Triticale crisp bread enriched with selected bioactive additives: volatile profile, physical characteristics, sensory and nutritional properties

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Abstract The effect of selected plant additives (couch grass, artichoke, kale, nettle, ground buckwheat husks, broad beans, fenugreek seeds, and extracts of yellow tea and mulberry leaf) on the volatile compounds, color, texture, sensory attributes, polyphenols, and antioxidant properties of triticale crisp bread was studied. The volatile profile of control bread was dominated by lipid oxidation products with hexanal and (E)-2-nonenal predominant. The additives strongly modified the volatile profile of the extruded crisp bread. The greatest differences were recorded in the case of products with artichoke and kale additions, which had respectively about 12 and 8 times higher levels of total volatile compounds than the control crisp bread. The samples containing kale, buckwheat, and fenugreek as well as yellow tea extract characterized high levels of sulfur compounds, with methanethiol predominant. The additives, especially kale, nettle, and artichoke affected the color of the crisp breads, in most cases making them darker. In terms of texture only the crisp bread with addition of buckwheat husk was significantly harder than the control sample. On the basis of sensory evaluation it was stated that among all the additives, the artichoke and fenugreek resulted in dramatic deterioration in the extruded

product taste. The used additives also affected the antioxidant properties of triticale crisp bread. The greatest content of total phenolic compounds and the highest antioxidant activity were observed for the bread with yellow tea extract addition (3.5- and 6.5-fold higher, respectively, than in control sample).

Keywords Crisp bread · Volatile compounds · Sensory properties · Antioxidant activity

Introduction

In recent years, many studies of prohealth properties of various plants have been conducted. There are many plants that are rich in antioxidants and other substances with proven prohealth effects for various diseases. One such plant is couch grass (*Agropyron repens*), the extract of which is widely consumed to treat nephritis, urethritis, and urinary calculi. It is thought to exert antimicrobial properties, which may be responsible for its protective effect (Gürocak and Küpeli 2006). Another plant with bioactive properties is nettle (*Urtica dioica*), which is used to treat inflammatory disorders such as osteoarthritis (Johnson et al. 2013). Artichoke (*Cynara cardunculus*) is one of the richest dietary sources of polyphenols with high bioavailability, and it also contains high-quality inulin, fiber, and minerals. Moreover, pharmaceutical artichoke leaf extracts show hypocholesterolemic and choleretic properties (Lattanzio et al. 2009). Kale (*Brassica oleracea*) is a plant with high concentrations of vitamins, minerals, dietary fiber, and antioxidants. The concentration of total polyphenols and flavonoids in kale exceeds that of all other vegetables, including onions, green beans, spinach, broccoli, and leeks (Korus and Lisiewska 2011). Many types of pulses,

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including broad beans (*Vicia faba* L.), have been reported to contain high levels of health-promoting components. Due to their chemical composition, broad beans are a suitable food for diabetics and may help prevent heart disease and reduce blood glucose levels (Gumienna et al. 2006). Fenugreek (*Trigonella foenum-graecum* L.) is also a source of many prohealth substances, and is known to exhibit several pharmacological effects, including hypoglycemic, hypocholesterolemic, gastroprotective, chemopreventive, antioxidant, anti-inflammatory, antipyretic, laxative, and appetite-stimulation attributes (Naidu et al. 2011). Buckwheat (*Fagopyrum esculentum*) is a rich source of dietary fiber, flavonoids, and fagopyrins. Rutin and other flavonoids it contains antagonize capillary fragility, decrease the permeability of blood vessels, and reduce the risk of arteriosclerosis (Zhan-Lu et al. 2012). Buckwheat products, such as the hull and bran, may serve as raw materials for the development and production of functional foods (Krkoskova and Mrazova 2005).

Another plant with therapeutic applications is mulberry (*Morus species*), the ethanolic extract of whose leaves show good hypoglycemic and hypolipidemic effects in alloxan-induced diabetic rats (Kumar et al. 2010). In Thailand, beverages containing mulberry leaves are used to promote good health, especially for diabetics (Andallu et al. 2014).

A plant showing particularly high antioxidant potential is tea (*Camellia sinensis*). Its extracts have been the topic of many studies; they are the best dietary sources of catechins (such as epigallocatechin gallate). The most important flavonols in tea are quercetin, kaempferol, and rutin. It contains also phenolic acids—mainly caffeic, quinic, and gallic acids (Dufresne and Farnworth 2001).

The addition of components with bioactive properties and high antioxidant potential to conventional products makes it possible to produce foods with programmed health-promoting properties. A matrix for such additives may be provided by cereal products, particularly wholemeal products, which are recommended for regular consumption (Dziki et al. 2014). Crisp bread is a commonly consumed product made from wholemeal flour. It may be produced using traditional methods or by extrusion. During extrusion, the raw material is subjected to high pressure and temperatures, but the exposure period is very short, and it may be expected that more advances in the process would avoid deterioration of the bioactive properties of bioactive additives. In fact, the extrusion process has been proven to increase consumer acceptance of certain food products by developing desirable flavors (Majcher and Jeleń 2007).

From the consumers' point of view, the health-promoting value of a given product, as well as its sensory attractiveness, are important aspects. For this reason, the

aim of the study was to determine the effect of couch grass, nettle, artichoke, kale, broad beans, fenugreek seeds, buckwheat hulls, mulberry, and tea extracts on the volatile compounds, color, texture, sensory attributes, polyphenols, and antioxidant properties of triticale crisp bread.

Materials and methods

Materials

The raw material for the experiment was triticale grits made by chopping hulled triticale grain (cv. Leontino).

The bioactive components used were all freeze-dried, ground plant additives: couch grass, nettle, artichoke, kale, broad beans, fenugreek seeds, buckwheat hulls, and the dried water extracts of mulberry and yellow tea leaves.

Due to the higher concentration of polyphenolic compounds in the plant extracts than in the plant tissues, 50 g kg⁻¹ of leaf, seed or rhizome and 10 g kg⁻¹ of extract were used as additives in the current study. All bioactive components were ground and sieved (350 µm). In the first step, the bioactive additives were mixed with some triticale grits in the ratio 1:10. Next, the premixes were blended for 10 min with the remaining part of the triticale grits in a mixer, and directly transported to an extruder. All samples received 10 g kg⁻¹ of salt (NaCl).

The control sample was a crisp bread made from triticale grits without any bioactive additives.

Extrusion-cooking of crisp bread

The crisp bread was produced in a Cleextral BC-45 corotating twin screw extruder (Cleextral, Firminy, France). The retention time of the material passing through the extruder was about 30 s. The temperature of the process in successive barrels of extruder was 130–180 °C (the temperatures of the first zone, the second zone, and the head were 130, 180, and 180 °C, respectively). The screw diameter was 55 mm, and the extruder's efficiency was 200 kg per hour; the speed of rotation was 68 rpm. In order to calibrate the extruder, 20 kg of triticale grits was first extruded. After conditions had stabilized, the samples with the additions were extruded.

Immediately after leaving the extruder nozzle, the hot product was calibrated between two rolls and cut into pieces (50 × 120 × 5 mm) by a molding machine.

Volatile compound analysis

Extraction of the aromatic compounds from the crisp bread samples followed the procedure of Peres et al. (2013), with some modifications. For the extraction of the volatiles,

each bread sample was frozen in liquid nitrogen and mechanically ground. Next, the samples were placed in 20 mL vials at 9 grams each, and at the same time, an internal standard, ($^2\text{H}_6$)-phenol, was added to the final concentration of 200 ppb. The vials were then capped and placed in a 50 °C heating block for 10 min to equilibrate; the septum was then pierced with a SPME needle (Supelco, Bellefonte, PA, USA). The fiber was exposed to the headspace of the sample for 45 min and, after the extraction time, it was retracted into a needle and transferred immediately to the injection port of a gas chromatograph and desorbed at 260 °C for 5 min. CAR/PDMS/DVB fiber was used for the extraction analysis; this was conditioned prior to extraction, according to the producer's requirements.

The compounds were identified using the GC $\times$ GC system (Pegasus IV, LECO, St. Joseph, IL, USA) equipped with a DB-5MS (25 m $\times$ 0.2 mm $\times$ 0.33 μm) column (Agilent J&W, USA) coupled to a Supelcowax-10 (1 m $\times$ 0.1 mm $\times$ 0.1 μm) column (Supelco, Bellefonte, PA, USA) running in comprehensive multidimensional gas chromatography mode. The injector temperature was set at 260 °C. During the injection, the fiber was exposed for 5 min in splitless mode (1 min purge time). The operating conditions were as follows: helium flow 0.8 cm³ min⁻¹, initial oven temperature 40 °C (1 min), then 15 °C min⁻¹ to 250 °C (2 min). The GC $\times$ GC/TOFMS transfer line was kept at 260 °C. Mass spectra were collected in electron ionization mode with an ion source temperature of 220 °C, mass range m/z 33–330, acquisition rate of 150 scans s⁻¹, and a detector voltage of 1750 V. Volatiles were identified by comparing mass spectra of eluting compounds to those of the NIST 05 library match. The calculations were performed using Chroma TOF software (version 3.34). Each compound, presented as an average of three replicates, was quantified in relation to the internal standard, ($^2\text{H}_6$)-phenol, using characteristic ions.

Physical characteristic of crisp breads

Color measurement

The color of the crisp breads was measured using a Chroma Meter CR-410 (Konica Minolta Sensing Inc., Osaka, Japan) color meter in the CIE L*a*b* scale.

The total change in color, ΔE^* , was calculated according to the following formula:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

where ΔL , Δa^* , Δb^* are the differences between the coordinate values of the control bread sample and the bread with specific addition, respectively.

Texture analysis

The mechanical properties of the crisp bread samples were determined using the three-point bending test using a TA.XT plus texture analyzer (Stable Micro Systems, Surrey, UK) equipped with a 50-kg load cell. The experimental conditions for the breaking-strength tests were as follows.

Test speed 3.0 mm s⁻¹, distance 5 mm, trigger force 50 g, and support distance 50 mm. The rupture stress σ of the crisp bread bars was derived from the maximum force at rupture F and calculated according to:

$$\sigma = F \frac{3L}{2e^2W}, \quad (2)$$

where W is the width of the snack (50 mm), L the distance between the supports (50 mm), and e the thickness of the snack (5 mm).

Consumer analysis

The crisp breads were evaluated using consumer traits by a panel of 105 people aged 21–27. Women constituted 68% of the consumer group. The investigations were conducted in an appropriately designed and equipped sensory analysis laboratory. The participants were consumers of crisp breads, as confirmed by a demographic questionnaire including product usage questions. Participants were asked not to drink or eat anything for at least 1 h prior to testing. The panel members evaluated color, aroma, taste, texture, and overall desirability of all the types of crisp bread on 10 cm line acceptance scales with the margin denotations of *undesirable* and *highly desirable* (Hein et al. 2008). The scales were divided into 10 segments. Participants started with evaluating 5 crisp breads and, after a 45-min interval, continued tasting the next five kinds of samples. All the crisp breads were served as small pieces on plates coded with random three digit numbers. Tap water was used in between to remove the effect of the previous product from the tongue.

Nutritional characteristics

The total phenolic compound (TPC) level was measured using the Folin–Ciocalteu method, as described by Singleton and Rossi (1965).

Ground dry material (500 mg) was weighed into test tubes and 10.0 mL of solvent (70% aqueous acetone) was added. Tubes were shaken for 60 min and centrifuged for 10 min, and the clear supernatant was collected. The procedure was repeated. Supernatants were combined and added with solvent to reach a final volume of 25 mL.

Extracts (0.5 mL, triplicate) were introduced into test tubes; 2.5 mL of the Folin–Ciocalteu reagent (2 M F–C reagent: water, 1:9) and 2.0 mL of sodium carbonate (7.5%) were added. The tubes were shaken and left for 60 min. Absorption at 765 nm was measured (UV–vis spectrophotometer). The total phenolic content was expressed as gallic acid equivalents (GAE) in μg per gram of dry material. The antioxidant activity (AA) of the extracts was determined according to Re et al. (1999). ABTS radical cations were produced by reacting water solutions of ABTS (7 mM) with potassium persulfate (2.45 mM), 1:1. The mixture was left in the dark at room temperature for 16 h before use, and then diluted in ethanol to an absorbance of 0.70 (± 0.02) at 734 nm. The ethanol solution of the ABTS radical cation was introduced into test tubes and 30 μL solutions of phenolic extracts, blank solution, or Trolox standard in ethanol was added. Absorption at 734 nm after 20 min was measured using a UV–vis spectrophotometer. The inhibition of absorbance was calculated as a function of the concentration of antioxidants and expressed as Trolox (TOX) in μM per gram of dry material.

Statistical analysis

All experiments were performed in triplicate. Significant differences between samples were calculated using the Statistica 10.0 PL software (StatSoft, Tulsa, OK, USA) at a significance level of $P < 0.05$. Analysis of variance (ANOVA) with the Duncan test was performed to determine the differences. The Tukey test was used to test any significant differences in consumer evaluation. Additionally, principal component analysis (PCA) was carried out in order to simplify the results and to discriminate between the crisp bread samples. On the basis of the PCA plots, correlations between the investigated characteristics were demonstrated.

Results and discussion

Volatile compound analysis

Several volatile components that contribute to the aroma profile of flat breads were determined using SPME-GC $\times$ GC/TOFMS and are listed in Table 1. These compounds included sulfur compounds, aldehydes, alcohols, and ketones. In terms of flavor, the extrusion process causes chemical degradation through oxidation, hydrolysis, and other reactions occurring inside the barrel, as well as volatile component flush off (Arêas et al. 2016; Ho and Riha Iii 2005). Thus, most of identified components represented groups of characteristic volatiles produced

through lipid peroxidation, the Maillard reaction, and caramelization. However, according to Mauron (1981), the flavor formation in heat-treated food is often associated with the Maillard reaction, and further interactions between the Maillard reaction and lipid degradation products.

The volatile profile of control sample was dominated by carbonyl compounds with hexanal and (*E*)-2-nonenal predominant. Those compounds contributed to nearly 63% of the total amount of volatiles, and may have been formed during lipid peroxidation at the beginning of the heating process (Hansen and Schieberle 2005). However, according to Heydanek and McGorin (1981), it is also possible that some aldehydes are products of reducing sugar and amino acid interaction. Significant levels of 1-octen-3-ol were also noted ($192 \mu\text{g kg}^{-1}$). That compound, a product of the oxidation of linoleic acid (Grosch 1987), gives a mushroom-like flavor. The control sample was also characterized by a slight level of sulfur compounds ($25 \mu\text{g kg}^{-1}$). Volatile sulfur compounds occur either naturally in foods or are a result of processing or storage conditions. Even small concentrations of these substances may play a key role in the aroma of the product, as a result of their low odor detection thresholds (Belitz et al. 2004).

The additives used here resulted in changes in the volatile profile of the extruded crisp breads. Although the control crisp bread and bread with the addition of broad bean flour showed similar levels of volatiles, there are significant differences in the concentrations of particular components. Generally, the levels of methional, methanethiol, (*E,E*)-2,4-decadienal, and 1-octen-3-ol increased by factors of 10, 4, 2, and 2 compared with the control, respectively, while in turn the level of 2-(*E*)-nonenal significantly decreased (a factor of 2) with the addition of broad bean flour. The other additives strongly modified the volatile profile. The greatest differences were recorded in the case of artichoke flour and kale flour, which had respectively about 12 and 8 times higher levels of total volatile compounds than the control crisp bread. The kale-formulated bread was characterized by about 216 times more sulfur compounds, with methanethiol ($755 \mu\text{g kg}^{-1}$) and dimethyl disulfide ($3395 \mu\text{g kg}^{-1}$) predominant. High levels of methanethiol were also identified in samples with buckwheat ($165 \mu\text{g kg}^{-1}$) and fenugreek ($102 \mu\text{g kg}^{-1}$) flours and with yellow tea extract ($55 \mu\text{g kg}^{-1}$). During cooking, the Maillard reaction is a major route to sulfur aroma compounds. Methanethiol and dimethyl disulfide are formed during the heating of food from Strecker degradation of the amino acid methionine (Belitz et al. 2004).

Dimethyl trisulfide was detected in the products with the kale addition ($1072 \mu\text{g kg}^{-1}$), but was absent from the other samples. Dimethyl trisulfide with its cabbage-like flavor is formed indirectly in the Strecker degradation of methionine through methional and dimethyl disulfide

Table 1 Contents of volatile compounds in triticate crisp bread enriched with bioactive additives

Volatile compound	Ion	Control	Couch grass	Nettle	Artichoke	Kale	Broad bean	Fenugreek	Buckwheat	Mulberry	Yellow tea
Sulphur											
Methanethiol	47	2.5 ± 0.4 ^a	16.7 ± 3.1 ^c	9.7 ± 0.7 ^b	2.4 ± 0.3 ^a	755 ± 24.5 ^g	11.3 ± 1.1 ^b	102 ± 10.5 ^e	165 ± 14 ^f	2.5 ± 0.3 ^a	55.4 ± 5.4 ^d
Dimethyl disulfide	94	15.5 ± 2.1 ^{ab}	31.7 ± 4.8 ^c	35.3 ± 3.6 ^{cd}	13.2 ± 1.3 ^a	3395 ± 65 ^f	21.7 ± 3.4 ^b	44.5 ± 5.2 ^d	49.2 ± 5.2 ^d	60.8 ± 5.4 ^e	35.9 ± 4.3 ^{cd}
Dimethyl trisulfide	126	nd	nd	nd	nd	1072 ± 37	nd	nd	nd	nd	nd
Dimethyl sulfide	62	5.2 ± 0.5 ^{bc}	12.2 ± 2.5 ^d	11.3 ± 0.9 ^d	7.5 ± 0.6 ^c	122 ± 9.8 ^e	3.7 ± 0.4 ^b	2.1 ± 0.3 ^a	7.9 ± 0.7 ^c	7.8 ± 0.6 ^c	7.0 ± 0.9 ^c
2,2-methional	104	1.5 ± 0.3 ^{ab}	40.5 ± 3.8 ^e	1.4 ± 0.2 ^a	0.8 ± 0.1 ^a	3.2 ± 0.4 ^b	15.4 ± 2.2 ^d	nd	9.7 ± 0.7 ^{cd}	3.0 ± 0.3 ^b	nd
Aldehydes											
2-methylbutanal	58	111 ± 12.3 ^b	238 ± 15.1 ^d	273 ± 19.8 ^d	139 ± 12 ^c	292 ± 18.4 ^d	137 ± 12.5 ^c	101 ± 9.2 ^b	391 ± 28 ^e	264.3 ± 18.9 ^d	61.3 ± 7.4 ^a
3-methylbutanal	58	93 ± 8.4 ^a	385 ± 18.8 ^d	210 ± 18.4 ^{bc}	114 ± 10 ^{ab}	175 ± 16.5 ^b	105 ± 8.7 ^{ab}	79.6 ± 8.5 ^a	315 ± 21 ^d	191.1 ± 17.4 ^b	84.1 ± 9.1 ^a
2-methylpropanal	72	46.7 ± 5.1 ^a	199 ± 9.1 ^c	77.8 ± 8.1 ^b	50.8 ± 7.4 ^{ab}	134 ± 14.4 ^{cd}	44.8 ± 4.6 ^a	39.8 ± 4.5 ^a	158 ± 14 ^{de}	112.5 ± 11.2 ^c	45.7 ± 5.6 ^a
Hexanal	57	779 ± 45 ^{ab}	976 ± 37.2 ^c	1329 ± 69 ^d	2752 ± 76 ^f	1885 ± 42 ^e	722 ± 28.8 ^a	1875 ± 33 ^e	1507 ± 34 ^{de}	1636 ± 39.7 ^e	1280 ± 28 ^{cd}
Pentanal	57	75 ± 6 ^a	155 ± 17 ^b	197 ± 17 ^{bc}	409 ± 30 ^e	301 ± 19.8 ^d	79 ± 7 ^a	222 ± 19.7 ^c	193 ± 18 ^{bc}	294.9 ± 15.4 ^d	150 ± 14.2 ^b
(E)-2-nonenal	70	277 ± 19 ^d	124 ± 10 ^a	127 ± 9 ^{ab}	278 ± 22 ^d	182 ± 18.3 ^c	137 ± 10 ^{bc}	120 ± 12.8 ^a	177 ± 17 ^c	158.1 ± 14.9 ^c	102 ± 9.2 ^a
(E,E)-2,4-decadienal	81	14.3 ± 1.8 ^a	39.5 ± 3.9 ^b	50.6 ± 6.3 ^c	121.6 ± 10.5 ^d	60.4 ± 5.4 ^c	30.9 ± 3.4 ^b	63.8 ± 7.5 ^c	52.0 ± 4.8 ^c	99.4 ± 8.9 ^d	41.9 ± 5.9 ^{bc}
Others											
1-octen-3-ol	57	192 ± 11 ^a	368 ± 22 ^b	3710 ± 80 ^g	13,176 ± 109 ^h	3223 ± 98 ^f	307 ± 18 ^b	664 ± 22 ^c	1017 ± 38 ^d	2050 ± 61 ^e	623 ± 21 ^c
1-octen-3-one	70	61.2 ± 5.9 ^a	168 ± 17 ^c	398 ± 16 ^d	3160 ± 78 ^f	2113 ± 52 ^e	70.2 ± 7.1 ^{ab}	91.2 ± 8.7 ^b	153 ± 14 ^c	472 ± 19 ^d	101 ± 12 ^{bc}
2-ethyl-3,5-dimethylpyrazine	135	5.6 ± 0.6 ^b	28.1 ± 3.3 ^d	6.9 ± 0.5 ^b	4.9 ± 0.5 ^b	25.4 ± 3.0 ^d	5.6 ± 0.7 ^b	6.5 ± 0.5 ^b	21.3 ± 3.1 ^{cd}	15.2 ± 2.1 ^c	1.5 ± 0.2 ^a

Each point corresponds to the average value ± standard deviation. Different letters for each column indicate significant differences ($P < 0.05$)

nd not detected

(Belitz et al. 2004). In turn, the addition of artichoke flour led to a 65-fold increase in the contents of 1-octen-3-ol and 1-octen-3-one and an over 5.5-fold and 3.5-fold increase in pentanal and hexanal contents. Similarly, the addition of mulberry extract produced bread with about 10 times higher levels of 1-octen-3-ol and 1-octen-3-one. The nettle-formulated crisp bread was characterized by about 4 times higher levels of volatiles with 1-octen-3-ol and hexanal being predominant (78% of total amount of volatiles). The other additives caused about 3-fold (in the case of mulberry extract and buckwheat hull flour) and 2-fold (yellow tea extract, fenugreek flour and couch grass flour) increases in the total amount of volatiles compared to the control samples. The couch grass flour addition to crisp bread produced significantly higher levels (3-fold) of 3-methylbutanal and 2-methylpropanal. 3-methylbutanal is generated by Strecker degradation of leucine (Belitz et al. 2004); it can therefore be assumed that it was formed in a similar way in the extruded bread.

Physical characteristic of crisp bread

Crisp bread color

The additives affected the color of the crisp breads (Table 2), in most cases making them darker (lower values of coordinate L*). Only the addition of fenugreek and broad bean flour had no effect on this attribute. The greatest darkening of the product was recorded for the artichoke, nettle, and kale additions.

The values of coordinate a* for the analyzed samples ranged from −3.7 (crisp bread with the addition of kale) to 3.7 (crisp bread with the addition of yellow tea extract). The addition of buckwheat husk resulted in a decrease in b* values. In contrast, other additives led to an increase in

this. The greatest differences were observed in the case of the kale addition. Color differences (ΔE) were calculated based on the recorded values. It is assumed that an inexperienced observer can notice the difference between two products if the color difference (ΔE) is greater than 3.5 (Mokrzycki and Tatol 2011). On basis of this, we can state that the addition of broad bean flour, yellow tea extract, or fenugreek seeds does not change the color of these products in a perceptible manner. A significant difference was caused by the addition of dried kale, nettle, and artichoke.

Crisp bread texture

The addition of buckwheat hulls resulted in an increased hardness of the triticale crisp bread (20% harder than the control sample) (Table 2). This may have been caused by the high proportion of the insoluble fiber fraction. It is well known that fiber increases the hardness of extruded products as a result of its effect on cell thickness (Robin et al. 2011). No statistically significant effect of other additives on the rupture stress of the samples was observed, and only a slight effect in terms of an increase in the strength properties of crisp breads was found in the case of the couch grass, nettle, artichoke, and kale additions; the reason for this may be connected with the relatively lower starch content in the product as a result of the substitution of a portion of the cereal material with the bioactive addition. Stojceska et al. (2008) indicated that there was a negative correlation between the level of starch in samples and the hardness of extrudates. The texture of extrudates may have been affected not only by the amount of dietary fiber, but also by its composition and origin. Similarly, the addition of broad bean flour caused no changes in the texture parameters of crisp bread. This is consistent with the results of a study that showed that an addition of beans

Table 2 Color and hardness of triticale crisp bread enriched with bioactive additives

Sample (addition)	Color coordinates			Delta E	Rupture stress (MPa)
	L*	a*	b*		
Control	76.0 ± 0.8 ^{fg}	2.7 ± 0.2 ^{de}	16.7 ± 0.0 ^b	0	2.69 ± 0.31 ^a
Couch grass	73.8 ± 0.1 ^d	0.0 ^g	18.9 ± 0.2 ^f	3.1	3.08 ± 0.36 ^{ab}
Nettle	67.8 ± 0.6 ^b	−0.7 ± 0.1 ^b	18.8 ± 0.1 ^f	9.1	3.19 ± 0.43 ^{ab}
Artichoke	66.4 ± 0.1 ^a	1.7 ± 0.0 ^c	18.0 ± 0.1 ^d	9.7	3.01 ± 0.38 ^{ab}
Kale	69.7 ± 0.4 ^c	−3.7 ± 0.2 ^a	26.4 ± 0.2 ^h	13.2	2.95 ± 0.44 ^{ab}
Broad bean seed	75.4 ± 0.3 ^f	2.9 ± 0.1 ^{ef}	17.4 ± 0.4 ^c	0.9	2.85 ± 0.28 ^{ab}
Fenugreek seed	77.0 ± 0.4 ^g	2.4 ± 0.1 ^d	18.6 ± 0.0 ^e	2.1	2.57 ± 0.30 ^a
Buckwheat hull	70.7 ± 0.4 ^c	3.0 ± 0.0 ^f	15.4 ± 0.1 ^a	5.5	3.24 ± 0.30 ^b
Mulberry extract	73.8 ± 0.4 ^d	2.9 ± 0.1 ^{ef}	20.3 ± 0.5 ^g	4.2	2.48 ± 0.33 ^a
YellowTea extract	74.9 ± 0.1 ^c	3.7 ± 0.1 ^h	18.2 ± 0.2 ^d	2.1	2.39 ± 0.31 ^a

Each point corresponds to the average value ± standard deviation. Different letters for each column indicate significant differences ($P < 0.05$)

at levels below 15% does not have any observable influence on the hardness of extrudates (Anton et al. 2009).

Consumer analysis

Since all the additions, to a lesser or greater degree, altered attributes that might affect consumer acceptance of the crisp breads, the study included a consumer evaluation of the products (Table 3). The overall desirability of the crisp breads was variable. The highest scores were obtained by the breads with mulberry extract, couch grass, broad beans, yellow tea extract, nettle, buckwheat husks, and for the control sample; lower scores were for the kale and fenugreek seed and the lowest was for artichoke. No statistically significant changes in the odor, color, or texture scores for the samples with bioactive additives were observed. The addition of couch grass, nettle, broad beans, buckwheat husks, and yellow tea extract did not change the taste desirability from that of the control crisp bread. The addition of the mulberry extract even resulted in the crisp bread receiving maximum scores on all evaluated parameters. Products with fenugreek seed and artichoke additives had significantly lower taste evaluation, and the crisp breads with these additives were disqualified due to the pungent, astringent, and bitter taste. Gamlath and Ravindran (2009) added fenugreek to extruded snacks and showed that this addition should not be used at levels above 20 g kg⁻¹ due to the bitter aftertaste of the product. However, Hooda and Jood (2005) produced good quality biscuits with fenugreek additions as high as 100 g kg⁻¹. The bitterness present in conventional extracts of fenugreek typically comes from the hydrolytic breakdown of lipids present in the fixed oil fraction. In the case of the artichoke addition, the bitter taste observed was probably

caused by the presence of sesquiterpene lactones, mainly cynaropicrin (Menin et al. 2012).

Prior to investigating the nutritional properties of the samples, principal component analysis was carried out (Fig. 1). The two dimensions explained 65.63% of the total variance in the data. The descriptors that were highly correlated to the factors were taste, odor, color, and some volatile compounds (long vectors, Fig. 1a). No correlation between mechanical properties (texture or rupture stress) and the factors was found (short vectors, Fig. 1a). On the basis of the relative positions of the vectors, the correlations between characteristics were determined. Strong positive correlation between scores for color in the sensory analysis and the a* values was noted (the vectors of color and a* are close to each other), while no correlations were found between color, and L*, and b*. Taste and volatile sulfur compounds (dimethyl sulfide, dimethyl disulfide, dimethyl trisulfide, and methanethiol), as well as taste and odor, were not correlated (the vectors were orthogonal to each other). The odor scores and levels of volatile sulfur compounds (dimethyl sulfide, dimethyl disulfide, dimethyl trisulfide, and methanethiol) were inversely correlated (the vectors were located on opposite sides of the plot). It can be said that the low odor scores resulted from high concentrations of sulfur compounds.

Principal component analysis allows objects to be grouped into clusters. Samples that are most similar belong to the same cluster, and are positioned close to each other on the chart (plot 1B). The farther away the points are, the more different the samples are. The control sample of crisp bread and the crisp breads with the addition of yellow tea extract, broad beans, fenugreek, mulberry extracts, nettle, buckwheat hulls, and couch grass differed slightly from the control sample. The samples with artichoke and kale were significantly different.

Table 3 Consumer evaluation results of triticale crisp breads enriched with different bioactive additives

Sample (addition)	Odour	Colour	Taste	Texture	Overall desirability
Control	9.5 ± 0.6 ^a	9.5 ± 1.4 ^a	9.5 ± 1.2 ^c	9.0 ± 1.7 ^a	9.0 ± 1.2 ^d
Couch grass	9.5 ± 2.0 ^a	9.5 ± 2.4 ^a	9.5 ± 2.0 ^c	9.5 ± 2.6 ^a	9.5 ± 1.5 ^d
Nettle	9.0 ± 2.5 ^a	8.0 ± 3.8 ^a	9.5 ± 2.0 ^c	8.5 ± 2.0 ^a	9.2 ± 1.1 ^d
Artichoke	9.0 ± 2.2 ^a	9.0 ± 1.9 ^a	3.5 ± 1.3 ^{a*}	9.0 ± 1.3 ^a	3.0 ± 1.7 ^a
Kale	8.0 ± 2.3 ^a	7.0 ± 2.8 ^a	8.0 ± 2.5 ^{b**}	9.5 ± 0.5 ^a	8.2 ± 1.8 ^c
Broad bean seed	9.5 ± 1.3 ^a	9.5 ± 1.9 ^a	9.5 ± 1.1 ^c	9.5 ± 0.5 ^a	9.5 ± 0.9 ^d
Fenugreek seed	9.5 ± 2.2 ^a	9.5 ± 2.0 ^a	6.0 ± 2.4 ^{b*}	9.5 ± 0.5 ^a	6.4 ± 2.0 ^b
Buckwheat hull	9.0 ± 1.9 ^a	9.0 ± 1.5 ^a	9.0 ± 1.4 ^c	9.5 ± 0.5 ^a	9.0 ± 1.1 ^d
Mulberry extract	10 ± 0.8 ^a	10 ± 0.9 ^a	10 ± 1.2 ^c	10 ± 0.5 ^a	10 ± 0.3 ^d
Yellow tea extract	9.5 ± 0.8 ^a	9.5 ± 2.0 ^a	9.5 ± 0.9 ^c	9.5 ± 0.5 ^a	9.4 ± 1.2 ^d

Each point corresponds to the average value ± standard deviation. Different letters for each column indicate significant differences ($P < 0.05$)

* Bitter taste

** Grassy taste

Fig. 1 The results of PCA. **a** A loadings plot showing the relationship between analyzed descriptors of crisp bread. **b** A score plot showing the relationship between crisp bread samples enriched with different bioactive additives

Nutritional characteristics

In the final stage of the study, the crisp breads were analyzed for their phenolic compound levels (Fig. 2) and their antioxidant activity (Fig. 3). The analysis was conducted only on those products that received positive scores in the sensory examination.

It was found that TPC values in the crisp bread with the buckwheat hulls and the mulberry extract were the same as in the control bread, but the antioxidant activity was higher. The addition of couch grass and broad beans modified the TPC values to a relatively limited extent. The greatest increase in the levels of phenolic compounds and antioxidant activity was recorded in the crisp bread with the addition of yellow tea extract (which showed a 3.5-fold

increase in TPC content and 6.5-fold increase in anti-oxidant activity compared to the control). The addition of nettle and kale resulted in respectively a 68 and 50% increase in the levels of phenolics; however, the observed increase in antioxidant activity was not similar to the increase in TPC. A number of studies have been conducted to determine effects of the extrusion process on phenolic compounds and antioxidant activity of extrudates (Brennan et al. 2011; Sharma et al. 2012; Stojceska et al. 2009); these studies indicate that the TPC and TAA either increased in the extrudates, because of Maillard reaction products that form at high temperatures and act as antioxidants, or decreased, because of the destruction of already present antioxidants and phenolic compounds due to the high shearing during extrusion (Altan and Maskan 2011). No

Fig. 2 Total phenolic compounds in triticale crisp bread enriched with bioactive additives [Different letters for each column indicate significant differences ($P < 0.05$)]

Fig. 3 Antioxidant activity of triticale crisp bread enriched with bioactive additives [Different letters for each column indicate significant differences ($P < 0.05$)]

significant effect of the process on antioxidant capacity and phenolic content has been observed for extrudates containing brewer's spent grain, but extrudates containing red cabbage had a slight increase in antioxidant activity and phenolic content after extrusion (Stojceska et al. 2009). Anton et al. (2009) indicated that extrusion cooking resulted in a significant decrease in the antioxidative potential of corn starch–bean mixtures. In their study, total phenol levels were reduced by an average of 10% in extrudates, in comparison to the raw mixtures. The results depended on raw materials as well as extrusion conditions. However, products with high levels of TPC and AA can be obtained through the use of plant additives that contain high levels of phenolics.

Conclusion

This study indicates the feasibility of producing crisp bread by extrusion cooking with the addition of plant tissues or extracts exhibiting bioactive properties. Such additions provide the product with much higher levels of antioxidant activity, while retaining or improving (in the case of mulberry and yellow tea extracts) its sensory attributes. It is known that an addition of mulberry markedly improves the dietary properties of bread by reducing the absorption of monosaccharides. This is of paramount importance in the control of diabetes. In turn, tea is one of the richer sources of phenolic compounds exhibiting high antioxidant activity. Despite the advantageous properties of artichoke and fenugreek being extensively documented in the literature, their addition to crisp bread is of little value, due to the adverse changes produced in the sensory attributes of the product.

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