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Investigating the effect of adding microgreen rice powder and transglutaminase enzyme treatment on nutritional value and color characteristics of sponge cake

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ABSTRACT

Enriching sponge cake with microgreens can significantly increase its nutritional value by raising the concentrations of vitamins, minerals, and bioactive phytochemicals, thereby transforming a widely consumed confectionery into a functional food with potential benefits for general health and adequate micronutrient supply. This study investigated the effect of adding rice microgreen powder (RMP) at four levels (0, 2.5, 5, and 7.5% w/w, as a replacement for wheat flour) and transglutaminase (TG) enzyme at two levels (0 and 0.15%) on the composition and color characteristics of sponge cake. Results showed that RMP significantly increased moisture, ash, and total fiber ($P < 0.001$), while TG increased only moisture ($P < 0.01$), contributing to improved texture. Color analysis indicated that RMP reduced all three-color parameters (L*, a*, and b*), whereas TG only had a significant effect on brightness, and increased the L* values of both the crumb and the crust ($P < 0.05$). Overall, based on crust color, there was no significant difference between the sample containing 2.5% RMP (with or without TG) and the control; moreover, all RMP-enriched samples exhibited acceptable color quality. Therefore, the use of RMP at levels of 5–7.5% for sponge cake enrichment along with TG enzymatic treatment is recommended.

1- Introduction

Wheat products are among the most consumed food items worldwide because they are easy to eat and have a long shelf life. Among these products, cake is widely consumed due to its desirable sensory characteristics [1]. Cake is a high-energy product favored by the market because of its porous texture, consisting of small holes with thin walls. Every 100 grams of sponge cake provides approximately 1920 kJ (460 kcal) of energy [2, 3]. Cake has remained popular for centuries because of its pleasant taste, relatively high nutritional value, ease of consumption, versatile uses, and broad appeal across different population groups. Cakes are classified into various types—such as sponge, layer, and oil cakes—based on their formulation and preparation methods [4]. Today, cakes occupy a prominent place in diets around the world: they can be eaten in any season and at any time, and are commonly available as ready-made foods with an attractive and appetizing appearance [3]. Because of the wide variety of cake types and formula variations, it is difficult to provide a single precise definition. In general terms, however, a cake can be described as a baked product made from a soft batter containing flour, sugar, fat (oil or butter), eggs, baking powder, water (or sometimes milk), and sweetener.

Transglutaminase is classified among the transferase enzymes. It is widely distributed in animal tissues and body fluids and has also been detected in plants, fish, and microorganisms. Before 1989, transglutaminase used industrially was obtained from pig liver; subsequent research identified a microbial source—Streptoverticillium species—for enzyme production. The enzyme's optimum pH for activity is 6–7, and its optimal temperature range is 37–50 °C. A key difference between the animal-derived enzyme and the microbial enzyme is calcium dependence. Transglutaminase affects baked products by modifying cereal proteins: it alters product properties by forming cross-links between proteins [6, 7]. Functionally, the enzyme is a γ-glutamyl transferase that catalyzes the formation of a covalent bond between an ε-amino group of lysine and the γ-carboxamide group of glutamine (i.e., an ε-(γ-glutamyl) lysine cross-link), and it does so without reducing the nutritional availability of lysine [8].

Nowadays, new methods have been developed in many countries for cultivating agricultural products, as well as for their marketing and consumption. One of these innovations is the cultivation of certain plants as microgreens. Microgreens are small, edible seedlings composed of three main parts: (1) stem, (2) cotyledon leaves (usually two), and (3) young true leaves (typically a pair) [9]. They represent a growth stage between seed germination and established seedlings [10]. Microgreens include delicate forms of herbs, flowers, seeds, and vegetables; they are an intermediate stage between sprouts and young vegetables and are usually harvested at a height of 2–8 cm [11]. The period from sowing to harvest for microgreens is typically 1–3 weeks [9]. Because of their rapid growth cycle, concentrated nutritional content, and positive effects on human health, microgreen production and consumption have become important components of urban agriculture [12]. Approximately 115 plant species can be cultivated as microgreens. Modern offerings include microgreens from basil seedlings, various cabbages, beetroot and chard, radish, coriander, celery, and even crops such as rice and buckwheat, illustrating the wide diversity of microgreen products [10].

In the past decade, especially after the COVID-19 pandemic, people around the world have been increasingly interested in eating fresh, healthy, and functional foods, such as sprouted grains and microgreens [13]. New foods, known as "functional foods," contain bioactive substances in appropriate concentrations and are produced and marketed with the aim of improving or preventing health problems for consumers. These bioactive substances, such as proteins, vitamins, minerals, fatty acids, antioxidants, phenols, flavonoids, and primary and secondary metabolites, are found in various foods, especially cereals and vegetables [14]. In addition to their nutritional value, microgreens contain some bioactive compounds that are effective in promoting health and controlling diseases. As part of a strategy to promote health and prevent fatal cardiovascular diseases, the consumption of microgreens is highly recommended because they are rich in nutrients and phytochemicals [15]. Various studies have shown that microgreens contain higher amounts of vitamins C, E, and K and carotenoids such as beta-carotene, lutein, and zeaxanthin than similar products at the fully grown stage [16]. Lipid profiles of microgreens produced from chia, flax, soybean, sunflower, and rapeseed (which are notable for their oil content) have shown that flax and chia microgreens are rich sources of alpha-linolenic acid (ALA), with the highest amounts of triglycerides and sterol esters found in rapeseed, sunflower, and flax, respectively [17]. The presence of minerals and other bioactive compounds such as vitamins and phenolic compounds in various microgreens significantly enhances their functional aspects related to health and nutrition [18]. Microgreens are rich in minerals such as potassium (K), calcium (Ca), nitrogen (N), phosphorus (P), sulfur (S), manganese (Mn), selenium (Se), and molybdenum (Mo) [19]. It has been reported that the antioxidant activity of various plants at the microgreen stage is about ten times higher than that of plants at the fully grown stage [9]. Meanwhile, rice alone is a good source of tocopherols, tocotrienols, vitamin E, the diterpenes momilactone A and B, and B vitamins such as thiamine, riboflavin, and niacin [20]. Rice germ is the embryo of a seed that germinates and produces a new plant. This part is particularly rich in tocopherol, which is the most active form of vitamin E. Rice germ also contains relatively high concentrations of B vitamins and gamma-aminobutyric acid (GABA), which acts as a neurotransmitter in mammals [21]. Therefore, rice microgreens can be used in fresh or powdered form to produce food.

Various studies have investigated the incorporation of microgreens into food products, including baked goods. However, no research has examined the effect of transglutaminase (TG) on the properties of cakes containing rice microgreen powder (RMP). Mansouri et al. [22] evaluated sunflower microgreen powder (SMG) at 4, 8, and 12% as a flour substitute in gluten-free cakes, measuring moisture content, texture, color, crude fiber, protein, fat, total phenolic content, antioxidant activity, and mineral composition. They found that increasing SMG levels raised moisture, crude fiber, protein, fat, and mineral content, while the lightness value (L*) decreased. Kaur et al. [23] similarly reported improvements in physicochemical and antioxidant properties of gluten-free cakes made with wheatgrass and mung bean microgreens. Zheng et al. [24] examined the effect of *Polygonatum syrtonum* powder on the quality of rice cake, a traditional Chinese product; addition of the powder increased moisture and water absorption and imparted a bright yellow color, enriching the cake's chemical composition and appearance. In another study, the combined addition of pomegranate seed powder and TG to gluten-free rice-flour cake positively influenced fiber, ash, protein, and moisture content [25]. Klopsch et al. [26] incorporated pea and lupin microgreens and mature leaves into bread dough to enhance nutritional value; despite reductions in carotenoids and chlorophylls during baking, flavonoid levels were maintained and significant pheophytin formation occurred. Bread containing lupin microgreens retained high levels of genistein, a compound with noted anticancer properties, particularly for women [27]. Beyond fresh consumption, microgreens have been used to develop innovative foods—beverages, condiments, weaning foods, probiotic products, yogurt, flours enriched with microgreen powder, bakery items, and tea

[28]. Therefore, the present study aimed to produce functional sponge cakes containing varying amounts of rice microgreen powder and transglutaminase enzyme and to evaluate their effects on the products' physicochemical properties and color characteristics.

2- Materials and methods

2-1- Materials

Wheat flour for cakes with an extraction percentage of 73% (Setareh Komijan Flour Factory, Arak), vegetable oil (Behshahr Industrial Company, Iran), ground sugar, egg yolk, baking powder (Golvash Company, Isfahan) with ingredients of sodium acid pyrophosphate, monocalcium phosphate monohydrate, sodium bicarbonate and wheat starch, vanilla with a heat resistance above 280 degrees Celsius (Behtam Powder Company, Karaj) and microbial transglutaminase enzyme (TG) prepared from the microorganism *Streptoverticillium Morbaeaense*, with the trademark ACTIVA YG (Ajinomato Company, France) were used. The activity of each gram of this enzyme powder was determined to be 100 units per gram of protein. The transglutaminase enzyme powder used included lactose, yeast extract, maltodextrin, vegetable oil and transglutaminase enzyme.

2-2- Methods for preparing rice microgreen powder and cake

2-2-1- Rice microgreen powder

Rice microgreens were harvested when seedlings reached a length of 5 ± 2.5 cm. The harvested seedlings were rinsed thoroughly, then oven-dried at 48 °C for approximately 48 hours until constant weight was achieved. The dried material was ground to a fine powder and sieved through a 60-mesh screen (250 µm). The resulting rice microgreen powder (RMP) was incorporated into the cake formulations as a partial flour replacement at levels of 2.5, 5.0, and 7.5% (w/w).

2-2-2- Cake production

Sponge cakes incorporating rice microgreen powder were prepared following Jooyandeh et al. [29]. Dry ingredients were combined first: 100 g wholemeal flour, 72 g sugar, 1.34 g baking powder, and 0.4 g vanilla. In a separate bowl, 72 g of the combined egg yolks and whites, 57 g liquid corn oil, and 35 g water were blended together, then incorporated into the dry mix until homogeneous. Rice microgreen powder (RMP) replaced flour at levels of 2.5, 5.0, and 7.5% (w/w). Microbial transglutaminase (TG) was included in the dry mix at 0 and 0.15% levels. A formulation lacking both RMP and TG served as the control. Batter portions of 35 g were placed into greased, parchment-lined aluminum molds (3 cm diameter) and baked at 200 °C for 17 minutes. After baking, cakes were cooled at room temperature for 30 minutes, packaged in polyethylene bags, and stored at 23 ± 2 °C until analysis.

2-3- Determination of sponge cake composition

The moisture content of the cake samples was measured according to AACC standard No. 16-44 (using hot oven air and aluminum Petri dishes), the fat content according to AACC standard No. 25-30 (Soxhlet method and using petroleum ether as solvent), the ash content according to AACC standard No. 01-08 (using an oven at 550°C for about 6 hours), the protein content according to AACC standard No. 12-46 (measuring nitrogen by the Koldahl method and using boric acid and a nitrogen-to-protein conversion factor of 6.25), and the fiber content according to AACC standard No. 05-32 (enzymatic digestion and using ethanol solvents to precipitate soluble fibers and washing with acetone) [30]. The carbohydrate content was measured using the difference method and subtracting the moisture, fat, protein, ash, and total fiber values from 100 [31].

2-4- Color evaluation

The color characteristics of the cake samples were measured with a colorimeter (Konica Minolta, model 400-CR, made in Japan). The measurement indices included lightness (L* index), tendency to redness (a* index), and tendency to yellowness (b* index) of the cake crust and core. Before performing the test, the device was calibrated using a white standard plate (B*=2.04 A*=0.25 L*=94.43). The L* value represents the lightness of the samples and its range is from zero (pure black) to 100 (pure white), and the a* value represents the closeness of the samples' colors to green and red and its range is from -120 (pure green) to +120 (pure red). The b* value also indicates the degree to which the color of the samples is close to blue and yellow, and its range varies from -120 (pure blue) to +120 (pure yellow) [32].

2-5- Analysis of data

Eight cake treatments were prepared in a factorial arrangement with two factors: rice microgreen powder (RMP) at four inclusion levels (0, 2.5, 5.0, and 7.5% w/w) and microbial transglutaminase (TG) enzyme at two levels (0 and 0.15% w/w), yielding 8 treatment combinations. The experiment followed a completely randomized design; each treatment was produced in three replicates. Data were analyzed using a two-way factorial analysis in SPSS version 23, and treatment means were compared by Duncan's multiple range test at the 5% significance level. Physicochemical parameters and color characteristics of the cake samples were measured after production.

3- Results and discussion

3-1- Nutritional composition of cake

The results of analysis of variance showed that rice microgreen powder (RMP) had a significant effect on increasing the moisture, ash and fiber values ($P<0.001$) of sponge cake samples, but transglutaminase (TG) enzyme had a significant effect only on cake moisture ($P<0.01$) and its effect on other characteristics was insignificant (Table 1). Also, the interaction effect of RMP and TG enzyme on all nutritional components evaluated was not significant ($P<0.05$).

As shown in Figure 1, the addition of rice microgreens to the sponge cake formulation significantly increased the moisture, ash, and total fiber content of the samples, such that all treatments containing 7.5% RMP had higher moisture, ash, and total fiber content than the control treatment. However, no significant differences were observed between the enriched and control treatments in terms of fat and protein content at any level ($P<0.05$).

One of the factors that maintain and preserve moisture in the texture of baked products is the entrapment of water by product components, especially proteins, which prevents moisture from escaping from the texture of the final product during and after the baking process. The ability to retain water in foods, including baked products, depends on the water absorption capacity of the product formulation components. Among carbohydrates, dietary fibers, including bran and fruit and vegetable pulp powder, have a high ability to absorb water. Microgreens contain soluble fibers and hydrophilic molecules (pectin, polysaccharides, plant proteins) that absorb water and retain it in the dough matrix. These substances keep water in a trapped or gelled form and prevent rapid evaporation during baking. Microgreen particles can also act as fillers in the starch-gluten matrix and change the porosity or pore distribution; as a result, water evaporation is reduced and moisture retention is improved [33]. In this regard, Sahraiyan et al. [34] stated that with increasing the amount of rice bran, the moisture content increased. Therefore, rice microgreens, due to their high fiber content in their structure and ability to bind with water molecules present in the formulation, are able to increase the moisture content of the cake.

Table 1. The main and interaction effects of rice microgreen powder (RMP) and transglutaminase enzyme (TG) on composition and color characteristics of sponge cake.

Treatments	df	Moisture[1]	Ash[1]	Total fiber[1]	Crumb color[1]			Crust color[1]		
					L*	a*	b*	L*	a*	b*
RMP	3	3.22***	0.088***	0.129***	52.7***	77.4***	28.8*	43.5***	95.8***	178.7***
TG	1	0.437**	0.000^{NS}	0.000^{NS}	7.91*	0.025^{NS}	3.16^{NS}	11.8*	0.023^{NS}	5.44^{NS}
RMP× TG	3	0.004^{NS}	0.000^{NS}	0.001^{NS}	0.43^{NS}	0.055^{NS}	0.082^{NS}	0.115^{NS}	0.136^{NS}	0.291^{NS}
Error	16	0.032	0.003	0.001	1.101	0.351	6.66	2.52	0.313	0.870

1: Mean square values; NS, *, **, and *** indicate non-significance and significance at the $P<0.05$, $P<0.01$, and $P<0.001$ levels, respectively.

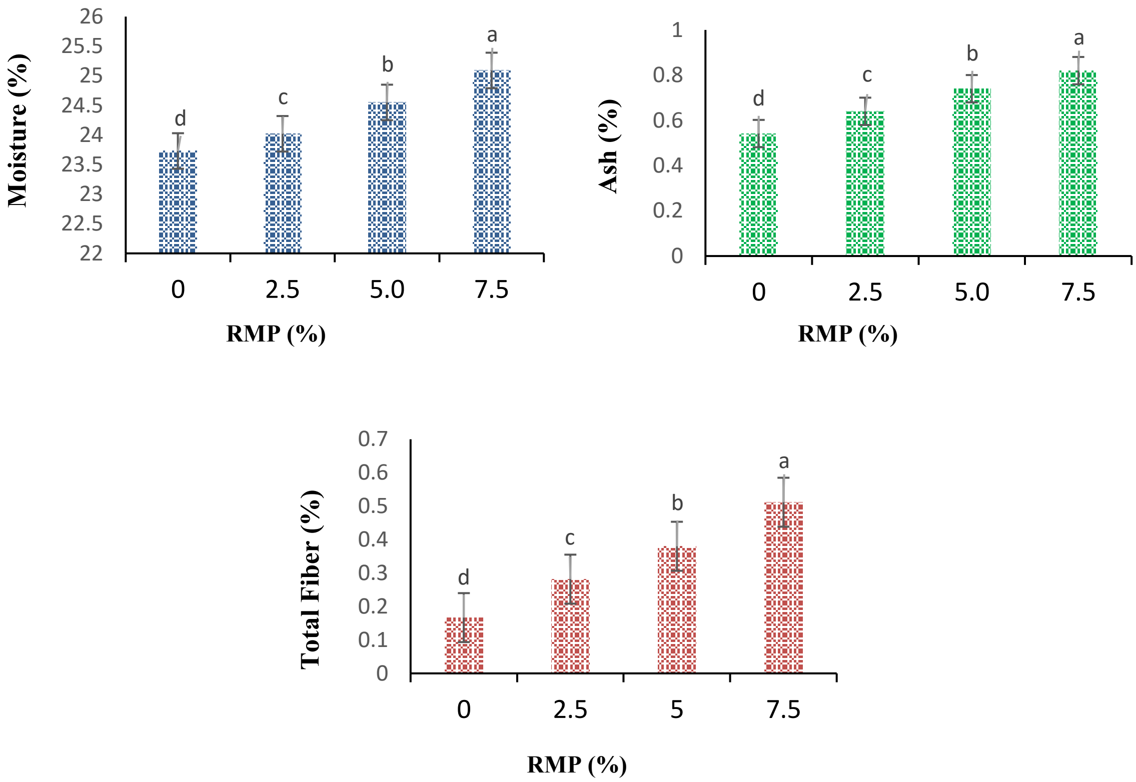


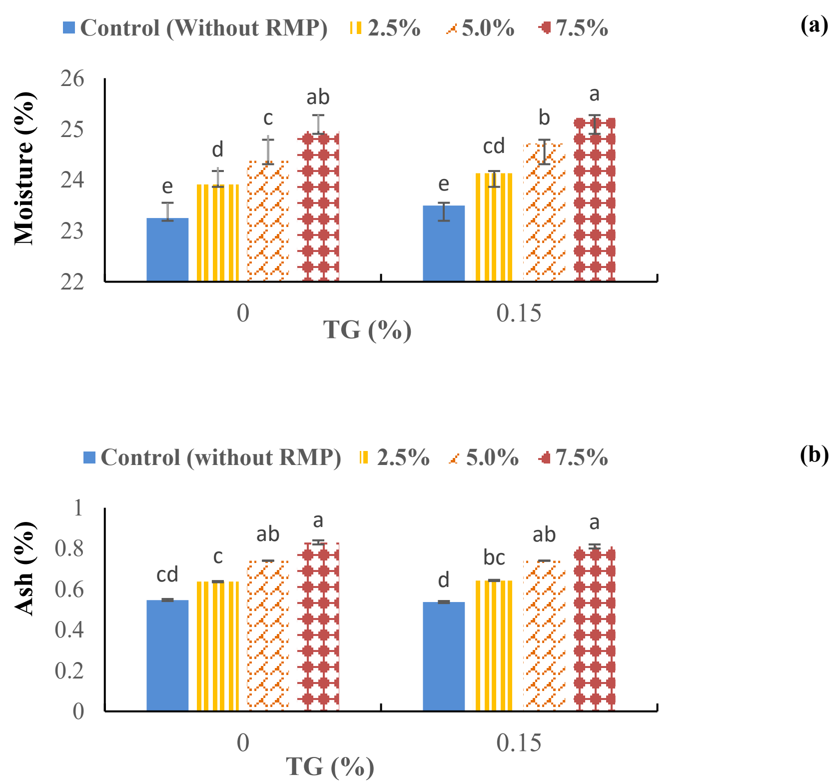
Figure 1. Effect of adding rice microgreen powder (RMP) on the nutritional composition of sponge cake

In addition to the presence of compounds such as proteins and carbohydrates, treatment with some enzymes can also affect the amount of water absorption in the product [35]. The TG enzyme creates a more cohesive protein matrix through amide bonds and crosslinking between the amino acids lysine and glutamine, and this new structure leads to an increase in the ability to retain water and, as a result, an increase in moisture in the product [36].

According to the results of the present study, TG treatment increased the moisture content of the cake samples by 7.3%.

Also, the increase in ash content in samples containing rice microgreens can be attributed to the presence of high mineral content in rice. According to the results of the study by Safari Koshali et al. [37], increasing the amount of grapefruit fiber from 0.25 to 1% increased the ash content in cookie samples. Also, Javaheripour et al. [38] reported that the use of wheat germ flour and quinoa flour significantly increased the ash content of sponge cake. On the other hand, Asghari-pour et al. [39] reported that the addition of date kernel flour improved the nutritional composition of an extruded snack, especially crude fiber. Also, Saeidi et al. [25] reported that the addition of pomegranate seed powder and transglutaminase enzyme treatment had positive effects on fiber and ash content.

The results of the interaction effects of TG and RMP enzymes on sponge cake moisture indicated that with increasing percentage of rice microgreens and transglutaminase enzyme, cake moisture content increased, so that the highest cake moisture content was observed in the sample containing 7.5% RMP along with 0.15% TG (25.22% moisture) and the lowest value of this parameter was observed in the control sample (23.25% moisture) (Figure 2-a). In this regard, Babakhani et al. [40] reported that the increase in moisture content in sponge cakes with fish protein powder and transglutaminase enzyme compared to the control cake indicates the ability of transglutaminase enzyme and fish protein powder to absorb moisture.



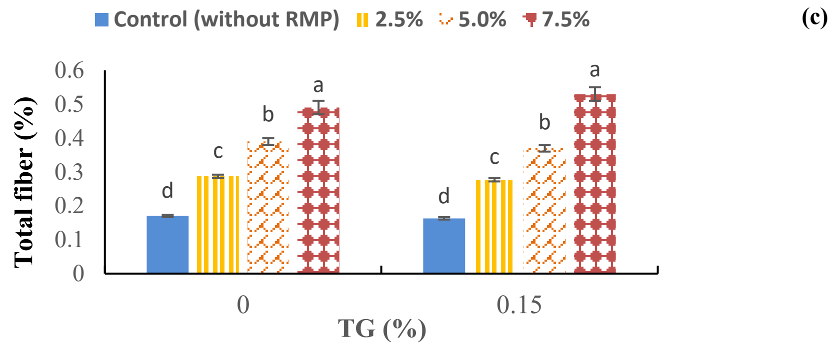


Figure 2. The effect of adding different amounts of rice microgreen powder (RMP) and transglutaminase enzyme (TG) on the moisture (a), ash (b) and fiber (c) of sponge cakes

The results of the interaction effects of TG × RMP enzyme on sponge cake ash showed that the highest amount of cake ash was 0.83% in the sample containing 7.5% rice microgreens without transglutaminase enzyme and the lowest amount was 0.55% in the control sample. However, according to Figure 2-b, no significant difference was observed between the samples containing high levels of microgreens (7.5 and 5%) with or without the enzyme. It can also be seen in this graph that the enzyme treatment had no effect on the ash percentage of the cake samples. However, Babakhani et al. showed in their research that the addition of transglutaminase enzyme and fish protein powder increased the cake ash [40]. Also, according to the results of Figure 2-c, the highest fiber content (0.53%) was obtained from the cake sample containing 7.5% RMP along with 0.15% TG enzyme, which did not differ significantly from the cake sample containing 7.5% RMP without TG enzyme (0.49%), and the lowest total fiber content (0.16%) was obtained in the cake samples without RMP treated with rice TG enzyme.

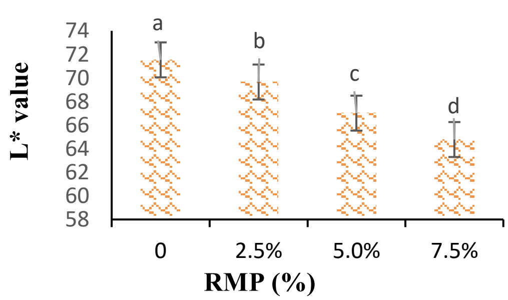
3-2- Color characteristics of cake

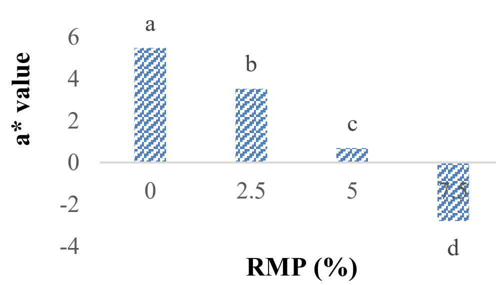
3-2-1- Characteristics of the crumb color of the cake

Cake color is one of the most important factors affecting its market acceptance. The comparison of the mean color indices L*, a* and b* showed that the addition of rice microgreen powder (RMP) caused significant differences in the levels of the aforementioned characteristics ($p<0.05$), but the addition of TG enzyme, except for the brightness index, had no significant effect in this regard ($P<0.05$). Increasing RMP in the formulation of cake samples caused a decrease in the brightness of the cake core (Figure 3). The color of the cake core is mainly related to the color of the ingredients. The presence of fiber and chlorophyll compounds in rice microgreens can be an effective factor in reducing the brightness of sponge cakes [39]. Also, by adding 5.7% RMP, the a* index or red color in the cakes was minimized, which can be attributed to the green color of chlorophyll in the rice microgreen powder used in sponge cakes. Also, the presence of RMP in the cake had a decreasing effect on the b* index (the degree of yellowness of the cake). The reason for the result can be attributed to the increase in the moisture content of the sponge cakes. The addition of RMP, by increasing the final moisture content, dilutes the effect of the reactants (sugars, amino acids) and increases the heat/evaporation capacity during baking, which can reduce Maillard browning, which produces yellow-brown pigments [41]. In similar results, Santos et al. [42] showed that adding 3.8% carrot leaf powder to sponge cake reduced the brightness and redness index.

However, contrary to the results of the present study, these researchers reported an increase in the yellowness (b*) value in the cake samples.

As can be seen in Figure 4-a, adding different amounts of RMP created a significant difference in the brightness index (*¬L) among the cake treatments and caused a significant decrease in this characteristic. In contrast, the TG enzyme treatment increased the brightness value ($p<0.05$) (Table 1). Among the different cake samples, the lowest brightness (63.94) was related to the treatment containing 7.5% rice microgreen powder without enzyme and the highest brightness (72.21) was related to the treatment without rice microgreen powder along with 0.15% transglutaminase enzyme (Figure 4-a). In fact, according to the results of this study, the higher the percentage of rice microgreen powder and the lower the percentage of transglutaminase enzyme, the lower the brightness and, consequently, the whiteness of the color. Babakhani et al. (2019) reported that excessive addition of fish protein powder increased the darkening of the cake color, and they used transglutaminase enzyme to overcome this problem and improve the quality of the cake [40]. Increased brightness as a result of TG enzymatic treatment has also been reported in other foods such as ice cream [43] and cheese [44], and the reason for this has been attributed to increased protein hydration and an increase in the number of serum pores and the creation of a porous texture [45]. As previously mentioned, TG treatment creates a more hydrated network by creating protein crosslinks that retain water better. This increases humidity, resulting in a dilution of the environment and a decrease in the likelihood of reactants encountering in Maillard browning. On the other hand, TG reduces or changes the color of the product by creating crosslinks and preventing the access of molecules participating in Maillard browning (amino acids) [35].





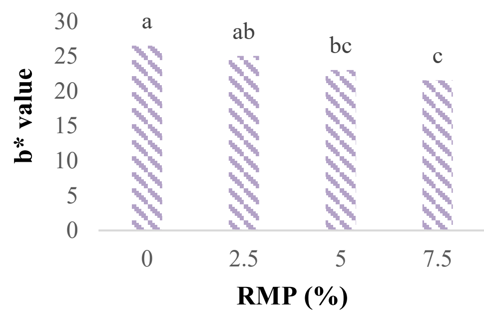
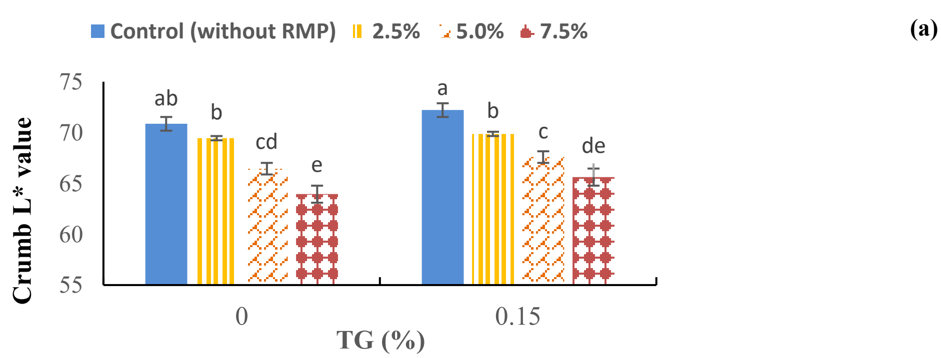
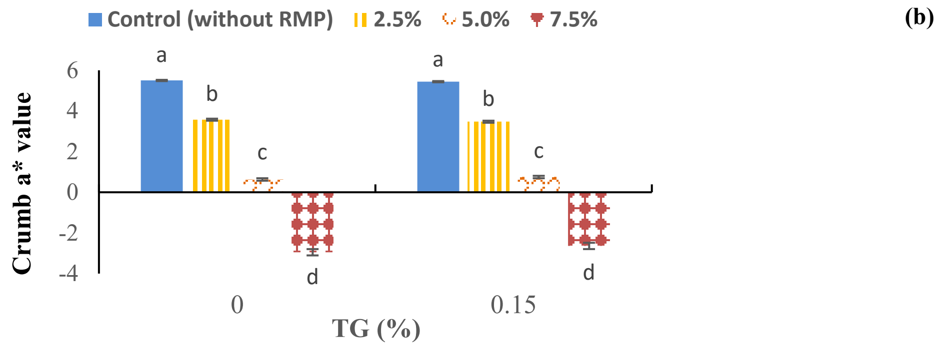


Figure 3. Effect of adding rice microgreen powder (RMP) on the crumb color values of sponge cake





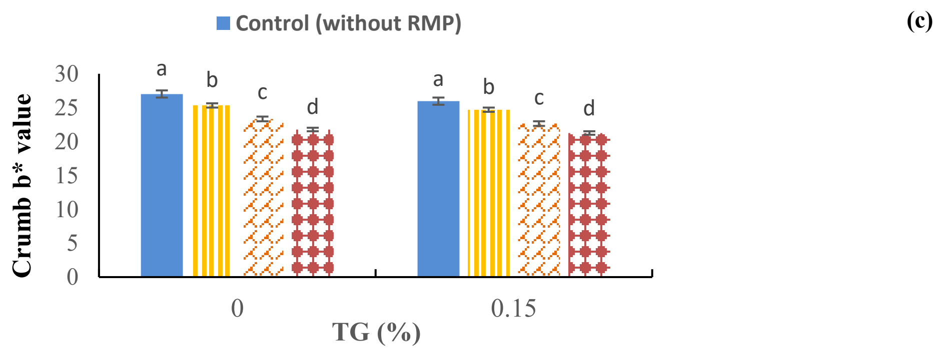


Figure 4. The effect of adding different amounts of rice microgreen powder (RMP) and transglutaminase enzyme (TG) on the crumb color values of sponge cake

According to Figure 4-b, the highest value of the cake core index*a was for the control sample (5.50), which was not significantly different from the treatment without RMP treated with 0.15% TG enzyme (5.44). The lowest value of the cake core index*a (-2.95) was for the cake sample containing 7.5% RMP without TG enzyme, which was not significantly different from the cake sample containing the maximum amount of RMP treated with TG enzyme (-2.64). Also, the highest and lowest values of the cake core index*b (cake yellowness) were for the control sample (27.02) and the cake containing 7.5% RMP treated with 0.15% TG enzyme (21.26), respectively (Figure 4-c). In fact, the addition of rice microgreen powder reduced the yellowness of the cake.

3-2-2- Characteristics of the crust color of the cake

The results of this study showed that, like the bread crumb, the addition of rice microgreen powder or RMP had a significant effect ($p<0.05$) on the L, a, and b indices of sponge cake samples (Figure 5). In contrast, like the results obtained for the bread crumb color, transglutaminase (TG) enzymatic treatment had no significant effect on the measured crust color indices except the brightness index ($P<0.05$). The results showed that with an increase in the percentage of RMP substitution, the cake color became darker and the levels of all crust color indices (*L, *b, and *a) decreased significantly. In general, the crust color of baked products is affected by the intensity of the Maillard and caramelization reactions [46]. Azadmard-Damirchi and Raei [47] reported that the effect of adding date syrup powder up to 100% caused the crust color to be darker compared to the control sample. The results of Ivani et al. [4] showed that increasing the substitution of pomegranate seed powder with wheat flour had a negative effect on the L and b indices of cake samples. Jeong and Shim [48] reported a decrease in yellowness and brightness and an increase in redness of the cake crust with increasing the substitution of oyster mushroom powder with flour used in the preparation of sponge cake. Hosseini ghaboos et al. [49], in studying the effect of adding rice bran, and Roozbahani et al. [50], in studying the effect of enriching sponge cake with mycoprotein prepared from Fusarium venenatum, also stated that adding these compounds made the cake darker. Kowalski et al., similar to the results of this study, also reported a decrease in all three measured color parameters in sponge cake samples enriched with edible insect powder [51].

According to Figure 6-a, the cake sample without rice microgreens or RMP and containing transglutaminase enzyme has the highest (61.6) and the sample without TG enzyme and containing 7.5% RMP has the lowest (14.54) L* index of the crust. Saeidi et al. [52] reported similar results in their study of the effect of adding pomegranate seed powder and transglutaminase enzyme based on flour on sponge cake. Regarding the effect of the enzyme, it should be noted that adding too much TG enzyme reduces the brightness of food products, including the cake crust. Wheat has a strong gluten network, which becomes stronger due to the addition of transglutaminase enzyme, and the cake texture is compact and its physical structure changes. In fact, the compaction of the cake texture affects the reflection of light and the color appears darker.

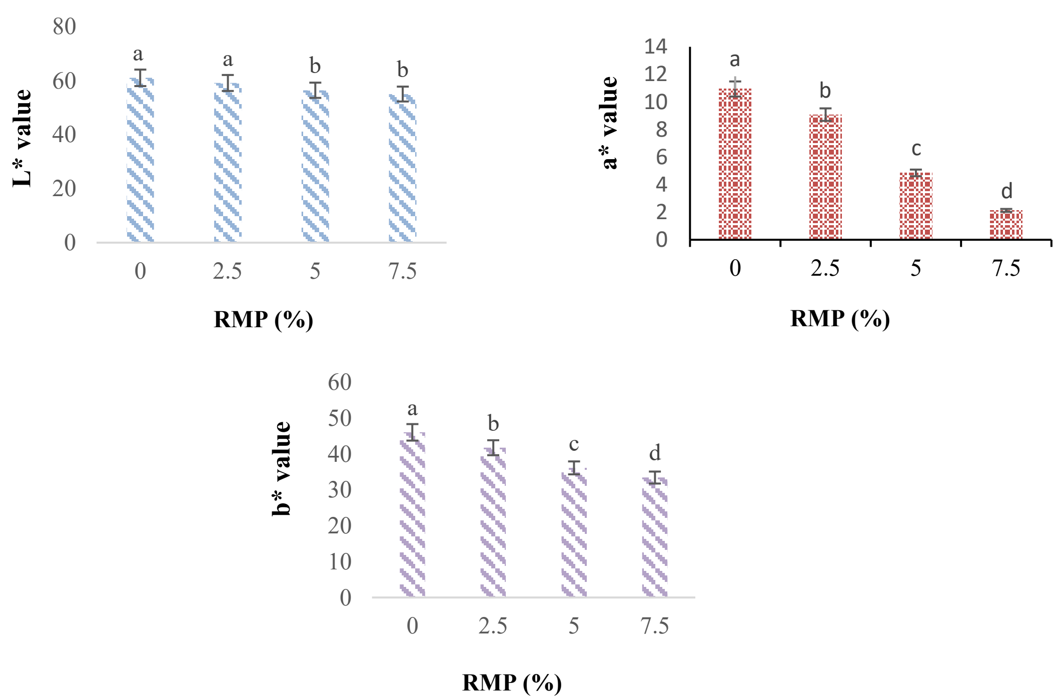
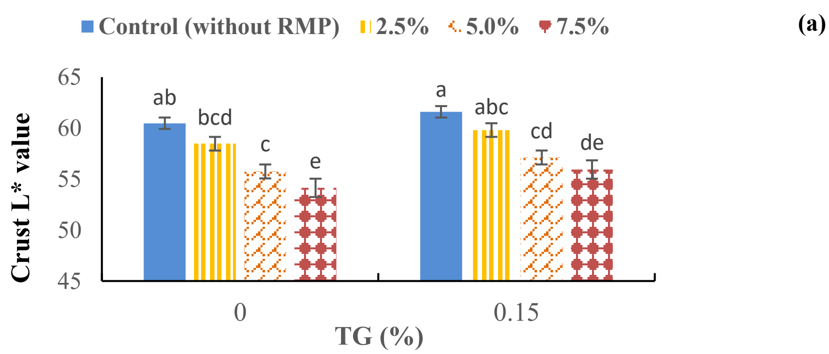
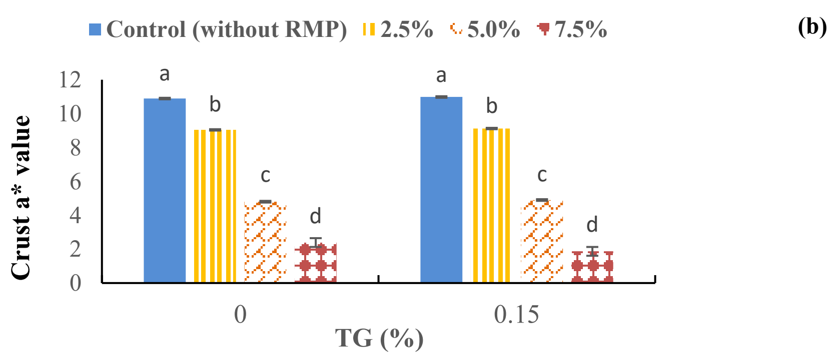


Figure 5. Effect of adding rice microgreen powder (RMP) on the crust color values of sponge cake

Figure 6-b shows the interaction between the TG and RMP enzyme variables on the *a color index of sponge cake. According to the results obtained among all cake samples containing transglutaminase enzyme and rice microgreens, the sample without RMP (with or without TG enzyme with values of 10.98 and 10.89, respectively) had the highest crust color index *a and the sample containing 7.5% RMP (with or without 0.15% TG enzyme with values of 1.87 and 2.39, respectively) had the lowest crust color index *a among the different samples. Therefore, the results showed that the addition of RMP significantly reduced the *a color index, while the TG enzyme treatment had no significant effect on the redness of the cake samples. The results of the interaction between rice microgreen powder and transglutaminase enzyme on the *b index (yellowness) of the crust of sponge cake samples also showed that among all cake samples containing transglutaminase enzyme and rice microgreen, the sample without RMP (with or without TG enzyme, with values of 44.87 and 46.12, respectively) had the highest *b color index, and the sample containing 7.5% RMP (with or without 0.15% TG enzyme, with values of 32.71 and 34.09, respectively) had the lowest *b color index of the crust among the different samples (Figure 6-c).





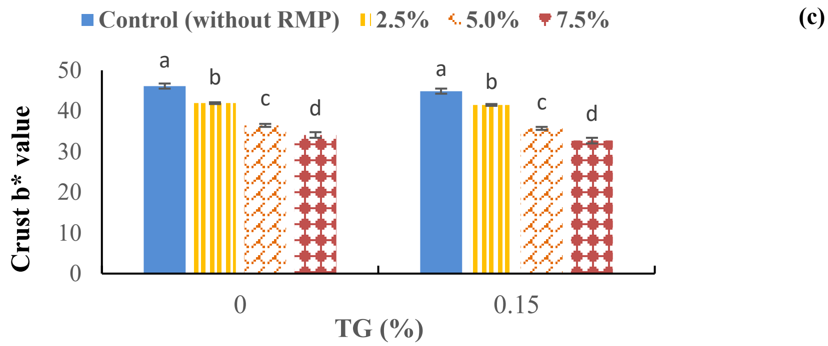


Figure 6. The interaction effect of rice microgreen powder (RMP) and transglutaminase enzyme (TG) on the crust color values of the sponge cakes

4- Conclusion

The increasing consumer demand for healthier food products has created a significant challenge for the food industry. This is especially important in the case of widely produced and consumed baked goods, where a balance between nutritional properties and taste must be achieved, as their consumption has often been questioned and criticized due to their high calorie content and lack of essential nutrients. Recent research has focused on enriching these products with functional ingredients to increase their nutritional value. This study also investigated the development of a sponge cake enriched with rice microgreen powder (RMP) along with transglutaminase (TG) enzymatic treatment to produce a product with higher nutritional value while maintaining acceptable quality. The results of the chemical properties of sponge cake samples showed that adding RMP to the sponge cake formulation significantly increased the moisture, ash, and total fiber content of the samples, such that all treatments containing 7.5% RMP had higher moisture, ash, and total fiber content than the other samples. However, no significant difference was observed between the enriched and control treatments in terms of fat and protein content ($P<0.05$). Also, the transglutaminase (TG) enzyme had a significant effect only on cake moisture ($P<0.01$) and its effect on other characteristics was insignificant ($P<0.05$). In the study of the color characteristics of the product, it was found that RMP caused a significant decrease in all color indices, but the TG enzyme did not have much effect in this regard. Given the positive effect of adding RMP, especially at levels of 5 and 7.5%, on the sensory properties of sponge cake (results not shown in this study) and improving the nutritional content of the product, this powder can be used as a suitable enrichment material in the formulation of sponge cake and other foods commercially. In addition, the combined use of TG enzyme with RMP can improve the quality of sponge cake and possibly other baked products.

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Data availability

Data will be made available on request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Author Contributions

Hossein Jooyandeh: Conceptualization, Project administration, Investigation, Visualization, Methodology, Software, Validation, Writing – review & editing.

Behrooz Alizadeh Behbahani: Conceptualization, Project administration, Investigation, Visualization & Writing - original draft.

Sara Saniee: Data collection, Formal analysis, Resources.

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بررسی تأثیر افزودن پودر میکروگرین برنج و تیمار آنزیمی ترانس‌گلوتامیناز بر ارزش تغذیه‌ای و ویژگی‌های رنگ کیک اسفنجی

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چکیده

غنی‌سازی کیک اسفنجی با میکروگرین‌ها می‌تواند با افزایش غلظت ویتامین‌ها، مواد معدنی و مواد شیمیایی گیاهی زیست‌فعال، ارزش غذایی آن را به میزان قابل توجهی افزایش دهد و از این طریق، یک شیرینی پرمصرف را به یک غذای کاربردی با فواید بالقوه برای سلامت عمومی و تأمین کافی ریزمغذی‌ها تبدیل کند. بنابراین، هدف از این مطالعه بررسی تأثیر افزودن پودر میکروگرین برنج (RMP) در چهار سطح ۰، ۲/۵، ۵ و ۷/۵ درصد (جایگزینی با آرد مصرفی، وزنی/وزنی) و آنزیم ترانس‌گلوتامیناز (TG) در دو سطح ۰، ۰/۱۵ درصد بر ترکیبات و شاخص‌های رنگی کیک اسفنجی بود. نتایج ارزیابی ترکیبات کیک نشان داد که افزودن RMP باعث افزایش معنی‌دار (P<۰/۰۰۱) رطوبت، خاکستر و فیبر کل شد، اما افزودن TG تنها موجب افزایش (P<۰/۰۱) رطوبت نمونه‌های کیک گردید و از این طریق توانست به بهبود بافت نمونه‌ها کمک کند. بررسی خواص رنگ نمونه‌ها نیز نشان داد که افزودن RMP سبب کاهش هر ۳ فاکتور رنگ (L^*، a* و b*) گردید، درحالی‌که TG تنها بر مقادیر روشنایی اثر معنی‌داری داشت و سبب افزایش روشنایی مغز و پوستهٔ نان شد (p<۰/۰۵). در یک نتیجه‌گیری کلی و براساس رنگ پوستهٔ محصول می‌توان عنوان نمود که هرچند فقط میان نمونهٔ حاوی ۲/۵ درصد RMP (با یا بدون آنزیم TG) با شاهد اختلاف معنی‌داری مشاهده نگردید، اما تمامی نمونه‌های غنی شده با RMP از کیفیت رنگ قابل قبولی برخوردار بودند. بنابراین استفاده از RMP در سطوح ۵ تا ۷/۵ درصد برای غنی‌سازی کیک اسفنجی همراه با تیمار آنزیمی TG پیشنهاد می‌گردد.