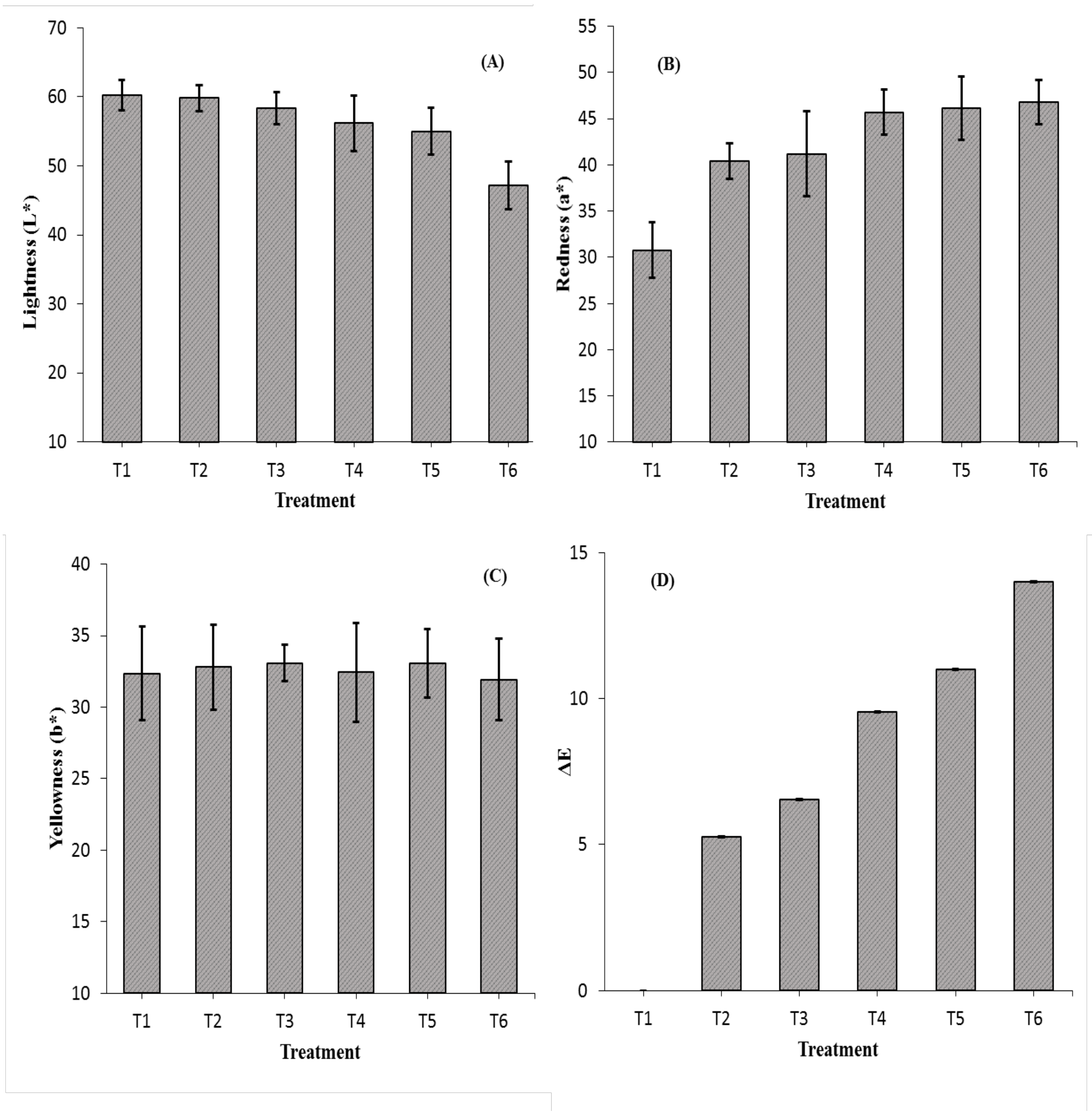

Figure 1. CIE-LAB color coordinates *L** (A), *a** (B), *b** (C), and ΔE* (D) difference to baseline case T1, for savory crackers made with various WF:GGF blend proportions. T1, T2, T3, T4, T5 and T6 represent WF:GGF flour's different blend ratios for making crackers (100:0, 80:20, 60:40, 40:60, 20:80 and 0:100).

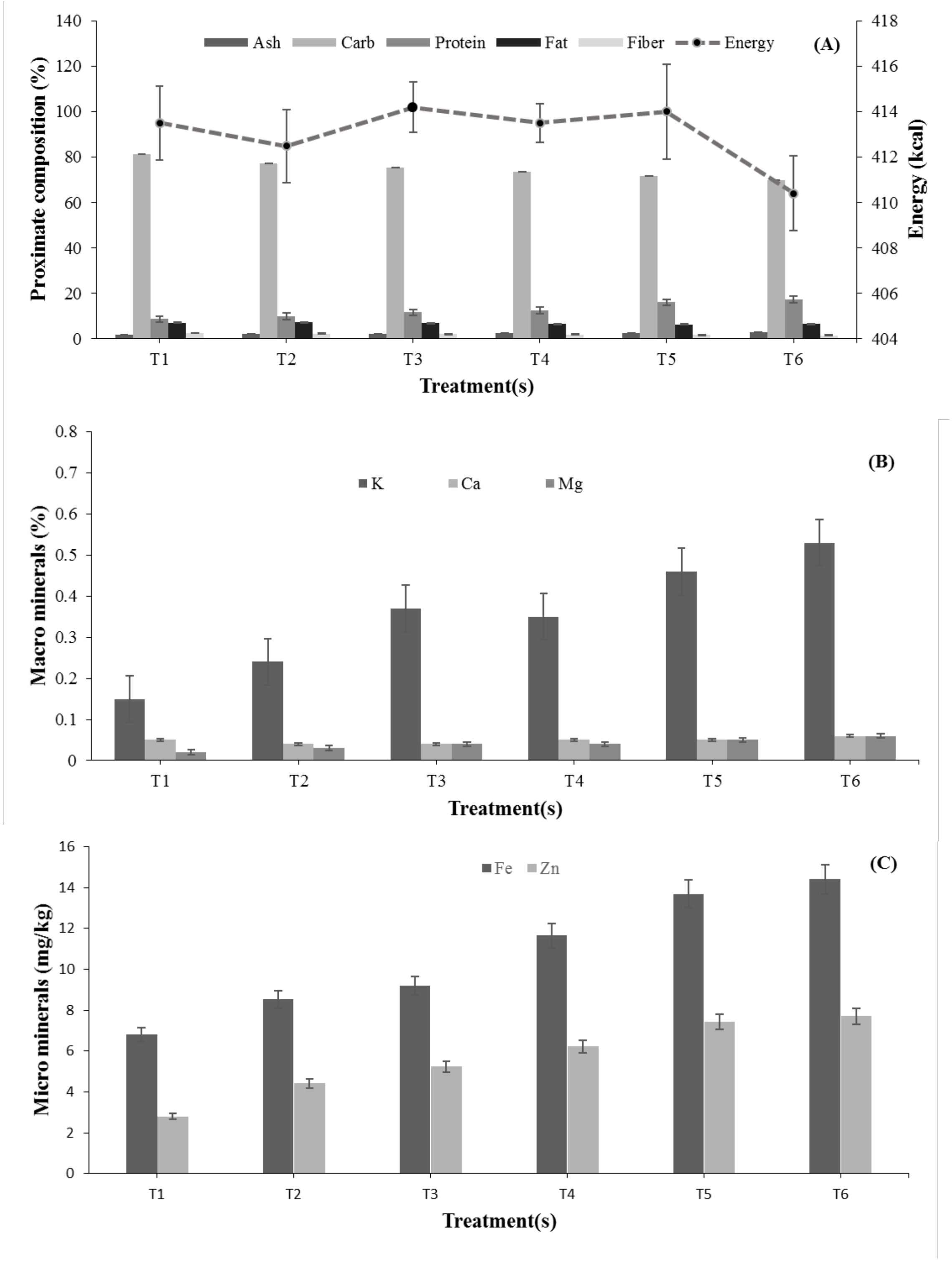

Figure 2. Proximate composition (A), energy (A) and mineral contents (B& C) of the various savory crackers. T1, T2, T3, T4, T5 and T6 represent WF:GGF flour's different blend ratios for making crackers (100:0, 80:20, 60:40, 40:60, 20:80 and 0:100).

Antioxidant properties of the crackers with various WF:GGF blend ratios are presented in Fig. 3. The antioxidant abilities of the crackers are directly linked to their ingredients, and the predominant contribution is from the GGF ingredient. The phytochemical content was highest in the GGF rich crackers, and TCC increased with GGF content (Fig. 3A), being maximal in case T6 made with only GGF. FERRUZZI *et al.* (2002) reported that natural pigments such as chlorophyll exhibited antioxidant capabilities along with the other phytochemicals, such as polyphenols in plants. Similar patterns were found for TPC and TFC (Fig. 3A), both increasing gradually with the content of GGF in the dough mixture, which is in agreement with the study by KARTHIGA and JAGANATHAN (2013).

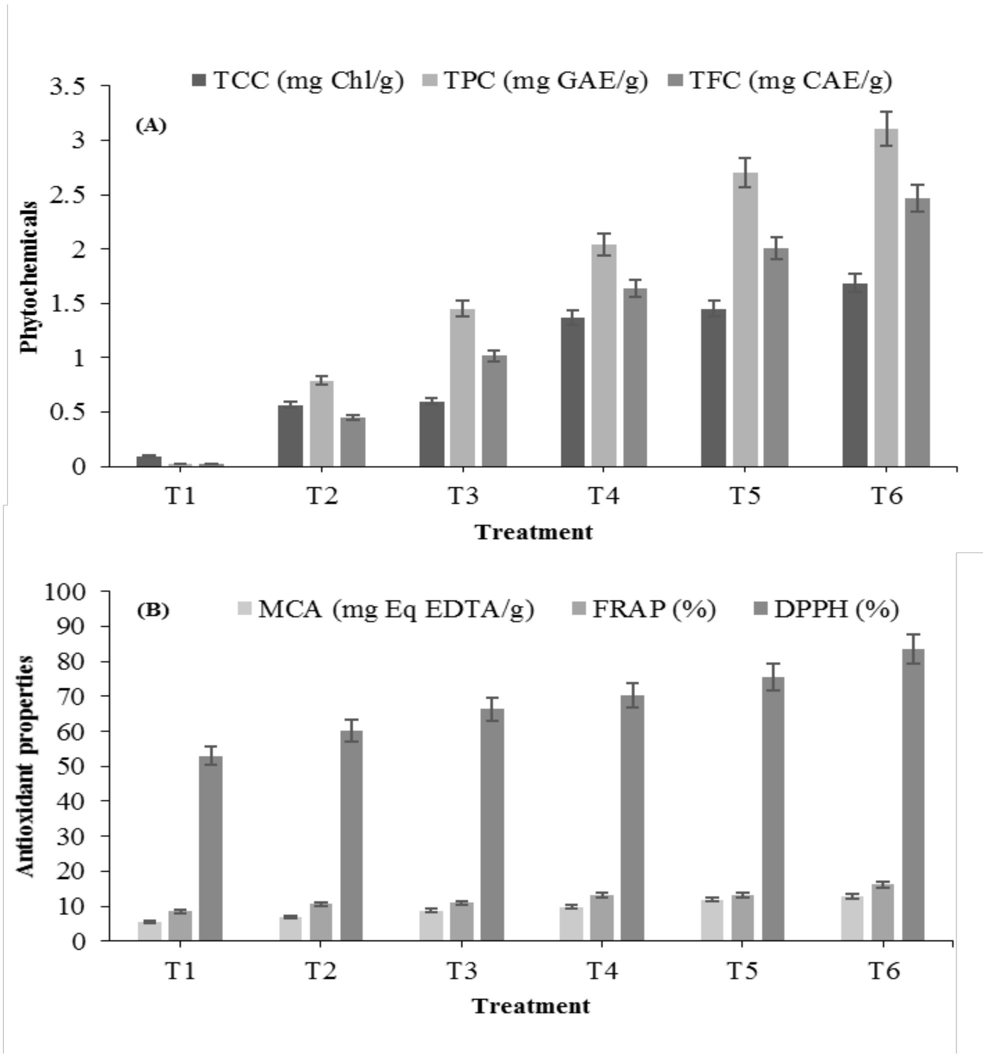

Figure 3. Phytochemical contents (A) and antioxidant properties (B) of the various savory crackers. T1, T2, T3, T4, T5 and T6 represent WF:GGF flour's different blend ratios for making crackers (100:0, 80:20, 60:40, 40:60, 20:80 and 0:100). TCC: Total chlorophyll content; TPC: Total phenolic content; TFC: Total flavonoid content; MCA: Metal chelating activity; FRAP: Ferric reducing antioxidant power; DPPH: 2,2-Diphenyl-1-picrylhydrazyl radical scavenging capacity.

Normally, whole green gram legumes contain more phytochemicals than processed green gram, such as split grains or flour, and generally, GGF contains more phytochemicals than WF. This was also very distinct in the present study, as TPC and TFC increased with GGF content. While for the GGF made crackers rich in phytochemicals, uncooked GGF would be superior in this respect. SHARMA and GUJRAL (2014) reported that a continuous baking process could modify the chemical structure of a phenolic compound, particularly by polymerization, and consequently reduce extractable polyphenols in baked products. The antioxidant properties of crackers were evaluated in terms of DPPH radical scavenging activity and a FRAP assay (Fig. 3B). The GGF in crackers increased the radical scavenging ability from 50.92 to 83.57%, even though the GGF enriched crackers (T5-T6) had improved radical scavenging ability (RSA) and also the WF rich crackers had a reasonable RSA. Similarly, the ferric reducing potential was improved by GGF in the crackers, probably because of the phytochemicals, namely polyphenols. In addition, the added honey and garlic, and the chemical reactions during baking may have contributed to the antioxidant potential of the end product.

Surface ultrastructure for crackers made of WF:GGF flour mixes is shown in Fig. 4. The mixing proportions significantly affected the ultrastructure of the cracker surface. The high content of WF in the composite flour (T1-T3) induced continuous aggregation with few fissures on the cracker surface, while the GGF rich crackers had smoother surfaces with reduced or no aggregation. The samples T5 and T6 with a high proportion of GGF had small discontinuous patches on the surfaces. The smoother compact cell surfaces of GGF rich crackers might be the results of complete gelatinization during baking, whereas, WF rich crackers have rough surface which could be the cause of incomplete gelatinization and leaving intact or partially embedded sugars and lipids in the protein matrix (CHEVALLIER *et al.*, 2000; FILIPČEV *et al.*, 2014). DACHANA *et al.* (2010) reported that incomplete gelatinization of starch in the crackers could be caused by insufficient water in the matrix. Such lack of water in the WF rich crackers could be caused by tight bonding of water to gluten during dough making (JAMES and RINTOUL, 1982). With less gluten, the crackers might leave more water for starch gelatinization, which could improve the surface smoothness of the crackers (AHMED and ABOZED, 2015).

The sensory attributes of the savory crackers made with WF:GGF flour blends are presented in Table 2. The sensory scores were better for crackers with a high proportion of WF and correspondingly low proportion of GGF. The blend composition significantly affected color (7.23 for WF vs 5.17 for GGF), odor (7.67 for WF vs 5.17 for GGF), taste (8.63 vs 6.23, similarly), texture (7.27 vs 6.17), crispness (7.70 vs 5.57), appearance (7.80 vs 6.30) and overall acceptability (7.88 vs 6.17). All traits were negatively affected by GGF content in the crackers. GGF does have its specific color and aroma, which the consumers are not used to. Furthermore, DOKIĆ *et al.* (2015) reported that increasing the level of dietary fiber in crackers could degrade texture and crispness due to weak rheological behavior and poor uniformity of structure. The acceptability of food products always depend on texture, and crispness is of particular importance when making crackers or other crispy snack products (ROUDAUT *et al.*, 1998). In the present study, texture and crispness were affected, nevertheless not excessively, by the GGF content; crispness is a very important trait for acceptable crackers (SIAW *et al.*, 1985). The relatively high fiber content of GGF, as compared to WF, is evident from the proximate composition of crackers (Fig. 2A). While the GGF enriched composite crackers had slightly lower sensory scores than the unblended WF, still, acceptable mean scores greater than 4.5 were found: indicating neither like nor dislike. Of relevance is that samples T4, T5 and T6 always had similar grades. Therefore, despite their slightly inferior sensory scores and considering the superior nutritional and health benefits, the T6 crackers could be proposed as a possible alternative to bread wheat crackers.

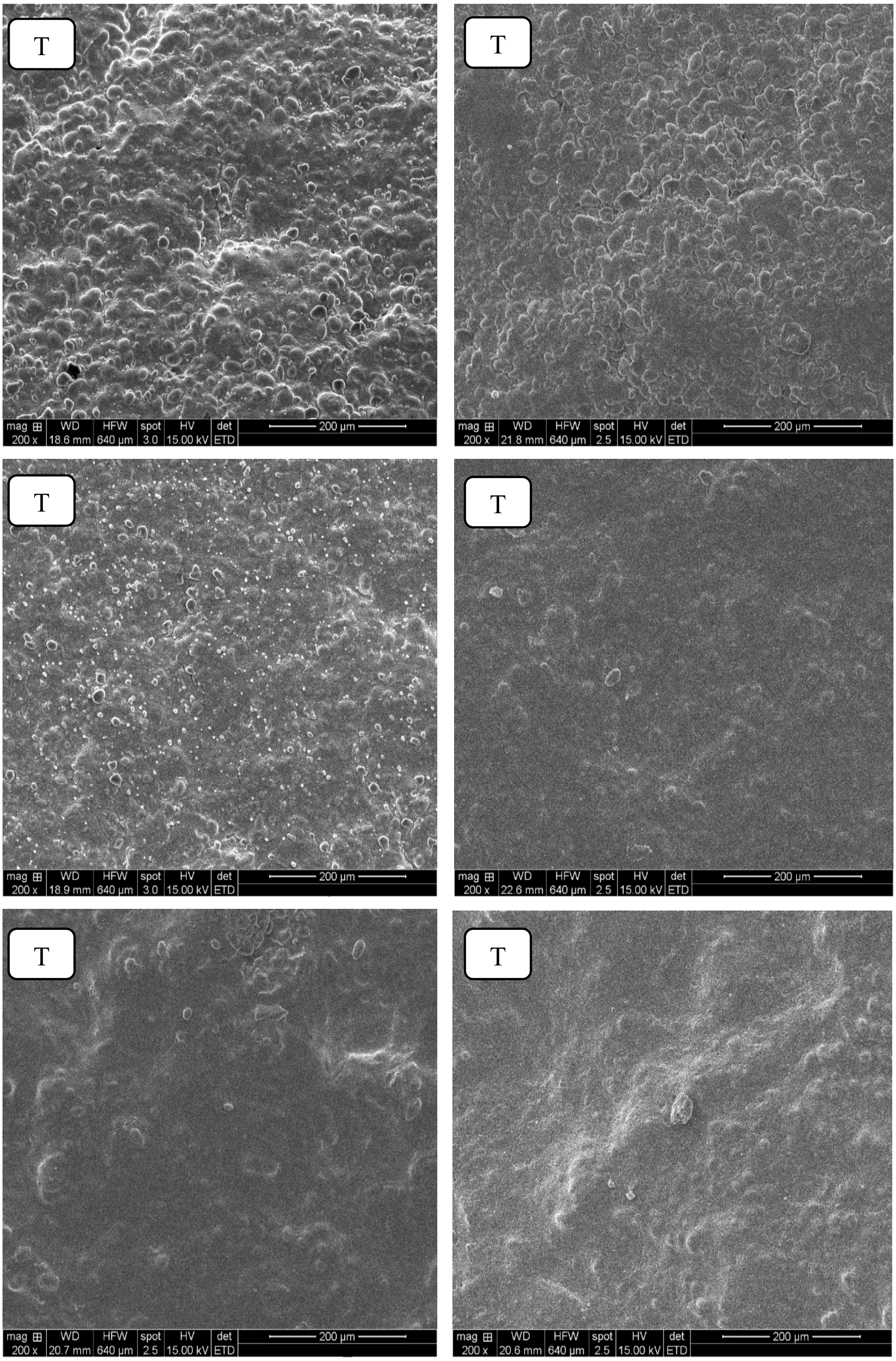

Figure 4. Surface ultrastructure images of the different savory crackers. T1, T2, T3, T4, T5 and T6 represent WF:GGF flour's different blend ratios for making crackers (100:0, 80:20, 60:40, 40:60, 20:80 and 0:100).

Table 2. Sensory scores of savory crackers made with various blend proportions of WF and GGF.

Sensory attribute	Flour blend					
	T1	T2	T3	T4	T5	T6
Color	7.23±1.17[a]	6.20±1.49[b]	5.67±1.92[bc]	5.50±1.25[bc]	5.70±1.49[bc]	5.17±1.82[c]
Odor	7.67±1.54[a]	7.70±1.66[a]	7.37±1.61[ab]	6.17±1.60[b]	5.87±1.49[bc]	5.60±1.69[bc]
Taste	8.63±1.47[a]	7.70±2.00[ab]	7.03±1.77[bc]	6.87±2.06[bc]	6.23±2.18[bc]	6.37±1.77[bc]
Texture	7.27±1.76[a]	7.63±1.63[ab]	6.63±1.96[c]	6.53±1.96[c]	6.17±1.82[c]	6.50±1.59[c]
Crispness	7.70±2.10[a]	7.63±1.90[a]	6.83±2.42[ab]	5.83±1.90[b]	5.83±2.18[b]	5.57±1.96[b]
Appearance	7.80±1.63[a]	7.00±1.58[b]	6.53±1.68[bc]	6.93±1.51[bc]	6.37±1.75[bc]	6.30±1.40[bc]
Overall acceptability	7.88±1.11[a]	7.20±1.30[b]	6.40±1.65[c]	6.83±1.60[c]	6.17±1.66[c]	6.23±1.50[c]

T1, T2, T3, T4, T5 and T6 represent WF:GGF flour's different blend ratios for making crackers (100:0, 80:20, 60:40, 40:60, 20:80 and 0:100).
Note: The data are shown as mean±SD.
Different letters in the same row indicate significant differences ($P \leq 0.05$) among samples.

4. CONCLUSIONS

The present study assessed key effects of replacing wheat flour (WF) with green gram flour (GGF) in savory crackers. The results indicate GGF as a potential alternative to WF in bakery products, especially in crackers. The GGF enriched crackers exhibited improved nutritive and functional properties, with the elevated antioxidant activities possibly providing health benefits to consumers, and perhaps extending shelf life. However, in sensory acceptance testing, the GGF enriched crackers received slightly poorer scores than the baseline WF based crackers. Overall, GGF appears to be a good alternative to WF, especially for use in gluten-free bakery products. Other types of bakery products other than crackers may be assessed in further studies, for the suitability of GGF as raw material.

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