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Research article

Optimization of green tea extract, rosemary extract, and rice bran in multifunctional bread: A concept for reduction of acrylamide and phytic acid

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A R T I C L E I N F O

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A B S T R A C T

This research aimed to produce a multifunctional bread by adding hydrothermally processed rice bran (RB), green tea extract (GTE), and rosemary extract (RE). In the first step, hydrothermal processing was used to reduce the amount of phytic acid in RB, which decreased by 55 %. Based on the acrylamide amount, texture profile analysis, and color parameters, 3 % RB was selected as the optimum concentration in the bread formulation. The acrylamide amount in the RB-fortified bread showed a significant ($p < 0.05$) reduction trend with the addition of GTE and RE. So the lowest amount of acrylamide concentration was reported in the sample containing 1.5 % GTE (17.18 ppb). The addition of GTE and RE significantly ($p < 0.05$) decreased the hardness value of bread samples. However, the cohesiveness, springiness, and adhesiveness parameters of bread samples were significantly ($p < 0.05$) increased by the addition of GTE and RE. In addition, the fortified breads with 0.1 % RE and 1.5 % GTE exhibited the lowest and highest ΔE values, respectively. The addition of GTE and RE caused no adverse effect on the sensory properties of the RB-fortified bread. In conclusion, the combination of RB, GTE, and/or RE is an effective strategy for providing health benefits as well as reducing acrylamide formation in this food.

1. Introduction

Bread as a staple food has a crucial role in providing nutrients and dietary needs all over the world [1]. In this regard, the fortification of bread with functional plant sources can affect the health of a greater number of people without needing them to alter their previously established eating patterns [2,3]. Furthermore, the addition of compounds with antioxidant activity can prevent the formation of hazardous compounds in bread like acrylamide.

Recently, there has been a focus on the fortification of bread with rice bran (RB), which contains various proteins (such as albumin, globumin, glutamine, and prolamin), soluble and insoluble fibers, minerals, and B-group vitamins [4,5]. Furthermore, substantial quantities of bioactive compounds, such as oryzanol, phytosterols, and polyphenols, are present in RB. RB additionally demonstrates anticancer, anti-inflammatory, antidiabetic, and antioxidant properties [6–8]. Nevertheless, the application of RB for human consumption is severely restricted due to concerns regarding its potential association with elevated levels of phytic acid, a compound whose chelating effect is linked to mineral deficiency in humans [9,10]. Practical strategies exist for augmenting inorganic phosphorus

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and inositol phosphate concentrations, thereby reducing the presence of PA and its salts [11,12]. The hydrothermal treatment of RB is regarded as the most efficient way to decrease its phytic acid content [13].

On the other hand, the perspective of bread fortification with functional plant extracts has become a growing trend [14]. Green tea extract (GTE) comprises 30 % of the dried weight of the leaves of the green tea plant and is composed of polyphenolic compounds derived from the plant, including catechins [15]. Numerous researchers have identified the antioxidative, anti-carcinogenic, and antimicrobial properties of these naturally occurring polyphenolic compounds [16]. In recent years, GTE has been used for the fortification of bread and bakery products to provide health advantages, as well as the reduction of acrylamide formations in these products [17–19].

Rosemary extract (RE) is another of the most widely commercialized plant extracts; it is reported to have antioxidant activity, it is also used as a culinary herb for flavoring and as an antioxidant in processed foods and cosmetics [20,21]. The antioxidant activity of rosemary extract is associated with the presence of phenolic compounds, such as carnosic acid, rosmarinic acid, carnosol, rosmanol, rosmariquinone, and rosmaridiphenol, which react with free radicals formed in the oxidation process [22]. A wealth of studies on the rosemary plant demonstrated antioxidant, diuretic, anti-inflammatory, anti-microbial, anti-carcinogenic, hypoglycemic, and hypolipidemic activities of rosemary [23]. Recently, this plant extract has been used for nutritional enrichment of different foodstuffs, especially types of bread [22,24–26].

According to the research, there is no study on the combination use of RB, GTE, and RE for the fortification of food products, especially bread. In this regard, this study aims to fortify bread with RB and to investigate the effects of GTE and RE on reducing the amount of acrylamide that results from the addition of RB. The ultimate purpose is the production of healthy and functional foodstuffs for consumption by all consumer groups.

2. Materials and methods

2.1. Materials

Wheat flour (87 % extraction rate, 14 % moisture, 12 % protein, 2 % fat, and 30 % gluten) was procured from the Khoosheh flour factory (Rasht, Iran). The RB of the Hashemi variety (0.2 mm average particle size) was obtained from the Mousavi rice factory (Khomam, Iran). Iron (III) chloride, Hydrochloric acid (HCl), sodium chloride, and other chemicals (acetate buffer (pH = 7), hexane, acetonitrile, sulfate sodium, sodium chloride, acetonitrile, potassium bromide, hydrobromic acid, saturated bromine water) were purchased from Merck Chemical Co. (Darmstadt, Germany).

2.2. Hydrothermal treatment

Firstly, 50 g of RB was wet-slept in acetate buffer (pH = 7) at the ratio of 1:8 and incubated at 47 °C for 94 min. Then, the soaked brans were kept in a hot-air oven at 60 °C for 24 h. Following that, the samples were desiccated in an oven preheated to 50 °C after being rinsed multiple times with distilled water to a final pH of 6.2 [27].

2.3. Phytic acid determination

First, phytic acid was isolated from RB samples using a 0.8 M HCl solution. The phytic acid concentration was determined. The regression equation of the phytic acid calibration curve was $y = -0.035x + 0.0196$, $R^2 = 0.9992$. The results were expressed in g of phytic acid per 100 g of the sample or 100 mL of extract [27].

2.4. Bread preparation

Firstly, the hydrothermally treated and untreated RB was added to wheat flour at 0, 3, 6, and 9 % w/w concentrations. Then, yeast and salt were added at concentrations of 0.4 and 1.5 % of wheat flour weight, respectively. After that, the dough was prepared with the addition of water and using a mixer (Sanaye Pokht-e Mashhad Co., Mashhad, Iran) at a speed of 2 rpm for 8 min. After selection of the best type and concentration of RB (hydrothermal treated RB at 3 % w/w), GTE (0.5, 1, and 1.5 % w/w) and or RE (0.1, 0.2, and 0.5 % w/w|) were added along with water addition. The mixing time was determined by experimentally evaluating the consistency of the resulting dough. The obtained dough samples were poured into galvanized molds and were incubated at 35 °C and 70 % relative humidity for 45 min. All samples were baked using an oven (KF1800, Kaveh Co., Isfahan, Iran) at 200 °C for 32 min. Finally, the bread samples were cooled for 1 h followed by packing in plastic bags and stored at 25 °C [28].

2.5. Acrylamide determination

To separate acrylamide, 5 g of sample was mixed with 5 mL hexane and equal proportions of distilled water and acetonitrile. Then, 5 g of sulfate sodium and sodium chloride were added. After centrifugation at 4500 rpm for 10 min, a layer of acetonitrile was completely isolated. Then, the collected acetonitrile layer was brominated using potassium bromide, hydrobromic acid, and saturated bromine water. The resulting solution was placed in the refrigerator at 4 °C for one night. Then, the excess bromine was decolorized by adding the required amount of 0.7 M sodium thiosulfate, and after adding the resulting sodium sulfate solution with 65 mL of ethyl acetate, it was extracted in two steps. The resulting organic phase after dehydrating with a sufficient amount of sodium sulfate, was first evaporated by a rotary evaporator under vacuum and then concentrated under nitrogen gas to a volume of 250 μL. The sample ready for injection was kept in the freezer until the analysis [17].

The amount of acrylamide was determined by a gas chromatography device (Pye Unicam Ltd., Cambridge, England) equipped with a diode array detector. For this purpose, a column ODS-3 C18 (250 × 4.6 mm, Intersile, Japan) was used.

2.6. Texture profile analysis (TPA)

The texture parameters of bread samples were assessed by a texture analyzer (TA-CT3, Brookfield, USA). The size of the probe was 25 mm, the penetration speed of the probe in toast samples was 2 mm/s, and the penetration depth of the probe in the bread was 50 %. The measured texture parameters were hardness, cohesiveness, adhesiveness, springiness, gumminess, and chewiness [29].

2.7. Color measurement

The color of the samples was measured by a HunterLab chromometer (Minolta CR 400, Osaka, Japan). The CIELAB color parameters were investigated by an original program CromaLab®, following the recommendations of the Commission Internationale de L'Eclariage. Using the color coordinates L* or lightness (black = 0 to white = 100), a* (greenness = −120 to redness = +120), and b* (blueness = −120 to yellowness = +120), the total color difference (ΔE) was calculated by the following equation:

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

2.8. Sensory analysis

The sensory evaluation of toasts was done by 30 trained evaluators. A 5-point hedonic form was used to check toasts in terms of color, smell, taste, texture, and general acceptance.

2.9. Statistical analysis

The experimental design used in this research was a simple experimental design. IBM SPSS Statistics 19 (IBM Corporation, Armonk, NY, USA) was used to perform a one-way analysis of variance (ANOVA) on the collected data. In addition, the Tukey multiple comparison test was conducted at a 5 % significant level.

3. Results and discussion

3.1. Phytic acid determination

The concentrations of phytic acid in the hydrothermal rice bran and normal bran were 296 and 538 ppm, respectively. Thus, the application of hydrothermal processing resulted in a 55 % reduction of phytic acid in RB compared to untreated RB. The instability of phytic acid content in cereal brans under heat treatments has been reported by previous studies [30,31]. According to previous literature [32], the reduction of phytic acid by heating treatment can be attributed to the enzymatic hydrolysis and structural changes of phytic acid due to the increase of phytase activity in grains by heating.

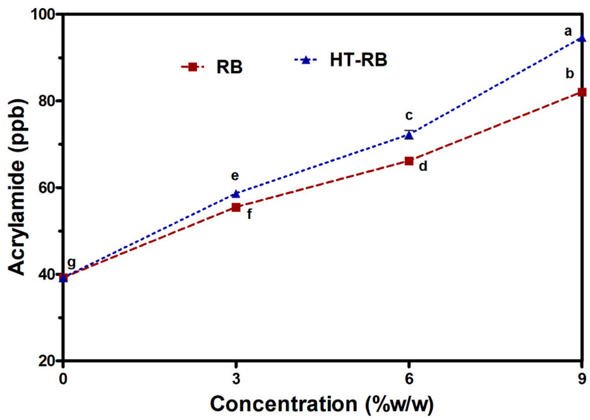

Fig. 1. The acrylamide amount in the fortified bread samples with hydrothermal processed RB and un-treated RB. The data is presented in the form of mean ± standard deviation (n = 3) and small letters indicate a significant difference between the bread samples at the 5 % confidence level of Tukey's test. RB: rice bran, HT: hydrothermal.

3.2. Optimization of RB concentration

3.2.1. Acrylamide determination

The acrylamide concentrations in the fortified bread samples with hydrothermal treated and untreated RBs are shown in Fig. 1. As a result, the addition of RBs significantly ($p < 0.05$) increased the acrylamide concentration in the bread samples. In addition, the acrylamide concentration showed an increasing trend by increasing of RBs percentage. The acrylamide concentration in the fortified samples with the hydrothermal processed RB was significantly higher than its values in the fortified samples with untreated RB. In this regard, the lowest and highest values of acrylamide related to the control sample (49.7 ± 0.45 ppb) and the fortified sample with 9 % hydrothermal treated RB (94.66 ± 0.45 ppb), respectively. The inclusion of bran resulted in an increase in protein, fiber, and ash content, all of which serve as viable precursors to the development of acrylamide. In addition, the increase in the amount of bran leads to an increase in the amount of fat. At a temperature higher than the smoke point, fats can be converted into acrolein and finally produce acrylamide on the other hand, insoluble fibers in food can ease the conditions for the Maillard reaction by reducing the amount of water activity [33]. According to previous literature [34,35], the addition of lysine and alanine to flour will increase the amount of acrylamide in bread. In this regard, RB contains large amounts of lysine and the presence of lysine leads to an increase in the production of acrylamide.

3.2.2. TPA

As can be seen in Fig. 2a, the lowest and highest hardness values were related to the control sample and the fortified sample with 9 % hydrothermal processed RB their values were 1.91 ± 0.26 and 6.61 ± 0.02 N, respectively. As a result, the addition of RB in the bread formulation significantly ($p < 0.05$) increased the hardness value and the increasing effect of hydrothermal treated RB more than the effect of untreated RB. The increasing effect of RB on the bread hardness can be due to the dilution of gluten, because gluten with the ability to hold gas creates a porous texture in bread, and with the increase in the amount of bran, this ability decreases and the hardness also increases. Also, the increase of bran can cause stiffness of the bread by thickening the wall of the air bubbles. Due to its high viscosity and water-absorbing hydrocolloids, bran reduces lubrication and consequently increases stiffness [36]. Due to having more fiber than normal bran, hydrothermal bran is expected to cause more hardness in bread, which is consistent with the obtained results [29].

The springiness value of bread samples significantly ($p < 0.05$) was decreased by the addition of RB and increasing of its concentration (Fig. 2b). In this regard, the lowest and highest values of springiness were attributed to the fortified sample with 9 % hydrothermal processed RB (10.63 ± 0.02) and the control sample (14.55 ± 0.01). Springiness is the result of the interaction between gelatinized starch and gluten in the dough, which increases the elasticity of the dough and creates a sponge-like structure in the bread after heating. By adding bran to bread and creating internal links of the bread, the viscous behavior of the tissue increases and the humidity decreases, which can be a reason for the decrease in the amount of springiness. A similar result has been reported in a previous study [28]for the wheat bran fortified bread, which related the decrease of springiness to the loss of crumb elasticity.

As presented in Fig. 2c-e, the changes in adhesiveness, gumminess, and chewiness parameters in the bread samples by the addition of RBs are similar to the changes in hardness value in the samples. So, the lowest and highest values of these parameters were attributed

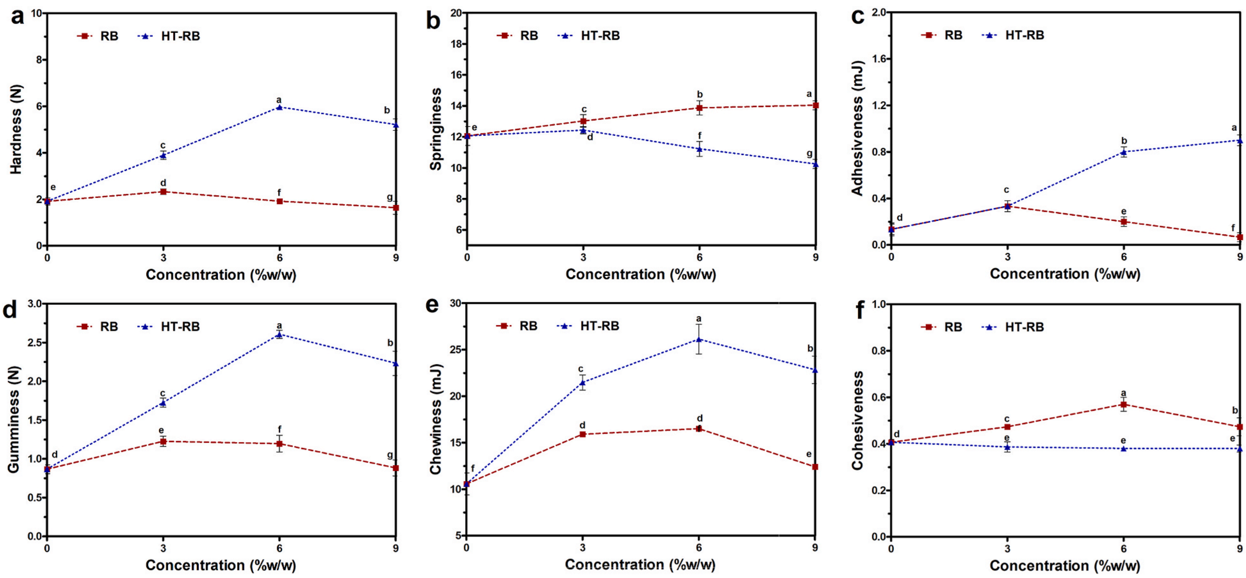

Fig. 2. The texture parameters of the fortified bread samples with hydrothermal processed RB and un-treated RB. The data is presented in the form of mean ± standard deviation ($n = 3$) and small letters indicate a significant difference between the bread samples at the 5 % confidence level of Tukey's test. RB: rice bran, HT: hydrothermal.

to the control and the fortified sample with hydrothermal processed RB, respectively. Chewiness has a direct relationship with gumminess and hardness, and with the increase of these two characteristics, the amount of chewiness also increases. However, the cohesiveness value of bread samples showed different changes with the addition of RBs (Fig. 2f). In this case, the lowest value of cohesiveness (0.45 ± 0.01) was related to the fortified sample with hydrothermal processed RB. However, the lowest value of this parameter (0.47–0.5) was associated with the control and the fortified samples with untreated RB at concentrations of 3 and 6 %. Cohesiveness describes the internal resistance of the bread structure, which has an inverse relationship with the hardness of the bread.

3.2.3. Color measurement

The color parameters of bread samples are summarized in Table 1. As a result, the L* value of samples showed a significant ($p < 0.05$) reduction trend with the addition of RBs. Moreover, the reduction effect of hydrothermal processed RB was higher than the effect of untreated RB. In this regard, the lowest value of L* (58.57 ± 1.21) was related to the fortified sample with 9 % hydrothermal processed RB. Additionally, this sample showed the highest ΔE value (9.97 ± 1.28) among other samples. The a* and b* parameters were significantly ($p < 0.05$) enhanced by addition of RBs. The color of the bread crust is dependent on the amount of Maillard and caramelization reactions that occur in it. These reactions themselves are dependent on other factors such as humidity, pH, and temperature, and creates a brown-golden color in the bread crust [33]. Thus, the obtained results can be explained by the moisture absorption of the fiber content of RB and the increase of the possibility of the Maillard reaction, resulting in the brightness decreases and the yellowness and redness increase. By our results, it has been reported that addition of RB [37,38] and corn bran [29] in bread decreased its crust lightness value.

3.3. Optimization of GTE and RE concentration

According to the results of the prior section especially the results of phytic acid measurement, we selected the hydrothermal processed RB at a concentration of 3 % for use in the fortified breads with extracts.

3.3.1. Acrylamide determination

Table 2 displays the acrylamide concentrations in the fortified breads with GTE and RE. As can be seen, the acrylamide amount was significantly ($p < 0.05$) decreased by the addition of GTE and Rein in the bread samples. In addition, the reduction effect of GTE was more than the effect of RE. In this regard, the lowest amount of acrylamide (17/18 ± 0.07 ppb) was observed in the fortified sample with 1.5 % GTE. Based on Table 4, a significant correlation ($p \leq 0.05$) between acrylamide content and hardness with a correlation coefficient of Pearson equal to 0.467 and a significant correlation ($p \leq 0.01$) between acrylamide content and ΔE values with a correlation coefficient of Pearson equal to −0.894 were observed. Flavonoids contain antioxidant properties and the inhibitory properties of green tea leaves containing epicatechin and epigallocatechin gallate and their flavonoid structure have been confirmed to reduce the amount and formation of acrylamide from Millard. The effect of catechins on the formation of acrylamide is related to their carbonyl-trapping capacity [15]. The effect observed by RE can also be explained by the same mechanism. So rosemary includes compounds that can trap the carbonyl structure inhibit the Maillard reaction and finally limit the formation of acrylamide. In this regard, previous studies reported that the reduction of acrylamide amount by addition of GTE [17,18] and RE [22,24] in bread and bakery products can be related to their antioxidant properties.

3.3.2. TPA

Table 2 represents the texture parameters of the fortified bread with GTE and RE. The hardness of the control sample was 4.55 ± 0.02 N and the addition of GTE and RE significantly ($p < 0.05$) decreased this parameter. The fortified sample with 1 % GTE exhibited the lowest value of hardness that its value was 3.24 ± 0.02 N. Basis in Table 4, a significant correlation ($p \leq 0.01$) between hardness and cohesiveness with correlation coefficient Pearson equal to −0.766, between hardness and springiness with correlation coefficient Pearson equal to −0.901 and significant correlation ($p \leq 0.05$) between hardness and gumminess with correlation coefficient Pearson equal to 0.508 were observed. The presence of moisture-absorbent compounds such as fibers leads to moisture absorption increases the percentage of moisture and as a result, reduces tissue stiffness. On the other hand, the reaction between the added plant extract and the

Table 1
The color parameters of RB fortified bread samples.

Bread Samples	Color parameters			
	L*	a*	b*	ΔE
Control	64.18 ± 0.67^{a}	3.65 ± 0.49^{d}	8.57 ± 0.68^{f}	–
RB3%	63.00 ± 0.14^{ab}	5.73 ± 0.69^{cd}	16.66 ± 0.27^{e}	1.97 ± 1.60^{d}
RB6%	61.83 ± 0.31^{bc}	4.42 ± 0.97^{c}	15.44 ± 0.28^{d}	4.94 ± 0.39^{c}
RB9%	59.68 ± 0.40^{d}	7.61 ± 0.02^{ab}	18.57 ± 0.06^{c}	7.62 ± 0.78^{abc}
HT-RB3%	59.04 ± 0.22^{c}	4.92 ± 0.35^{bc}	12.28 ± 0.22^{bc}	6.69 ± 1.19^{bc}
HT-RB6%	58.57 ± 1.21^{d}	3.20 ± 0.05^{bc}	13.69 ± 0.20^{ab}	8.39 ± 0.71^{ab}
HT-RB9%	58.95 ± 0.67^{d}	5.79 ± 0.15^{a}	8.63 ± 0.34^{a}	9.97 ± 1.28^{a}

The data is presented in the form of mean ± standard deviation (n = 3) and small letters indicate a significant difference between the bread samples at the 5 % confidence level of Tukey's test. RB: rice bran, HT: hydrothermal.

Table 2
The acrylamide and texture parameters of GTE and RE fortified bread samples.

Bread Samples	Acrylamide (ppb)	Texture parameters					
		Hardness (N)	Springiness	Adhesiveness (mJ)	Gumminess (N)	Chewiness (mJ)	Cohesiveness
Control	39.20 ± 0.05^{a}	4.55 ± 0.02^{a}	12.54 ± 0.03^{e}	0.39 ± 0.00^{f}	2.09 ± 0.06^{b}	26.27 ± 0.81^{b}	0.46 ± 0.01^{f}
GTE0.5 %	24.30 ± 0.24^{e}	3.87 ± 0.00^{e}	13.10 ± 0.00^{c}	0.64 ± 0.01^{d}	2.19 ± 0.01^{a}	28.78 ± 0.25^{a}	0.56 ± 0.00^{b}
GTE1%	20.51 ± 0.25^{f}	3.24 ± 0.02^{g}	13.43 ± 0.01^{a}	0.43 ± 0.02^{f}	1.92 ± 0.00^{cd}	25.84 ± 0.10^{b}	0.59 ± 0.00^{a}
GTE1.5 %	17.18 ± 0.07^{g}	4.20 ± 0.02^{b}	13.04 ± 0.02^{d}	0.92 ± 0.01^{a}	2.15 ± 0.01^{ab}	28.14 ± 0.17^{a}	0.51 ± 0.00^{d}
RE0.1 %	34.15 ± 0.16^{b}	3.94 ± 0.01^{d}	13.18 ± 0.00^{b}	0.74 ± 0.02^{c}	1.97 ± 0.00^{c}	25.97 ± 0.10^{b}	0.50 ± 0.00^{de}
RE0.2 %	26.84 ± 0.08^{c}	3.80 ± 0.00^{f}	13.22 ± 0.02^{b}	0.53 ± 0.02^{e}	1.85 ± 0.02^{d}	24.47 ± 0.27^{c}	0.48 ± 0.00^{e}
RE0.5 %	26.18 ± 0.67^{d}	4.03 ± 0.01^{c}	13.19 ± 0.01^{b}	0.83 ± 0.03^{b}	2.17 ± 0.03^{ab}	28.70 ± 0.47^{a}	0.54 ± 0.01^{c}

The data is presented in the form of mean ± standard deviation (n = 3) and small letters indicate a significant difference between the bread samples at the 5 % confidence level of Tukey's test. GTE; green tea extract, RE: rosemary extract.

Table 3
The color parameters of GTE and RE fortified bread samples.

Bread Samples	Color parameters			
	L*	a*	b*	ΔE
GTE0.5 %	60.70 ± 0.59^{de}	3.43 ± 0.69^{cd}	17.66 ± 0.27^{e}	13.58 ± 0.32^{b}
GTE1%	62.72 ± 1.80^{d}	5.42 ± 0.97^{c}	13.44 ± 0.28^{d}	11.06 ± 0.27^{c}
GTE1.5 %	60.02 ± 0.04^{e}	4.21 ± 0.02^{ab}	17.57 ± 0.06^{c}	15.30 ± 0.29^{a}
RE0.1 %	77.40 ± 0.22^{a}	4.92 ± 0.35^{bc}	8.28 ± 0.22^{bc}	4.48 ± 0.14^{e}
RE0.2 %	73.36 ± 0.27^{b}	6.20 ± 0.05^{bc}	12.69 ± 0.20^{ab}	4.60 ± 0.08^{e}
RE0.5 %	67.14 ± 0.14^{c}	5.79 ± 0.15^{a}	12.63 ± 0.34^{a}	5.67 ± 0.14^{d}

The data is presented in the form of mean ± standard deviation (n = 3) and small letters indicate a significant difference between the bread samples at the 5 % confidence level of Tukey's test. GTE; green tea extract, RE: rosemary extract.

flour protein network leads to a change in the elastic properties of the dough a decrease in the gas holding capacity, and an increase in the consistency of the dough. In other words, the viscosity of the dough increases. This reaction in high amounts leads to a decrease in the residual moisture in the dough and an increase in the viscosity and hardness of the produced bread. The cohesiveness, springiness, and adhesiveness parameters of bread samples were significantly ($p < 0.05$) increased by the addition of GTE and RE. The increase in cohesiveness can be due to the decrease in the gas storage capacity of the dough by the addition of plant extracts. Additionally, the addition of GTE and RE caused to an increase in springiness, and the elasticity of the bread increased by creating hydrogen bonds and increasing the wall strength of the air bubbles. However, the gumminess and chewiness parameters showed no specific trend by the addition of GTE and RE. Previous researchers [18]observed opposite changes in the texture parameters of bread by the addition of (−)-epigallocatechin gallate (EGCG) extracted from green tea. These opposite results can be explained by the presence of RB in our bread formulation.

3.3.3. Color measurement

As a result (Table 3), the lowest and highest L* values were related to the fortified samples with 1.5 % GTE and 0.1 % RE, respectively. However, the fortified breads with 0.1 % RE and 1.5 % GTE exhibited the lowest and highest ΔE values. Green tea extract can adversely affect brightness because of its pigment, and rosemary can cause the flour to darken. However, the effects of green tea and rosemary on the product's color will be less in smaller amounts. Additionally, because of their antioxidant qualities and the development of their inhibitory properties against the Maillard reaction and product color change, these ingredients can partially offset the product's negative effects. Similar findings have been seen [39]. According to their report, the brown substances that are produced when the catechins oxidize to produce certain deep-colored materials, like theaflavins, thearubigins, and theabrownines, during high baking temperatures, are responsible for the reduction of bread brightness caused by the addition of GTE. Simultaneously, the chlorophyll disintegrated to form the brown-colored magnesium chlorophyll [17]. However, there was no significant change in the L* value of crust rye bread with the addition of GTE.

3.3.4. Sensory analysis

As a result (Fig. 3), no significant difference ($p > 0.05$) was observed in the acceptability of the bread samples in terms of color, smell, taste, texture, and overall acceptance. These results showed that the fortification of RB incorporated bread with GTE and RE had no adverse effect on its sensory properties.

4. Conclusion

The hydrothermally processed RB showed a 55 % reduction in phytic acid amount. The fortified bread sample with 3 % hydrothermally processed RB was selected as the optimum sample in terms of acrylamide amount, texture parameters, and color. The addition of GTE and RE significantly decreased the acrylamide amount in the RB-incorporated bread. The hardness value of bread

Table 4
Correlation coefficients of variables.

	Hardness	Cohesiveness	Springiness	Gumminess	chewiness	Adhesiveness	Acrylamide content	Delta E	Lightness
Hardness									
Cohesiveness	−0.766**								
Springiness	−0.901**	0.688**							
Gumminess	0.508*	0.155ns	−0.408ns						
chewiness	0.254ns	0.396ns	−0.109ns	0.952**					
Adhesiveness	0.202ns	0.059ns	0.196ns	0.495*	0.609**				
Acrylamide content	0.467*	−0.720**	−0.551**	−0.265ns	−0.471*	−0.457*			
Delta E	0.037ns	0.484*	−0.294ns	0.528*	0.528*	0.160ns	−0.894**		
Lightness	0.076ns	−0.643**	0.141ns	−0.562*	−0.588*	−0.076ns	0.935**	−0.934**	

****: (p** $\leq$ 0.01), * :(**p** $\leq$ 0.01) and ns: non significant

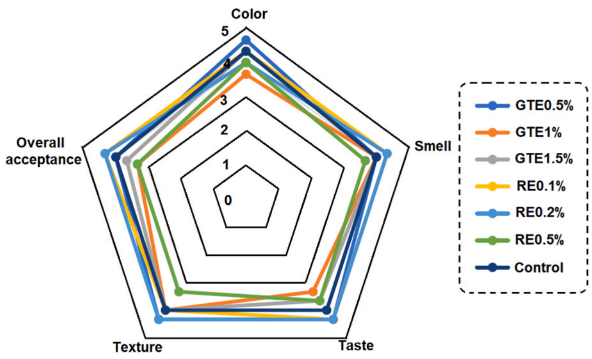

Fig. 3. The results of sensory analysis of the fortified bread samples with different concentrations of green tea extract (GTE) and rosemary extract (RE).

samples showed an increasing trend with the addition of GTE and RE. Also, the lowest and highest ΔE values were seen in the fortified breads with 0.1 % RE and 1.5 % GTE. The addition of GTE and RE caused no adverse effect on the sensory properties of the Also, according to the sensory evaluation results, the fortified samples with RB and plant extracts showed acceptable sensory characteristics in terms of color, smell, taste, texture, and overall acceptance. In general, the results of this research showed that the addition of GTE or RE can compensate for the negative effects of RB on bread or other bakery products, resulting in the production of healthy and functional food. Since the increase in the concentration of extracts in bread leads to a loss in its textural characteristics, therefore, the use of additives to compensate for the quality loss in bread is suggested in some research.

CRediT authorship contribution statement

Mandana Tayefe: Writing – review & editing, Supervision, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Leili Fadayi Eshkiki:** Writing – original draft, Methodology, Investigation. **Zahra Rahbar Dalir:** Data curation, Formal analysis. **Azin Nasrollahzadeh Masoule:** Methodology, Investigation.

Ethics statement

It is confirmed that the informed written consent of the sensory evaluation participants was obtained and all ethical rules were followed during the test. According to Iranian laws, it is not required to receive the code of ethics for the sensory evaluation of common food products.and/or publication of this article.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e41182.

References

[1] M. Ebrahimi, S.M. Ali Noori, A. Sadeghi, O. emir Coban, J. Zanganeh, S.M. Ghodsmofidi, Z. Malvandi, M. Raeisi, Application of cereal-bran sourdoughs to enhance technological functionality of white wheat bread supplemented with pumpkin (Cucurbita pepo) puree, LWT 158 (2022), https://doi.org/10.1016/j.lwt.2022.113079.
[2] M. Ortiz de Erive, T. Wang, F. He, G. Chen, Development of high-fiber wheat bread using microfluidized corn bran, Food Chem. 310 (2020), https://doi.org/10.1016/j.foodchem.2019.125921.
[3] A. Jakubczyk, M. Świeca, U. Gawlik-Dziki, D. Dziki, Nutritional potential and inhibitory activity of bread fortified with green coffee beans against enzymes involved in metabolic syndrome pathogenesis, LWT 95 (2018) 78–84, https://doi.org/10.1016/j.lwt.2018.04.071.
[4] C. Espinales, A. Cuesta, J. Tapia, S. Palacios-Ponce, E. Peñas, C. Martínez-Villaluenga, A. Espinoza, P.J. Cáceres, The effect of stabilized rice bran addition on physicochemical, sensory, and techno-functional properties of bread, Foods 11 (2022), https://doi.org/10.3390/foods11213328.

[5] C.E. Genevois, M.S. Grenóvero, M.F. de Escalada Pla, Use of different proportions of rice milling fractions as strategy for improving quality parameters and nutritional profile of gluten-free bread, J. Food Sci. Technol. 58 (2021) 3913–3923, https://doi.org/10.1007/s13197-020-04852-1.

[6] U. Ijaz, H.U. Nadeem, A. Shafique, A. Rasheed, R. Batool, F. Azeem, Rice bran composition and its emerging potential applications, in: Green Sustainable Process for Chemical and Environmental Engineering and Science: Plant-Derived Green Solvents: Properties and Applications, Elsevier, 2020, pp. 1–16, https://doi.org/10.1016/B978-0-12-821886-0.00001-4.

[7] S. Indriani, M.S. Bin Ab Karim, S. Nalinanon, S. Karnjanapratum, Quality characteristics of protein-enriched brown rice flour and cake affected by Bombay locust (Patanga succincta L.) powder fortification, LWT 119 (2020), https://doi.org/10.1016/j.lwt.2019.108876.

[8] Y. Wang, C. Xie, M. Pulkkinen, M. Edelmann, B. Chamlagain, R. Coda, M. Sandell, V. Piironen, N.H. Maina, K. Katina, In situ production of vitamin B12 and dextran in soya flour and rice bran: a tool to improve flavour and texture of B12-fortified bread, LWT 161 (2022), https://doi.org/10.1016/j.lwt.2022.113407.

[9] S.R. Bajaj, R.S. Singhal, Fortification of wheat flour and oil with vitamins B12 and D3: effect of processing and storage, J. Food Compos. Anal. 96 (2021), https://doi.org/10.1016/j.jfca.2020.103703.

[10] J. Pořízka, Z. Slavíková, K. Bidmonová, M. Vymětalová, P. Diviš, Physiochemical and sensory properties of bread fortified with wheat bran and whey protein isolates, Foods 12 (2023), https://doi.org/10.3390/foods12132635.

[11] M. Zerlasht, S. Javaria, M.A. Murtaza, R.K. Iqbal, M.Y. Quddoos, S. Azhar, A. Syed, A.M. Elgorban, Antimicrobial potential and phyto-physio-chemical characterization of brans from wheat, oat, and rice, J. King Saud Univ. Sci. 35 (2023), https://doi.org/10.1016/j.jksus.2023.102709.

[12] M. Irakli, A. Mygdalia, P. Chatzopoulou, D. Katsantonis, Impact of the combination of sourdough fermentation and hop extract addition on baking properties, antioxidant capacity and phenolics bioaccessibility of rice bran-enhanced bread, Food Chem. 285 (2019) 231–239, https://doi.org/10.1016/j.foodchem.2019.01.145.

[13] M. Pauline, P. Roger, N.E. Sophie Natacha Nina, T. Arielle, E.E. Eugene, N. Robert, Physico-chemical and nutritional characterization of cereals brans enriched breads, Sci Afr 7 (2020), https://doi.org/10.1016/j.sciaf.2019.e00251.

[14] A. Mukkundur Vasudevaiah, A. Chaturvedi, R. Kulathooran, I. Dasappa, Effect of green coffee extract on rheological, physico-sensory and antioxidant properties of bread, J. Food Sci. Technol. 54 (2017) 1827–1836, https://doi.org/10.1007/s13197-017-2613-9.

[15] A. Rashidinejad, S. Boostani, A. Babazadeh, A. Rehman, A. Rezaei, S. Akbari-Alavijeh, R. Shaddel, S.M. Jafari, Opportunities and challenges for the nanodelivery of green tea catechins in functional foods, Food Res. Int. 142 (2021), https://doi.org/10.1016/j.foodres.2021.110186.

[16] J. Ning, G.G. Hou, J. Sun, Z. Zhang, X. Wan, Effects of green tea powder on the quality attributes of hard red winter wheat flour and Chinese steamed bread, Int. J. Food Sci. Technol. 54 (2019) 576–582, https://doi.org/10.1111/ijfs.14016.

[17] S. Onacik-Gür, A. Szafrańska, M. Roszko, S. Stępniewska, Interaction of dough preparation method, green tea extract and baking temperature on the quality of rye bread and acrylamide content, LWT 154 (2022), https://doi.org/10.1016/j.lwt.2021.112759.

[18] Z. Fu, M.J.Y. Yoo, W. Zhou, L. Zhang, Y. Chen, J. Lu, Effect of (−)-epigallocatechin gallate (EGCG) extracted from green tea in reducing the formation of acrylamide during the bread baking process, Food Chem. 242 (2018) 162–168, https://doi.org/10.1016/j.foodchem.2017.09.050.

[19] D. Pasrija, P.N. Ezhilarasi, D. Indrani, C. Anandharamakrishnan, Microencapsulation of green tea polyphenols and its effect on incorporated bread quality, LWT 64 (2015) 289–296, https://doi.org/10.1016/j.lwt.2015.05.054.

[20] M. Atak, K. Mavi, I. Uremis, Bio-Herbicidal Effects of Oregano and Rosemary Essential Oils on Germination and Seedling Growth of Bread Wheat Cultivars and Weeds, 2016.

[21] L.C. De Conto, R.S. Porto Oliveira, L.G. Pereira Martin, Y.K. Chang, C.J. Steel, Effects of the addition of microencapsulated omega-3 and rosemary extract on the technological and sensory quality of white pan bread, LWT 45 (2012) 103–109, https://doi.org/10.1016/j.lwt.2011.07.027.

[22] K. Miśkiewicz, E. Nebesny, J. Rosicka-Kaczmarek, D. Żyżelewicz, G. Budryn, The effects of baking conditions on acrylamide content in shortcrust cookies with added freeze-dried aqueous rosemary extract, J. Food Sci. Technol. 55 (2018) 4184–4196, https://doi.org/10.1007/s13197-018-3349-x.

[23] H.Shetti Saad, A. Ali, A. Altae, Effect of Addition of Rosemary Leaves Powder on the Rheological Characteristics of Dough in Addition to the Quality Attributes of Bread Manufactured from to Local Wheat, 2019.

[24] B. Rwubatse, M.W. Okoth, A.A. Andago, S. Ngala, C. Bitwayiki, V. Ndungutse, J.B. Ndahetuye, Acrylamide Formation during baking of whole wheat flour incorporated with spent coffee grounds and juices of lemon fruits and rosemary leaves, J. Food Process. Preserv. 2023 (2023), https://doi.org/10.1155/2023/9952725.

[25] J.C. Kessler, V. Vieira, I.M. Martins, Y.A. Manrique, P. Ferreira, R.C. Calhelha, A. Afonso, L. Barros, A.E. Rodrigues, M.M. Dias, Chemical and organoleptic properties of bread enriched with Rosmarinus officinalis L.: the potential of natural extracts obtained through green extraction methodologies as food ingredients, Food Chem. 384 (2022), https://doi.org/10.1016/j.foodchem.2022.132514.

[26] V. Valková, H. Ďúranová, L. Galovičová, N.L. Vukovic, M. Vukic, M. Kačániová, In vitro antimicrobial activity of lavender, mint, and rosemary essential oils and the effect of their vapours on growth of penicillium spp. in a bread model system, Molecules 26 (2021), https://doi.org/10.3390/molecules26133859.

[27] M. Tayefe, S.A. Shahidi, J.M. Milani, S.M. Sadeghi, Development, optimization, and critical quality characteristics of new wheat-flour dough formulations fortified with hydrothermally-treated rice bran, J. Food Meas. Char. 14 (2020) 2878–2888, https://doi.org/10.1007/s11694-020-00532-y.

[28] S. Lin, X. Jin, J. Gao, Z. Qiu, J. Ying, Y. Wang, Z. Dong, W. Zhou, Impact of wheat bran micronization on dough properties and bread quality: Part II – quality, antioxidant and nutritional properties of bread, Food Chem. 396 (2022), https://doi.org/10.1016/j.foodchem.2022.133631.

[29] M. Ortiz de Erive, T. Wang, F. He, G. Chen, Development of high-fiber wheat bread using microfluidized corn bran, Food Chem. 310 (2020), https://doi.org/10.1016/j.foodchem.2019.125921.

[30] M. Majzoobi, S. Pashangeh, A. Farahnaky, M.H. Eskandari, J. Jamalian, Effect of particle size reduction, hydrothermal and fermentation treatments on phytic acid content and some physicochemical properties of wheat bran, J. Food Sci. Technol. 51 (2014) 2755–2761, https://doi.org/10.1007/s13197-012-0802-0.

[31] B. Özkaya, S. Turksoy, H. Özkaya, B. Duman, Dephytinization of wheat and rice brans by hydrothermal autoclaving process and the evaluation of consequences for dietary fiber content, antioxidant activity and phenolics, Innovative Food Sci. Emerging Technol. 39 (2017) 209–215, https://doi.org/10.1016/j.ifset.2016.11.012.

[32] X. Zhao, M. Li, F. Zhai, Y. Hou, R. Hu, Phosphate modified hydrochars produced via phytic acid-assisted hydrothermal carbonization for efficient removal of U(VI), Pb(II) and Cd(II), J. Environ. Manag. 298 (2021), https://doi.org/10.1016/j.jenvman.2021.113487.

[33] M. Palermo, A. Fiore, V. Fogliano, Okara promoted acrylamide and carboxymethyl-lysine formation in bakery products, J. Agric. Food Chem. 60 (2012) 10141–10146, https://doi.org/10.1021/jf302750q.

[34] Y. Shen, G. Chen, Y. Li, Effect of added sugars and amino acids on acrylamide formation in white pan bread, Cereal Chem. 96 (2019) 545–553, https://doi.org/10.1002/cche.10154.

[35] S. Žilić, I.G. Aktağ, D. Dodig, M. Filipović, V. Gökmen, Acrylamide formation in biscuits made of different wholegrain flours depending on their free asparagine content and baking conditions, Food Res. Int. 132 (2020), https://doi.org/10.1016/j.foodres.2020.109109.

[36] N.T. Alzuwaid, D. Pleming, C.M. Fellows, B. Laddomada, M. Sissons, Influence of durum wheat bran particle size on phytochemical content and on leavened bread baking quality, Foods 10 (2021) 1–13, https://doi.org/10.3390/foods10030489.

[37] C.E. Genevois, M.S. Grenóvero, M.F. de Escalada Pla, Use of different proportions of rice milling fractions as strategy for improving quality parameters and nutritional profile of gluten-free bread, J. Food Sci. Technol. 58 (2021) 3913–3923, https://doi.org/10.1007/s13197-020-04852-1.

[38] M. Irakli, A. Mygdalia, P. Chatzopoulou, D. Katsantonis, Impact of the combination of sourdough fermentation and hop extract addition on baking properties, antioxidant capacity and phenolics bioaccessibility of rice bran-enhanced bread, Food Chem. 285 (2019) 231–239, https://doi.org/10.1016/j.foodchem.2019.01.145.

[39] J. Ning, G.G. Hou, J. Sun, X. Wan, A. Dubat, Effect of green tea powder on the quality attributes and antioxidant activity of whole-wheat flour pan bread, LWT 79 (2017) 342–348, https://doi.org/10.1016/j.lwt.2017.01.052.