LATIN AMERICAN APPLIED RESEARCH 54(1): 11–20 (2024)

Chemical, physical and sensory properties of gluten-free potato crackers supplemented with cowpea, faba bean and mung bean flours

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ABSTRACT In this study, some characteristics of gluten-free potato crackers substituted with cowpea, faba bean and mung bean flours were determined. The crackers containing the legume flours had significantly higher ($p < 0.05$) fat, protein, insoluble and total dietary fiber, and essential amino acids (EAA) than the control cracker (C) produced with potato flour and starch. The cracker containing faba bean flour (FC) had the highest P, K, Ca, and Zn contents. C recorded the highest L^*, cracker containing cowpea flour (CC) recorded the highest a^* and FC recorded the highest b^* values. C had a higher hardness value than the other crackers, followed by the cracker containing mung bean flour (MC), CC and FC, respectively. SEM micrographs revealed that more cracks and pores were formed when legume flour was added to the crackers. CC, FC and MC scored higher in flavor, chewiness, crispiness and overall acceptability scores than C in sensory analysis.

KEYWORDS Legumes; Amino acid composition; Minerals; SEM; Sensory

1. Introduction

Celiac disease is a complex autoimmune disorder that presents in genetically susceptible individuals as a permanent intolerance to gluten, being main storage protein of wheat, barley and rye. Celiac disease is related with maldigestion and malabsorption of nutrients, vitamins and minerals in the gastrointestinal tract. The only available treatment for celiac disease is lifelong adherence to a gluten-free diet, and so the difficulties faced by celiac patients in finding "safe" meals outside home has led to a growing demand for packaged gluten-free products such as snacks, biscuits and crackers (Niewinski, 2008; Caponio et al., 2008). Crackers – a popular snack foods in the human diet – are dry, thin and crisp bakery snack foods that can be consumed easily and safely inside and outside the home (Han et al., 2010; Sedej et al., 2011). To satisfy the population with gluten intolerance, there is a need to use alternative gluten-free raw materials in new bakery products and crackers (Han et al., 2010; Sedej et al., 2011). In this regard, legumes provide opportunities through their utilization in such foods as bread, bakery products, snack foods, cereal bar filings, pastas, tortillas, meat, soups, etc. (Asif et al., 2013).

Legumes belong to the family of Leguminosae, and they have nearly 690 genera and 17,600 species. Edible legumes include pea, mung bean, faba bean, soybean, cowpea, small red bean, pigeon bean and kidney bean, among others, and offer such advantages as long shelf life, easy transportation and low cost (Hacıseferoğulları et al., 2003; Du et al., 2014).

Legumes are good sources of proteins, complex carbohydrates and dietary fibers, while containing also significant amounts of minerals and vitamins. They are used to enrich the variety of foods and serve as a cheap source of protein in developing countries, being good alternatives to expensive fish and meat proteins. The protein content of legume grains ranges between 17–40 g/100g, nearly equal to meat, and much higher than that of cereals (Hacıseferoğulları et al., 2003; Du et al., 2014; Rodehutscord et al., 2016).

In recent years there has been growing interest in the addition of legumes to bakery products for the creation of novel foods. In studies of this subject, legumes have been used to supplement wheat flour or used in gluten-free products, with lentil, soybean and chickpea flours used mostly in these studies. Faba bean (Vicia faba L.), cowpea (Vigna unguiculata L.) and mung bean (Vigna radiata L.) are examples of legumes that can serve as important plant-based protein sources in Turkey. Although there are a few studies in literature investigating the use of cowpea (Jeong et al., 2021), faba bean (Schmelter et al., 2021) and mung bean (Setyaningsih et al., 2019) flours in gluten-free muffins, cookies and biscuits, there has been no study to date assessing their use in the production of gluten-free crackers.

The objectives of this study were to formulate gluten-free potato crackers of cowpea, faba bean and mung bean flours, to determine their chemical, physical and sensory characteristics, and to contribute to the literature as an alternative study of the gluten-free cracker production.

DOI: 10.52292/j.laar.2024.1045
Received: April 13, 2022.
Accepted: March 18, 2023.
Recommended by Diego Lomonaco.

2. Methods

2.1 Materials

Faba bean (*Vicia faba* L.), cowpea (*Vigna unguiculata* L.) (Noba, Istanbul, Turkey), mung bean (*Vigna radiata* L.) (Ala Ciftci, Mersin, Turkey), potato starch (Migros, Istanbul, Turkey), margarine (Sana, Istanbul, Turkey), salt (Billur tuz, Izmir, Turkey), potato flour, xanthan gum (Tito, Izmir, Turkey), powdered sugar, baking powder (sodium bicarbonate, sodium acid pyrophosphate) (Dr. Oetker, Izmir, Turkey) were bought from local markets in Denizli, Turkey.

2.2 Preparation of the legume flours

For the production of legume flours, cowpea, faba bean and mung bean sourced from the market were cooked separately in water in a pressure cooker (Burcu, Emsan, Istanbul, Turkey) at a weight ratio of 1:3 for 30 minutes. The samples were then spread in thin layers over baking trays and dried in an air-flow turbo oven (Silverline, 6502 S, Istanbul, Turkey) at 50 °C for 12–16 hours until the moisture content dropped below 12 %. The samples were then ground in a grinder (Felix wave, Felix Household Supplies, Istanbul, Turkey) to pass through a 1.00 mm sieve (Mesh No. 18, Retsch, Haan, Germany).

2.3 Production of crackers

The formulations of the gluten-free crackers are presented in Table 1. For the production of the crackers, first, all solid materials were stirred for 1 minute, after which water was added. The resulting dough was kneaded for 5 minutes and then left to rest for 10 minutes at room temperature. The dough was sheeted to approximately 2 mm thickness using a manual wooden rolling pin and then cut into squares (2×2 cm) and baked at 210 °C for 12 minutes in a turbo-flow oven (Oscar M 4572 Turbo, Simfer, Istanbul, Turkey). After cooling, the baked crackers were stored in plastic bags (PE/PA/EVOH/PA/PE) at room temperature until the time of analysis.

Table 1: The gluten-free cracker formulations.

Ingredients (g)	C	CC	FC	MC
Legume flour	-	70.0	70.0	70.0
Potato flour	50.0	30.0	30.0	30.0
Potato starch	50.0	-	-	-
Water	95.0	130.0	130.0	110.0
Margarine	20.0	20.0	20.0	20.0
Salt	1.5	1.5	1.5	1.5
Powder sugar	3.0	3.0	3.0	3.0
Baking powder	1.0	1.0	1.0	1.0
Xanthan gum	1.8	1.8	1.8	1.8

C: Control cracker containing the potato flour and starch, CC: Crackers containing the cowpea flour, FC: Crackers containing the faba bean flour, MC: Crackers containing the mung bean flour.

2.4 Chemical analyses

The moisture, fat, ash and protein contents of the crackers and raw materials was determined according to the AOAC methods AOAC (1990). For the calculation of protein content, a combined conversion factor of 6.25 was applied for the crackers and raw materials. The amount of insoluble and soluble dietary fiber in the crackers and raw materials were analyzed according to the AOAC 991.43 AOAC (1995) and AACC 32-07 (AACC, 1995) approaches using a total dietary fiber analysis kit (Megazyme International Ireland Ltd, Wicklow, Ireland), with the total dietary fiber content calculated as the sum of the soluble and insoluble dietary fiber contents. An inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer, Optima 2100 DV, Massachusetts, US) was used to analyze the mineral composition (P, K, Ca, Mg, Zn, Mn, Fe) of the cracker samples and raw materials, for which nitric acid and hydrogen peroxide were added to 0.5 g of the sample. The mixture was left to stand for 30 minutes, and the wet decomposition method was applied in the microwave. After the samples were burned in the microwave, they were filtered through filter paper. The mineral element concentrations in the filtrate were analyzed with an ICP-OES and expressed as mg/100 g dry weight, using the standard curves for the determination of the analyzed elements (Kumaravel and Alagusundaram, 2014; Göncü and Çelik, 2020).

The method given in detail in Bilgin et al. (2019)had been used for the preparation of the samples, and analysis of amino acid compositions. LC-MS/MS device (Agilent Infinity 1260 HPLC system, Agilent Technologies, Santa Clara, CA, USA) and Jasem LC-MS/MS amino acid kits (Sem Laboratory Devices Marketing Inc. Istanbul/ TURKEY) had been used for the analysis. Jasem's mobile phase A and B with gradient elution at a flow rate of 0.7 mL/min was used for chromatographic separation. The optimal MS detector settings were adjusted to achieve a drying gas flow of 10 L/min, a drying gas temperature of 150 °C, nebulizer pressure of 40 psi and capillary voltage of 2000 V. The amino acid values were given as mg/100 g dry weight.

2.5 Physical analyses

The surface color measurements of the samples were carried out using a Hunter Lab Mini Scan XE model colorimeter (Hunter Associates Laboratory, Reston, VA) (Reston, VA, USA). The color values were expressed as L^* (whiteness/darkness), a^* (redness/greenness) and b^* (yellowness/blueness).

The hardness characteristics of the crackers ascertained through a texture analysis were determined with a three-point bending test (TA-TPB) using the Brookfield CT3 texture analyzer (Brookfield Engineering Laboratories Inc., USA). The pre-test, test and post-test speeds and trigger loads were adjusted to 1 mm/s, 2 mm/s, 2 mm/s and 102 g respectively.

2.6 Scanning electron microscopy (SEM)

For the imaging of the crackers via scanning electron microscopy, the crackers were first freeze-dried with a lyophilizer (Savant Modulyod-230, Thermo Electron Corporation, USA) and then mounted on aluminum studs and coated with gold through a sputtering method (Quorum, Q150R ES, UK). Inner and exterior surface images of the cracker samples were taken at 200X magnification using a scanning electron microscope (FEI Quanta 250 FEG brand, Hillsboro, Oregon, USA) at a voltage of 10 kV and 6 mbar pressure.

2.7 Sensory analyses

Gluten-free cracker samples were assessed for color, odor, flavor, crispiness, chewiness and overall acceptability, and was carried out by 36 untrained panelists (20 females and 16 males; aged 18-50) with celiac disease live in Denizli. The panelists made hedonic evaluations of the samples which were coded with randomly selected three-digit numbers. For sensory evaluation, a score-card was developed on which the panelists assessed the factors on seven-point scales from 1 (dislike extremely) to 7 (like extremely) (Turk Aslan and Isik, 2022).

2.8 Statistical analyses

This statistical analysis of the obtained results was conducted using the Minitab 16.0 software statistical program (LEAD Technologies, USA). The results of all analyses were expressed as mean values and standard deviation (SD). The means were tested for significant differences using Tukey's test (multiple comparison test) with analysis of variance (ANOVA) at a 5 % significance level.

3. Results

3.1 Chemical and physical properties of raw materials

The results of the chemical composition and color property analyses of potato flour (PF), potato starch (PS), cowpea flour (CF), faba bean flour (FF) and mung bean flour (MF) are presented in Table 2, in which it can be seen that CF, FF and MF had significantly ($p < 0.05$) higher fat, ash, protein, and insoluble and total fiber contents than PF and PS. In addition, MF, FF, PF, CF had significantly ($p < 0.05$) higher soluble dietary fiber contents than PS, with statistically the same values as each other. Our results for protein, fat, dietary fiber and ash contents of raw materials were in good agreement with the literature (Misra and Kulshrestha, 2003; Yadav et al., 2006; Alghamdi, 2009; Boukar et al., 2011; Rugheim and Abdelgani, 2012; Zia-Ul-Haq et al., 2010; Dahiya et al., 2013; Antova et al., 2014; Taneya et al., 2014; Karataş et al., 2017; Naiker et al., 2019; Kamel, 2020; Zhu and He, 2020; Mayer Labba et al., 2021).

The L^* (lightness) values of PS and PF were higher ($p<0.05$) and the a^* value of PF was lower than the values of the legume flours (Table 2). PS, what L^* value was the highest, gave the lowest b^* (yellowness) value. The differences in the color characteristics of the legume, PF and PS may be attributed to differences in pigmentations, which depend in turn on their biological origin (Singh et al., 2003).

According to the results of the mineral content analysis of the raw materials, legume flours have significantly ($p < 0.05$) higher P, Ca and Zn contents than PF and PS. PF has the highest K content, while the Fe content of all raw materials have been found to be statistically the same ($p > 0.05$). Furthermore, CF recorded the highest Mg content, followed in order by MF, FF, PF and PS. The mineral content determined for the raw materials concur with those reported in literature (Boukar et al., 2011; Luis et al., 2011; Dahiya et al., 2013; Baloch et al., 2014; Gerrano et al., 2019; Koch et al., 2019; Wu et al., 2020; Mayer Labba et al., 2021).

The results of the amino acid composition analysis showed that FF had significantly ($p < 0.05$) higher total amino acid (AA), EAA and non-essential amino acids (NEAA) values than the other flours, followed by MF, CF and PF, respectively. PS, on the other hand, contains no EAA. Our amino acid results concur with those reported in literature (Adel et al., 1980; Hussain and Basahy, 1998; Bártová et al., 2015; Laleg et al., 2016).

Amino acids (AA) are the building blocks for tissue proteins and are essential substrates for the synthesis of many low molecular-weight substances (e.g., creatine, melanin), and so have enormous physiological importance (Wu, 2013). Amino acids are classified as "nonessential" or "essential" in nutrition. EAA are described as either those amino acids whose carbon skeletons cannot be synthesized, or that are inadequately synthesized de novo by the body relative to needs, and which must be taken by diet to meet optimal needs (Wu, 2009). The results of our study show that the CF, FF and MF used in gluten-free legume crackers had these kinds of amino acids in ratios 3.93, 4.52 and 4.16 times higher, respectively, than the PF used in the control gluten-free cracker. This result is promising, in that gluten-free crackers can be enriched in EAA through the use of legumes.

3.2 Effect of legumes addition on the proximate chemical compositions of crackers

The addition of CF, FF and MF to the formulations significantly ($p < 0.05$) increased the fat, ash, protein, and insoluble and total dietary fiber contents when compared to the C sample (Table 3), which can be attributed to the higher fat, ash, protein, and insoluble and total dietary fiber content of legume flours than that of PF and PS (Table 2).

Protein is a basic component of tissue and nutrition in animals and humans, with its main function being to provide the necessary amino acids for the metabolism (Abdel-Aal and Hucl, 2002; Wu, 2016). Accordingly, the consumption of crackers with high protein-content legume flours is beneficial for health. In the present study, the crackers containing legume flours were found to contain more protein than the C sample, with CC, FC and MC recording protein contents of 4.50, 5.42 and 4.39 times that of C respectively.

In a study (Boonkong, 2013) in which gluten-free crackers were produced with legume flours (soy bean, red bean, navy bean) in different proportions, the crackers containing legume flours recorded higher protein, fat, ash and fiber values than those produced with wheat flour. Kamel (2020) supplemented corn flour with defatted soybean (20 %) and chickpea (40 %) flours and reported an increase in protein content up to more than a double that of the control crackers, while the carbohydrate content was decreased. The protein content of rice flour cakes was

Table 2: Chemical compositions and color properties of raw materials.

Parameters	PS	PF	CF	FF	MF
Protein (%)§	nd	8.42±0.33^{d}	24.38±0.53^{c}	30.10±0.48^{a}	25.87±0.42^{b}
Fat (%)§	0.75±0.40^{b}	0.77±0.28^{b}	2.04±0.31^{a}	1.56±0.34^{a}	2.05±0.31^{a}
Soluble dietary fiber (%)§	0.25±0.19^{b}	3.45±1.31^{a}	3.01±0.58^{a}	3.78±0.19^{a}	4.50±1.23^{a}
Insoluble dietary fiber (%)§	0.03±0.06e	3.80±0.26^{d}	22.46±1.45^{b}	17.73±1.53^{c}	26.55±2.18^{a}
Total dietary fiber (%)§	0.28±0.20e	7.25±1.17^{d}	25.47±1.30^{b}	21.51±1.54^{c}	31.05±1.00^{a}
Ash (%)§	0.35±0.19^{d}	2.98±0.10^{c}	3.42±0.02^{b}	3.48±0.04^{ab}	3.81±0.02^{a}
Minerals (mg/100 g)§					
P	77.0±8.5^{d}	262.3±41.7^{c}	505.6±11.9^{b}	655.9±2.7a	615.7±64.1^{a}
K	47.4±13.0^{d}	1575.5±35.7a	1230.1±53.9^{c}	1540.9±50.5^{a}	1354.5±15.3^{b}
Ca	16.5±9.2^{c}	34.3±1.1^{c}	114.2±20.2^{a}	76.7±18.3^{b}	96.2±2.6^{ab}
Mg	5.6±2.4^{c}	88.8±8.5^{b}	233.4±46.6^{a}	135.8±6.4^{b}	202.8±6.2^{a}
Mn	0.0±0.0^{b}	0.2±0.1^{ab}	0.8±0.4^{a}	0.6±0.2^{ab}	0.6±0.4^{ab}
Zn	0.1±0.1^{b}	0.4±0.2^{b}	1.5±0.4^{a}	1.5±0.4^{a}	1.1±0.3^{a}
Fe	3.7±0.9^{a}	3.2±1.2^{a}	4.0±0.3^{a}	4.1±1.7^{a}	3.4±0.9^{a}
Amino acid compositions (mg/100 g)§					
NEAA					
Alanine	nd	176.1±8.4^{c}	964.4±2.9^{b}	1180.3±29.4^{a}	995.7±29.3^{b}
Arginine	68.7±3.0^{e}	329.2±15.0^{d}	1531.9±13.9^{b}	2426.1±34.5^{a}	1492.2±2.2^{bc}
Aspartic Acid	nd	2456.4±98.2^{d}	2757.0±15.7^{c}	3686.2±41.3^{a}	3136.4±19.7^{b}
Cystine	nd	nd	136.4±1.5^{a}	279.1±10.0^{b}	133.0±6.9^{b}
Glutamic Acid	13.4±1.3^{d}	1211.3±55.0^{c}	3816.2±76.1^{c}	4623.3±110.6^{a}	4114.4±18.7^{b}
Proline	nd	421.7±22.6^{c}	1016.7±6.8^{b}	1278.2±31.6^{a}	1107.7±81.0^{b}
Serine	nd	350.4±16.6^{c}	1266.5±8.4^{b}	1482.2±25.3^{a}	1275.6±20.6^{b}
Glycine	nd	nd	594.6±3.1^{b}	962.4±34.7^{a}	586.8±0.9^{b}
Taurine	nd	nd	nd	nd	nd
Ornitine	nd	nd	nd	nd	nd
Tyrosine	nd	82.4±2.9^{d}	219.8±1.3^{c}	368.7±16.9^{a}	278.1±6.0^{b}
Total of NEAA	82.1±4.3^{e}	5027.3±218.7^{d}	12303.5±33.0^{c}	16285.6±334.0^{a}	13119.9±61.0^{b}
EAA					
Lysine	nd	623.7±30.6^{d}	2145.8±27.0^{c}	2815.5±120.7^{a}	2396.1±0.8^{b}
Leucine	nd	463.5±18.3^{d}	1822.6±6.0^{c}	2205.0±134.5^{a}	1966.5±16.7^{b}
Isoleucine	nd	142.6±5.8^{d}	778.3±7.6^{c}	938.3±16.8^{a}	814.4±10.7^{b}
Histidine	nd	189.9±7.6^{c}	872.2±1.4^{a}	851.1±13.5^{ab}	829.1±16.1^{b}
Phenylalanine	nd	407.5±22.6^{d}	1316.2±2.0^{b}	1235.8±14.6^{c}	1523.3±11.6^{a}
Valine	nd	340.7±16.7^{c}	934.0±8.5^{b}	1131.3±27.4^{a}	1109.0±10.3^{a}
Threonine	nd	107.6±4.3^{d}	1085.8±5.1^{b}	1263.2±24.0^{a}	887.7±4.2^{c}
Methionine	nd	80.1±2.8^{d}	263.3±3.5^{ab}	209.2±12.1^{c}	283.6±5.3^{a}
Total of EAA	nd	2355.6±108.6^{d}	9218.2±41.0^{c}	10650.4±364^{a}	9809.7±23.0^{b}
Total of AA	82.0±4.3^{e}	7382.9±327.3^{d}	21521.7±8.0^{c}	26936.0±698^{a}	22929.6±76.0^{b}
Hunter color values					
L^*	94.51±0.08^{a}	84.14±0.21^{b}	61.49±2.50^{e}	75.20±1.45^{c}	68.20±1.11^{d}
a^*	3.60±0.02^{c}	2.85±0.06^{d}	6.78±0.32^{a}	4.63±0.43^{b}	3.74±0.10^{c}
b^*	-3.29±0.07^{d}	14.17±0.14^{b}	10.68±1.03^{c}	19.45±1.33^{a}	15.01±0.84^{b}

Different superscript within the same row differ significantly ($p < 0.05$) using Tukey multiple range test. §: in dry basis, nd: not determined, PS: Potato starch, PF: Potato flour, CF: Cowpea flour, FF: Faba bean flour, MF: Mung bean flour.

also increased through the addition of chickpea, pea, bean, and lentil flours in Gularte et al. (2012).

The consumption of legumes is increasing globally in view of their high nutritional value, and low calorie and glycemic index. They are the richest source of dietary fiber, and can help lower triglycerides and cholesterol, as leguminous fibers are hypoglycosuria, consisting of more amylose than amylopectin (Asif et al., 2013).

A generous intake of dietary fiber reduces the risk of such diseases as hypertension, coronary heart disease, obesity, diabetes, stroke and certain gastrointestinal disorders. The recommended dietary fiber intake for adults generally falls within the 20–35 g/day or 10–13 g per 1000 kcal energy intake ranges (Marlett et al., 2002). Based on the assumption that a person should consume 27.5 g of dietary fiber a day, one portion (40 g) of the CC, FC or MC produced in this study would satisfy 31.43 %, 30.36 % and 32.60 % of daily dietary fiber needs, respectively, while one portion of C can satisfy only 14.30 % of this need. In addition to this result, considering the using and dietary

Table 3: Chemical compositions and color properties of raw materials.

Parameters	C	CC	FC	MC
Protein (%)§	3.53±0.24^c	15.88±0.47^b	19.14±0.38^a	15.49±0.22^b
Fat (%)§	11.01±0.35^c	13.39±0.42^a	12.25±0.67^b	12.81±0.11^{ab}
Soluble dietary fiber (%)§	4.02±1.52^a	3.30±1.41^a	4.62±0.68^a	5.27±1.38^a
Insoluble dietary fiber (%)§	7.09±1.87^b	21.50±1.41^a	19.85±2.00^a	19.85±1.63^a
Total dietary fiber (%)§	11.11±2.51^b	24.80±2.83^a	24.47±1.53^a	25.12±2.95^a
Ash (%)§	2.36±0.50^b	3.09±0.14^{ab}	3.49±0.51^a	3.17±0.52^{ab}

Different superscript within the same row differ significantly ($p < 0.05$) using Tukey multiple range test. §: in dry basis, C: Control cracker containing the potato flour and starch, CC: Crackers containing the cowpea flour, FC: Crackers containing the faba bean flour, MC: Crackers containing the mung bean flour.

Table 4: Mineral contents of cracker samples.

Minerals (mg/100 g)§	C	CC	FC	MC
P	262.7±28.8^b	462.8±25.7^a	567.6±108.0^a	460.6±40.1^a
K	770.3±13.7^b	963.1±175.3^b	1555.5±405.0^a	1182.4±97.7^{ab}
Ca	81.0±3.4^b	112.2±2.1^{ab}	151.1±39.8^a	137.3±10.5^a
Mg	52.7±9.7^b	134.3±0.6^a	127.7±32.5^a	142.2±15.2^a
Mn	0.1±0.0^a	0.4±0.1^a	0.4±0.2^a	0.4±0.2^a
Zn	0.2±0.1^b	0.8±0.4^{ab}	1.0±0.2^a	0.7±0.3^{ab}
Fe	1.8±0.1^c	2.9±0.0^a	2.4±0.2^b	2.9±0.0^a

Different superscript within the same row differ significantly ($p < 0.05$) using Tukey multiple range test. §: in dry basis, C: Control cracker containing the potato flour and starch, CC: Crackers containing the cowpea flour, FC: Crackers containing the faba bean flour, MC: Crackers containing the mung bean flour.

fiber ratios of raw materials, it is seen that the amount of dietary fiber in crackers were higher than expected. It is thought that this was related to the conversion of starch in flours and potato starch into resistant starch due to cooking and cooling processes, and acting as dietary fiber (Yadav et al., 2009; Raatz et al., 2016; Whitney and Simsek, 2020; Too et al., 2022).

In Gularte et al. (2012), gluten-free rice cakes supplemented with pea, lentil and bean flour had a significantly ($p < 0.05$) higher total dietary fiber content than the control cake produced only with rice flour, although the chickpea supplemented cake had significantly ($p < 0.05$) lower total dietary fiber content than the control sample. In Rajiv et al. (2012), the substitution of wheat flour at a 40 % level with green gram (mung bean) flour increased the total dietary fiber to 2.3 times that of the control sample.

Legume crackers contained significantly higher amounts of all of mineral contents than C (Table 4). The FC has the highest P, K, Ca, Zn contents and the MC has the highest mg content. The Mn content of all crackers was statistically the same. In addition, CC and MC recorded the highest Fe contents.

Minerals are essential for a wide variety of metabolic and physiologic bodily functions, such as normal heart rhythm, bone health, muscle contraction, immune function, oxygen transport, nerve impulse conduction, enzyme activation, antioxidant activity, blood acid-base balance and oxidative phosphorylation(Saldamlı and Sağlam, 2007; Williams, 2005). An adult needs approximately 800 mg P, 2000 mg K, 1000 mg Ca, 370 mg mg, 10 mg Zn, 9 mg Fe and 2 mg Mn per day (Metin, 2001; Baysal, 2006).

According to our calculations, the consumption of one portion (40 g) of C, CC, FC and MC meets 11.6 %, 20.2 %, 24.2 % and 20.5 % of daily adult P needs, respectively. Other mineral calculations of C, CC, FC and MC are as follows, respectively: 13.6 %, 16.8 %, 26.5 %, and 21.1 % for K; 2.9 %, 3.9 %, 5.2 % and 4.9 % for Ca; 5.0 %, 12.7 %, 11.8 % and 13.7 % for mg; 1.8 %, 7.0 %, 6.8 % and 7.1 % for Mn; 0.7 %, 2.8 %, 3.4 % and 2.5 % for Zn; and 7.1 %, 11.2 %, 9.1 % and 11.5 % for Fe. Based on the results, the legume crackers better meet the mineral needs of consumers other than for Mn.

Similarly, in Bilgicli (2013), noodles prepared with gluten-free flour blends (chickpea, soybean, buckwheat, quinoa, maize flours) all recorded higher mineral contents than the control sample produced with wheat flour, except for Mn. The highest Ca, Cu, Fe, K, Mn, P and Zn contents were determined in gluten-free noodles obtained using a flour mixture containing 25 % each of chickpea, soy, buckwheat and quinoa flours.

The results of an amino acid composition analysis revealed that the legume crackers contained significantly ($p < 0.05$) higher amounts of EAA and total AA contents than the C sample (Table 5). The FC gave the highest EAA and total AA values. As known, amino acids are protein phosphorylation cascade, key precursors for syntheses of hormones, regulators of gene expression, cell signaling molecules and low molecular-weight nitrogenous substances, each of which has great biological importance (Wu, 2009). Humans do not have the required enzymes for the biosynthesis of EAAs, and having a higher EAA increases the protein quality of a product (Aristoy and Toldra, 2012). In this case, our results indicate that these legumes could be used in cracker formulations for the fortification of essential and total amino acid compositions within gluten-free crackers prepared with potato flour and starch. Other studies have reported increases in the amino acid content of bakery products through the addition of other legume flours.

Kamel (2020) aimed to prepare crackers with an enhanced nutritional profile through the use of chickpea and defatted soybean flours in gluten-free corn crackers, and found that the addition of legume flours to the corn cracker recipes led to an increase in EAA content. The total EAA content increased by 40.7, 44.5, 44.5 and 49.9 % with the addition of 20, 30 and 40% of chickpea flour, and 20 % defatted soybean flour, respectively, over that of the control samples. The study also reported a remarkable increase in lysine (the first limiting amino acid in cereals) content with the use of 20 % defatted soybean and 40% chickpea flour, amounting to 2.4 and 3.4 times that of control cracker, respectively.

Laleg et al. (2016) compared the structural and nutritional properties of commercial gluten-free pastas pro-

Table 5: Amino acid compositions (mg/100 g) of cracker samples.

Amino acid compositions (mg/100 g)§	C	CC	FC	MC
NEAA				
Alanine	46.5±1.4^{d}	657.2±46.3^{b}	798.6±42.8^{a}	574.6±3.1^{c}
Arginine	108.1±5.6^{c}	939.3±8.0^{b}	1384.3±19.7^{a}	945.2±71.1^{b}
Aspartic Acid	953.8±46.8^{c}	2301.4±229.2^{b}	2694.2±24.6^{a}	2439.9±20.7^{ab}
Cystine	nd	nd	137.3±102.1^{a}	nd
Glutamic Acid	609.2±12.7^{c}	2586.9±102.0^{b}	3161.2±170.7^{a}	2621.2±9.2^{b}
Proline	210.0±8.2^{c}	777.5±70.2^{b}	929.9±70.6^{a}	749.4±3.1^{b}
Serine	154.7±7.1^{c}	853.4±50.0^{b}	940.1±27.7^{a}	853.2±3.7^{b}
Glycine	nd	nd	405.3±222.2^{a}	nd
Taurine	nd	nd	nd	nd
Ornitine	nd	nd	nd	nd
Tyrosine	33.7±1.4^{b}	306.3±94.1^{a}	338.1±97.4^{a}	177.1±3.6^{ab}
Total of NEAA	2116.0±83.4^{c}	8422.0±140.8^{b}	10789.0±96.9^{a}	8360.6±88.5^{b}
EAA				
Lysine	222.0±10.3^{d}	1196.3±44.6^{c}	1415.2±63.4^{a}	1283.1±4.7^{b}
Leucine	258.0±12.5^{d}	1172.6±71.2^{b}	1356.0±23.5^{a}	1058.7±11.2^{c}
Isoleucine	38.5±2.8^{c}	443.0±32.5^{b}	534.4±38.3^{a}	419.6±9.5^{b}
Histidine	106.1±5.6^{c}	564.8±31.6^{a}	571.2±34.9^{a}	499.8±29.8^{b}
Phenylalanine	206.3±10.7^{c}	890.6±23.9^{a}	818.4±29.2^{b}	925.4±22.6^{a}
Valine	162.7±7.3^{b}	689.0±73.6^{a}	738.2±79.2^{a}	647.6±6.7^{a}
Threonine	nd	594.8±60.8^{ab}	642.4±17.8^{a}	538.7±43.8^{b}
Methionine	27.9±2.8^{c}	154.0±24.5^{a}	112.9±21.7^{b}	119.8±5.4^{ab}
Total of EAA	1021.4±52.1^{c}	5705.1±178.6^{b}	6188.7±180.3^{a}	5492.8±28.8^{b}
General Total	3137.4±135.6^{d}	14127.1±41.0^{b}	16977.7±83.0^{a}	13853.4±104.0^{c}

Different superscript within the same row differ significantly ($p < 0.05$) using Tukey multiple range test. §: in dry basis, nd: not determined, C: Control cracker containing the potato flour and starch, CC: Crackers containing the cowpea flour, FC: Crackers containing the faba bean flour, MC: Crackers containing the mung bean flour.

Table 6: The physical properties of cracker samples.

Parameters	C	CC	FC	MC
Hunter color values				
L^*	74.27±3.56^{a}	50.24±0.39^{c}	66.23±3.37^{b}	51.24±7.89^{c}
a^*	9.35±2.20^{c}	13.95±0.73^{a}	11.66±2.60^{b}	11.05±3.31^{bc}
b^*	23.88±3.27^{b}	22.08±1.75^{b}	26.52±1.68^{a}	22.43±0.62^{b}
Hardness(g)	3047.7±844.7^{a}	1177.4±215.6^{bc}	1024.6±223.1^{c}	1284.8±372.0^{b}

Different superscript within the same row differ significantly ($p < 0.05$) using Tukey multiple range test. C: Control cracker containing the potato flour and starch, CC: Crackers containing the cowpea flour, FC: Crackers containing the faba bean flour, MC: Crackers containing the mung bean flour.

duced with a mixture of rice, millet and maize flours and cane sugar syrup with those of 100 % legume flour pastas. The commercial gluten-free pasta was found to be deficient in lysine content, and 3.5, 3.4 and 3.4 times less lysine content than the black-gram, lentil and faba pastas, respectively. In the present study, CC, FC and MC had 5.4, 6.4 and 5.8 times the lysine content of the C sample, respectively, revealing that the lysine content of potato flour products can be enriched through the use of CF, FF and MF.

3.3 Effect of legumes addition on color and texture properties of crackers

Color is an important sensory characteristic that affects the consumer acceptability of food products (Machado Alencar et al., 2015). The Hunter color parameters (L^*, a^*, b^*) of crackers are given in Table 6, where it can be seen that the C cracker recorded the highest L^*, CC recorded the highest a^* and FC recorded the highest b^* values in the color analysis ($p < 0.05$). Briefly, the C sample was the lightest, CC was the reddest and FC was the yellowest. Differences in the colors of crackers are thought to be attributed to the differences in the colors of the raw materials. The results of previous studies of legume or flours used in bakery goods have also reported the colors of the products to be directly related to the original color the legume flour.

Schmelter et al. (2021) reported that the replacement of 50 % or 100 % of the wheat flour by six varieties of faba bean flour during cookie production led to cookies that were darker in color cookies when faba bean was used in the formulation. Gularte et al. (2012) reported on the baking of gluten-free cakes in which 50 % of the rice flour was supplemented with chickpea, pea, lentil and bean flours, and recorded lower L^* crumb color values than the control cake produced with rice flour. In addition, red (a^*) and yellow (b^*) hues were significantly increased through the addition of legume flour, with the exception of lentil, which did not affect a^*, and bean flour, which decreased b^*. The researchers stated that the color results were directly related to the original color of the legume flours. In Han et al. (2010), the colors of gluten-free cracker snacks produced with nine commercially available pulse fractions were also affected by the colors of the pulse flours.

The results of texture profile analysis showed that C had a higher value of hardness than the others, followed in order by MC, CC and FC. High hardness values indicate a high resistance in the product, and a high force required to break the product (Noorakmar et al., 2012). The lower hardness values of the crackers containing legume flours were thought to be associated with their lower potato starch and higher dietary fiber contents. The potato flour, and specifically the potato-origin starch content of the crackers, decreased with the addition of legume flours to C, with the changes in ingredients having had an impact on the thermal and gelatinization properties of the gluten-free products (Alvarez-Jubete et al., 2010). The decrease in hardness of crackers made with legume flours may also be related to the dilution effects of fibers on the starch-protein matrix of the crackers, which is likely to disrupt the formation of a homogeneous matrix and thus lead to a weakening of the cracker structure (Mais and Brennan, 2008).

Different results have been obtained in hardness values of the crispy products depending on the types and ratios of the raw materials used and substituted in crackers, biscuits or cookies. In Wesley et al. (2021), biscuits produced with rice and bean gluten-free formulations recorded lower hardness values than those produced with wheat flour. In Boonkong (2013), however, gluten-free legume crackers with formulations containing soy bean, red kidney bean and navy bean flours recorded higher hardness values than those prepared with wheat flour. Similarly, Aziah et al. (2012) found that the hardness values of cookies increased with the supplementation of 50 % of wheat flour with chickpea and mung bean flours.

3.4 Scanning electron microscopy (SEM)

SEM micrographs (200x) showing the surface and inner structures of cracker samples are presented in Figure 1. When the surface and inner SEM micrographs were examined, the structure of the C sample seems to be more uniform than the samples containing legume flours. The C sample, in addition, had a smooth surface with no evident cracking. The higher dietary fiber contents (Table 2 and 3), and different composition and gelatinization characteristics of raw materials led to more cracks and pores in the legume crackers than in the C sample (Wronkowska et al., 2013). Thus, a more heterogeneous image was obtained from the legume crackers than from C. These images were also associated with the hardness value (Table 3), resulting in softer crackers with more cracks and pores when legume flour was added (Rajiv et al., 2012; Ahmed and Abozed, 2015; de Miranda et al., 2019).

3.5 Sensory analysis

The results of the sensory analysis of the cracker samples are summarized in Figure 2. The sensory scores of the cracker samples were based on an evaluation of color, odor, flavor, chewiness, crispiness and overall acceptability. The color, odor and flavor scores of the crackers were statistically ($p > 0.05$) similar, while all evaluations of the chewiness, crispiness and overall acceptability of crackers containing legume flours were higher than those of C. CC scored higher than all the other samples in all sensory characteristics except color. It was concluded from the

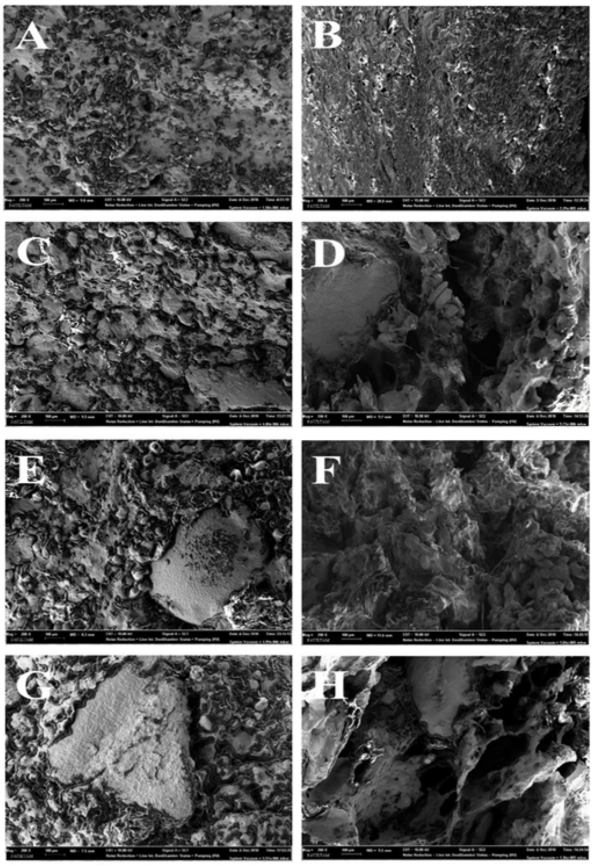

Figure 1: SEM micrographs (200x) for the surface structure of C (A), CC (C), FC (E), MC (G). SEM micrographs (200x) for inner structure of C (B), CC (D), FC (F), MC (H). C: Control cracker containing the potato flour and starch, CC: Crackers containing the cowpea flour, FC: Crackers containing the faba bean flour, MC: Crackers containing the mung bean flour.

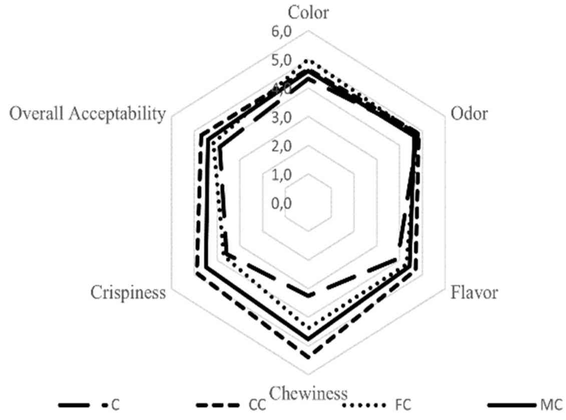

Figure 2: The sensory scores of gluten-free crackers adding the legumes flour. C: Control cracker containing the potato flour and starch, CC: Crackers containing the cowpea flour, FC: Crackers containing the faba bean flour, MC: Crackers containing the mung bean flour.

results of the sensory evaluations of gluten-free crackers that higher crispiness and chewiness scores of the crackers containing legume flours were associated with their lower hardness values (Table 6).

In a study by Kamel (2020), the sensory scores of the control cracker, produced with corn and potato flours, were higher than those of the gluten-free corn crackers produced with defatted soybean and chickpea flours. In the same study, the cracker supplemented with defatted soybean flour recorded statistically similar results in terms of appearance, color, texture, taste, crispiness and total score with the control sample.

In the study by Han et al. (2010) in which gluten-free cracker snacks were produced with nine pulse fractions (chickpea, green and red lentil, yellow pea, pinto and navy bean flours and pea protein, starch and fiber isolates), the overall acceptability scores ranged from 4.3/9.0 (pinto bean) to 5.9/9.0 (pea protein isolate) in the sensory evaluation. The panelists in the study were asked to indicate their most preferred sample, and while no outstanding "winner" was clearly evident, the cracker containing pea protein garnered 25 % of the most preferred scores. In Millar et al. (2017) in which 40 % of wheat flour was supplemented with faba bean, yellow pea and green pea during cracker production, the yellow pea and faba bean crackers were more frequently preferred by consumers over the control, to a significant degree, demonstrating the potential application of these flours to improve the eating quality and nutritional profile of crackers.

4. Conclusions

In this study, the potential use of legumes instead of potato flour and starch in gluten-free crackers has been investigated, and their chemical, physical and sensory characteristics have been determined. The addition of legume flours to cracker formulations led to significant ($p < 0.05$) increases in protein, fat, insoluble and total dietary fiber, EAA, NEAA and all mineral contents, and a significantly softer texture. According to the sensory evaluation made by a panel of people with celiac disease, the flavor, chewiness, crispiness and overall acceptability scores of the legume crackers were higher than those of the C sample. The cowpea flour crackers recorded the highest overall acceptability score, followed by those made with mung bean flour, faba bean flour and the control cracker. The results of our study demonstrate that legume flours can feasibly be used as ingredients in the production of high quality and healthy gluten-free crackers.

5. Fundindg statement

This study was funded by Pamukkale University, Unit of Scientific Research Projects (BAP), Turkey (Project No:2018FEBE016).

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