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Research Article

Effect of Green Tea Powder on Physicochemical Properties and Glycemic Potential of Sponge Cake

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Green tea powder (GTP) is rich in polyphenolic compounds, most particularly catechins. The effects of partial replacement of flour with GTP (10, 20, and 30%) on physicochemical properties, glycemic potential, and sensory attributes were investigated. Results showed a significant reduction in the moisture content, volume, and porosity of sample cakes with the increase in the GTP levels ($P \leq 0.05$). The utilization of GTP led to a harder texture and also darker color of sponge cake. The study showed that sponge cakes with good sensory attributes can be produced by the replacement of flour with 10% of GTP. Moreover, the glycemic potential and free radical scavenging activity of sample cakes improved as the GTP replacement increased ($P \leq 0.05$). GTP at 10% replacement level is recommended as it is very effective in improving the antioxidant properties, sensory attributes, and also glycemic potential.

1. Introduction

Tea is well known for its medicinal properties and health benefits, and various types of tea, such as white, black, green, or Oolong tea, are consumed in different parts of the world [1]. Consumption of green tea has the most significant effects on human health in comparison with other types of teas [2].

Green tea contains a class of polyphenolic flavonoid compounds known as catechins which contribute to the health-promoting effects ([3]. Epicatechin (EC), epicatechin gallate (ECG), epigallocatechin (EGC), and epigallocatechin gallate (EGCG) are the four main catechins in green tea [4–7].

It has been reported that green tea extract (GTE) may have a beneficial effect on the risk of developing diabetes and glucose tolerance due to the presence of bioactive compounds, which mainly act by controlling digestive enzyme activity and intestinal transit rate, resulting in a lower glycemic index [8,9]. Phenolic compounds have been shown to limit α-glucosidase and α-amylase, thus slowing down carbohydrates' digestion and glucose absorption [10–13].

However, many studies with green tea extract (GTE) have shown an insulin-enhancing activity after an oral glucose tolerance test (OGTT) [14–16]; in several studies, it was also found that GTE has an effect on insulin sensitivity, fasting glucose, or glucose levels after OGTT [17–19].

Excessive consumption of high-calorie-density foods and highly refined sugars leads to an increased incidence of chronic metabolic diseases [1]. Furthermore, high-glycemic-index (GI) diets are associated with a higher risk of type two diabetes and heart disease [20].

After bread and cookies, cakes are the most popular baked foods in the world [21]. Sugar is the main ingredient in cakes, which has an important effect on providing taste and texture [22].

Although sugar causes glucose levels to spike, it is an essential component of the cake and its removal has adverse textural and taste effects; therefore, as mentioned above, green tea powder as a rich source of phenolic compounds can reduce glucose digestion and absorption.

This study aims to formulate sponge cakes with 0%, 10%, 20%, and 30% replacement of cake flour with green tea

Table 1: The sponge cake formulation with various percentages of flour replacement with green tea powder (GTP).

Ingredients	GTP 0	GTP 10	GTP 20	GTP 30
Flour	100	90	80	70
Green tea powder	0	10	20	30
Sugar	72	72	72	72
Sunflower oil	52	52	52	52
Sodium chloride	3	3	3	3
Vanilla	0.5	0.5	0.5	0.5
Baking powder	1.34	1.34	1.34	1.34
Egg	72	72	72	72
Nonfat dry milk powder	4	4	4	4
Water	25	25	25	25

powder, to evaluate its effect on the glycemic index and physicochemical properties of cake.

2. Materials and Methods

2.1. Chemicals and Materials. Wheat flour with 6.5% protein content and 13.1% moisture content (Bartar, Iran); sugar (Golestan, Iran); sodium chloride, vanilla, and baking powder (Golha, Iran); sunflower oil (Oila, Iran); eggs (Telavang, Iran); nonfat dry milk powder (Pegah, Iran); green tea powder (IYEMON, Japan); 2,2-diphenyl-1-picrylhydrazyl (DPPH), methanol, pancreatin, amyloglucosidase, maleic acid, and ethanol (Sigma-Aldrich, Germany); and hydrochloric acid (37%), pepsin, and ethanol (96%) (Merck, Germany) were prepared and used as ingredients and also to carry out the quantitative analysis.

2.2. Sponge Cake Preparation. The sponge cakes were prepared according to a recipe and process described by [23]. The formulation consisted of variable percentages of wheat flour, which replaced green tea (Table 1), and constant amounts of sunflower oil (52 gr), fresh eggs (72 gr), sugar (72 gr), baking powder (1.34 gr), vanilla (0.5 gr), nonfat dry milk powder (2 gr), whey powder (4 gr), and water (25 gr).

The eggs, sugar, and emulsifier were mixed using a mixer (Bitron, China) at high speed for 3 min until the mixture became creamy. Flour, baking powder, and green tea powder were added to the mixture and mixed at low speed for 3 min. Sunflower oil was slowly added and mixed using a plastic spoon. The cake batter was transferred into a baking pan as a baking container (17.6 cm in diameter, 8.7 cm in height), and the baking process was immediately performed in an oven (Alton, Iran) at 180°C for 20 min. The cakes were allowed to cool for 2 h and then were removed from the pans. The cooled cakes were packed in polypropylene bags at room temperature and stored at 4°C before physicochemical and sensory evaluation analyses.

2.3. Physicochemical Characteristics Determination

2.3.1. Volume. The volume of sponge cakes was determined by solid displacement using rapeseeds [24]. The cake volume was calculated as V1 (empty cake pan volume) – V2 (rest of the volume of the cake pan after baking). The volume of sponge cake was averaged from three replications.

2.3.2. Porosity. The initial porosity of samples was calculated using the apparent density (kg of dry matter/m3 of total material including air) and the true density of the samples (kg of dry matter/m3 of total material excluding air), following the equation below [25]:

$$\varepsilon = \left(1 - \frac{\text{apparent density}}{\text{true density}}\right) \times 100. \qquad (1)$$

2.3.3. Moisture Content. The moisture of the samples was determined by drying in an oven at 105°C to constant weight [26].

2.3.4. Textural Characteristics. Texture profile analysis (TPA) was performed on cake samples by using a Texture Analyzer (TA.XTplus, Stable Micro Systems Ltd., Surrey, UK) in five replications [27]. After removing the crust of the cake samples, a cylindrical sample (diameter of 40 mm and height of 30 mm) was taken from the center of the crumb sample. The setting of Texture Analyzer was as follows: cylindrical probe diameter: 25 mm, distance = 10 mm, pretest speed = 3.5 mm/s, head speed = 2.0 mm/s, and 50% of sample compression. Hardness, springiness, cohesiveness, gumminess, and chewiness, as the textural parameters of cakes, were determined according to methods described by Bourne [28].

2.3.5. Image Analysis. Image analysis of cellular structure of the crumb was performed according to the method described by [29]. Samples were vertically sliced in 5 slices with a uniform thickness of 2 cm. The side of each slice was scanned using a scanner with a resolution of 300 dpi (HP LaserJet MFP M125nw, Shanghai, China). The scanned images were analyzed using the software ImageJ (Natl. Inst. of Health). First, the image was cropped in a 6 × 10 cm section. The image was split into color channels, then the contrast was enhanced, and finally the image was binarized after grayscale threshold. Cell density (cells' number per field [6 × 10 cm]), total cell area within the crumb, and cell circularity were calculated. The data were obtained by measuring cells in 5 different images for each formulation.

2.3.6. Color Measurement. The color parameters of L^* (lightness), a^* (redness), and b^* (yellowness) values were determined for the cake crust and crumb according to [30].

The crust and crumb color of the cakes were evaluated by taking images using a digital camera (SX40, Canon, Japan) in a space with color temperature of 6500 K. The resolution, contrast, and lightness of the images were set at 300 (dpi), 50, and 50%, respectively. The pictures were saved in TIFF format and analyzed by use of the ImageJ software (Natl. Inst. of Health). Conversion of RGB images into $L^*a^*b^*$

units was carried out using color space converter plugin under the illumination standard (D65).

2.3.7. Antioxidant Activity. Antioxidant activity of sample solutions was evaluated on 1,1-diphenyl-2-picryl-hydrazyl radicals (DPPH) according to the method in [31]. The cake samples (0.4 g) were extracted twice with 10 ml of a methanol-water solution (80 ml/ 100 ml) by shaking at 30°C for 1 h. After pooling the extracts, the residues were re-extracted again with 10 ml of a methanol-water solution (80 ml/ 100 ml) at 30°C for 12 h. The sample extracts were pooled and then filtered through a filter paper (Whatman No. 1). The filtrates were moved into a sample vial for DPPH radical scavenging.

Briefly, 0.1 mM solution of DPPH in ethanol was prepared, and 1 ml of this solution was added to 3 ml of the GTP extract solution in water at different concentrations (12.5–62.5 mg/ml). Thirty minutes later, the absorbance was measured at 517 nm. Lower absorbance of the reaction mixture indicates higher free radical scavenging activity. The DPPH concentration in the reaction medium was calculated from a calibration curve, determined by linear regression.

2.4. Glycemic Potential Determination. The effect of green tea powder on the glycemic potential of sponge cake was evaluated by determining the glucose after in vitro pancreatic digestion which was performed according to the method of [32].

Cake samples were cut into cubes (0.5 cm), weighed, and then transferred into biopsy pots containing 30 mL distilled water and a magnetic stirring rod with continuous stirring at 130 rpm. The biopsy pots were placed in a water bath (Memmert WNB10, Germany) with a constant temperature of 37°C.

The pancreatic digestion was carried out by the following steps: first, 1 mL of 5% pancreatin and 0.1 mL of amyloglucosidase were added to 0.2 M maleate buffer. Timed aliquots of 0.5 mL were removed after 20, 60, 90, 120, and 180 min and then moved to test tubes containing 2 mL absolute ethanol. The contents were stored at −20°C before HPLC (Agilent, USA) analysis.

Rapidly digestible starch (RDS) was considered as the amount of glucose present in the sample aliquot that was determined at 20 min from the beginning of pancreatic digestion while slowly digestible starch (SDS) was determined as the difference between the amount of glucose measured at 120 and 20 min.

2.5. Sensory Evaluation. Sensory analysis of the samples was performed 24 hours after baking to evaluate the overall acceptability of the samples by determining the mean score of sensory properties including mouthfeel, taste, flavor, texture, and color. The samples were sliced into pieces of uniform thickness and served with water. Twenty semi-trained panelists (10 males and 10 females) were selected from students and used for the study. Panelists evaluated cake samples using a 5-point hedonic scale (1 = extremely disliked, 5 = extremely liked). Samples were presented to a panel of judges with a 3-coded digit number. The pieces of cakes were served at room temperature in random order [33].

2.6. Statistical Analysis. Each measurement was carried out in triplicate (three independent batches of cake) with the mean values as well as standard deviations calculated. The experimental data were analyzed using an analysis of variance (ANOVA) for a completely random design. All tests were conducted at the 5% significance level, and SPSS software (version 22.0) was used to perform statistical analysis [34].

3. Results and Discussion

3.1. Physical Characteristics

3.1.1. Weight and Moisture. The obtained weight and moisture content of the sponge cakes with various percentages of flour replacement with green tea powder (GTP) are presented in Table 2. By increasing the GTP replacement, the sample weight and moisture content were decreased from 299 to 295 g and 25 to 22%, respectively. The results showed no significant differences between all the tested groups for the weight and moisture of all sponge cakes. These results are in agreement with the results obtained by [24] who reported a slight decrease in moisture content from 36 to 35% and weight from 22.6 to 22.4 g by increasing the GTP replacement in sponge cake.

3.1.2. Volume and Porosity. The volume of cake samples decreased significantly with an increase in the GTP replacement ($P \leq 0.05$) up to 38% compared to the control. The obtained results revealed that the cake volume and porosity were reduced when GTP was added. The GTP 30 led to a 555 ml decrease in sponge cake volume. The same results were reported for cakes with green tea [24] and apple pomace [35]. A significant decrease in the porosity of sponge cakes was noted with the increase in the replacement of flour with GTP.

The results of image analysis (Table 3) showed that an increase in the replacement of flour with GTP decreased the cell diameter and the cell number per mm2 in cake samples.

Wang et al. evaluated the porosity in green tea extract-fortified bread using image analysis and reported a reduction in cell numbers and total cell area in the bread with the increase in green tea extract levels [36].

During the baking process, gas is produced and vapor pressure is increased. The gluten network is responsible for retaining gas during rising and heating stages [37]. Thus, the replacement of flour with GTP in cake led to weakening the gluten matrix responsible for gas retention, which affects the volume and consequently the porosity [24].

3.2. Texture Characteristics. The changes in TPA parameters of sponge cake with added GTP are presented in Table 4. The hardness of samples indicated that the sponge cakes became

Table 2: Weight, volume, moisture content, and porosity of various sponge cake samples.

	Control	GTP 10	GTP 20	GTP 30
Weight (g)	302.0000 ± 2.00A	299.6667 ± 2.51AB	297.6667 ± 2.08BC	295.3333 ± 1.52C
Volume (ml)	1431.0000 ± 4.58A	1397.0000 ± 2.64B	1186.0000 ± 4.00C	876.3333 ± 7.57D
Moisture (%)	27.3333 ± 1.52A	25.6667 ± 2.51AB	23.6667 ± 1.52BC	22.0000 ± 1.00C
Porosity (%)	74.0000 ± 2.00A	70.0000 ± 1.00B	63.3333 ± 1.52C	51.0000 ± 2.00D

Control, GTP 10, GTP 20, and GTP 30: prepared with 0%, 10%, 20%, and 30% replacement of cake flour with green tea powder, respectively. Each value is expressed as mean ± standard deviation (n = 3). Means with the same letters within a column are not significantly different (P > 0.05).

Table 3: Results of image analysis of various sponge cake samples.

	Control	GTP 10	GTP 20	GTP 30
Number of cells per mm^2	4.3 ± 0.3	5.6 ± 0.2	6.6 ± 0.2	7.8 ± 0.3
Mean diameter, mm	0.25 ± 0.03	0.18 ± 0.04	0.09 ± 0.01	0.01 ± 0.01

Control, GTP 10, GTP 20, and GTP 30: prepared with 0%, 10%, 20%, and 30% replacement of cake flour with green tea powder, respectively. Each value is expressed as mean ± standard deviation (n = 10). Means with the same letters within a column are not significantly different (P > 0.05)

Table 4: Texture profile analysis of various sponge cake samples.

	Control	GTP 10	GTP 20	GTP 30
Hardness	1.5533 ± 0.02A	1.6833 ± 0.02B	1.9900 ± 0.03C	2.6200 ± 0.04D
Cohesiveness	0.81 ± 0.02A	0.78 ± 0.03AB	0.7367 ± 0.02B	0.65 ± 0.02C
Springiness	0.90 ± 0.02A	0.8800 ± 0.02A	0.7900 ± 0.02B	0.6800 ± 0.02C

Control, GTP 10, GTP 20, and GTP 30: prepared with 0%, 10%, 20%, and 30% replacement of cake flour with green tea powder, respectively. Each value is expressed as mean ± standard deviation (n = 5). Means with the same letters within a column are not significantly different (P > 0.05).

Table 5: Color properties of various sponge cake samples.

	Control	GTP 10	GTP 20	GTP 30
Crust				
L	53.2667 ± 1.06A	47.7000 ± 1.05B	41.0667 ± 1.32C	37.0000 ± 1.47D
a	13.2000 ± 0.10A	11.3667 ± 1.35A	9.1000 ± 1.41B	8.2000 ± 1.15B
b	19.0667 ± 0.208A	18.2667 ± 0.30B	17.5000 ± 0.20C	16.3000 ± 0.50D
Crumb				
L	82.4667 ± 1.90A	50.3333 ± 1.52B	46.1667 ± 1.13C	43.4333 ± 1.15C
a	4.2000 ± 0.30A	1.3333 ± 0.15B	0.1333 ± 0.50C	−1.5667 ± 0.32D
b	19.8667 ± 0.70A	17.9333 ± 0.15B	17.2000 ± 0.10B	16.0667 ± 0.30C

Control, GTP 10, GTP 20, and GTP 30: prepared with 0%, 10%, 20%, and 30% replacement of cake flour with green tea powder, respectively. Each value is expressed as mean ± standard deviation (n = 5). Means with the same letters within a column are not significantly different (P > 0.05).

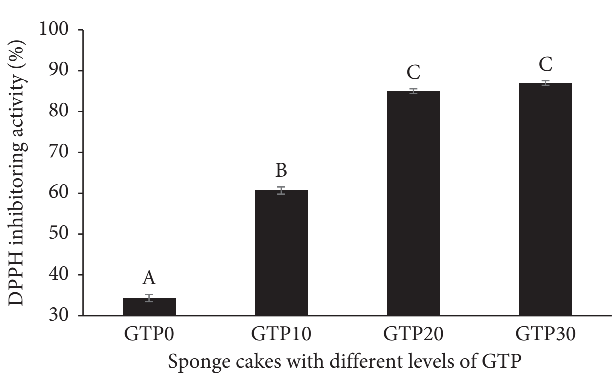

Figure 1: The antioxidant activity of cake samples with different GTP levels.

harder and lost flexibility with increased levels of GTP. An increase in chiffon cake and sponge cake hardness with the increase of GABA tea and black garlic powder, respectively, was reported in previous studies [38,39].

The structural and conformational changes of the protein in food can be affected by the interaction of hydrogen bonding and the hydrophobic interaction between protein molecules and phenolic groups [40,41]. Increasing the GTP replacement increases the phenolic compounds, which leads to more hydrogen bond formation between protein molecules and phenolic groups and consequently a harder texture.

In texture profile analysis, the cohesiveness parameter, as the ability of a material to stick to itself, presents the internal resistance of cake structure [42]. The obtained results indicated a significant decrease in samples with an increased level of GTP. This result shows that the sponge cakes formulated with GTP have a low ability to resist before the cake structure break down under the teeth.

Pasukamonset et al. found that the sponge cakes with *Clitoria ternatea* showed a significant decrease in the cohesiveness compared to the control cake [43]. A similar trend of decreased cohesiveness was also seen in the cake with added tea powder [44].

Table 6: Sensory evaluation of various sponge cake samples.

	Control	GTP 10	GTP 20	GTP 30
Crust color	6.1000 ± 0.30A	7.4000 ± 0.30B	5.0667 ± 0.25C	3.2333 ± 0.25D
Crumb color	6.7333 ± 0.15A	7.4667 ± 0.35B	5.5000 ± 0.36C	4.4000 ± 0.20D
Flavor	5.7667 ± 0.15A	6.3333 ± 0.15B	5.2333 ± 0.15C	5.1000 ± 0.30C
Texture	7.9333 ± 0.20A	7.1000 ± 0.15C	5.5667 ± 0.15C	3.2667 ± 0.25D
Overall	6.2667 ± 0.15A	7.1000 ± 0.26B	5.6333 ± 0.11C	5.3167 ± 0.10C

Control, GTP 10, GTP 20, and GTP 30: prepared with 0%, 10%, 20%, and 30% replacement of cake flour with green tea powder, respectively. Each value is expressed as mean ± standard deviation ($n = 20$). Means with the same letters within a column are not significantly different ($P > 0.05$).

Table 7: The glycemic potential of various sponge cake samples.

	RDS	SDS
Control	70.6667 ± 1.52A	37.6667 ± 1.52A
GTP 10	64.0000 ± 2.00B	33.3333 ± 2.08B
GTP 20	58.6667 ± 2.51C	26.6667 ± 1.15C
GTP 30	44.6667 ± 1.52D	22.3333 ± 2.08D

Control, GTP 10, GTP 20, and GTP 30 are prepared with 0%, 10%, 20%, and 30% replacement of cake flour with green tea powder, respectively. Each value is expressed as mean ± standard deviation ($n = 3$). Means with the same letters within a column are not significantly different ($P > 0.05$).

The extent of recovery between the first and second compression represents the elasticity of sample cakes and is described as the springiness value. The obtained results showed that the addition of GTP to cake formulation leads to a decrease in the cake springiness. The same result was obtained by [24] for springiness changes in sponge cakes with green tea.

Generally, by the addition of GTP to cake formulation, hardness increased whereas cohesiveness and springiness were decreased. These results are in agreement with the previous studies on sponge cake containing green tea [24], Cheonnyuncho powder [37], and tea powder [44].

3.3. Color Characteristics. The results of the current investigation regarding the color evaluation of sponge cake with GTP are presented in Table 5. A decrease in lightness, redness, and yellowness indexes for crust and crumb was observed. The lightness, redness, and yellowness indexes for crust were decreased up to 30, 36, and 15%, and for crumb up to 47, 131, and 16%, respectively.

These results are further assured by the work of [24], which substituted wheat flour with green tea powder in sponge cake indicating that using green tea powder resulted in a darker color. They reported that the changes in color indexes may be because green tea powder has coloring matter which created a darker color of cake; moreover, oxidation of polyphenols also participated in the darker look [45].

3.4. Antioxidant Activity. The antioxidant activity of cake samples with different GTP levels is presented in Figure 1. The results showed that the addition of GTP to the cakes significantly increased their antioxidant activity. Overall, the effectiveness in scavenging ability on DPPH radicals was in the descending order GTP 30 > GTP 20 > GTP 10 > control. This improvement in antioxidant properties of the cakes with green tea was due to the presence of phenolic compounds, mainly various catechins that existed in GTP, which had been shown to possess antioxidant activity [24].

Results show that the increasing rate of antioxidant activity decreased with the increase of the GTP replacement levels up to 20% and there was no significant difference between antioxidant activity of GTP 20 and GTP 30 ($P \geq 0.05$). It seems that a critical concentration of phenols is sufficient for maximum antioxidant activity, and it may be due to reaching the saturation level [46].

Bajerska et al. evaluated the effect of green tea extracts on the antioxidant properties of rye bread and reported that scavenging ability of cake increased with increasing green tea extra levels [47]. Furthermore, the same results were reported by [44] who tried to use green tea powder in chiffon cake.

3.5. Sensory Evaluation. Means of sensory property scores including crust and crumb color, flavor, texture, and overall acceptability of cake samples are presented in Table 6. The cake sample with 10% GTP had the highest score in all sensory parameters except texture. The highest texture score was achieved for the control sample. It was observed that adding GTP could be effective in changing the sponge cake color and resulted in a darker color. According to the sensory scores, it was found that substituting 20% flour with GTP could improve the color, odor, and flavor of sponge cake, and excessive GTP could decrease the organoleptic attributes of samples. As presented in Table 4, GTP 20 had the highest score in overall acceptability, whereas GTP 30 scored lower than the other ones. It was concluded that limited usage of GTP can improve the appearance features of sponge cakes, but excessive GTP can result in reducing the sensory quality of sponge cakes as well as the consumers' purchasing intention. The obtained results are assured by [24,48].

3.6. Glycemic Potential. The determined amount of RDS and SDS for cake samples with various GTP levels was presented in Table 7. This study demonstrated that there was a significant reduction in RDS and SDS amount with an increase in the utilization of GTP in sponge cakes. This means the presence of GTP could result in reduced digestibility of sponge cake. The amount of RDS shows the amount of readily digestible starch and has an essential role in predicting the acute in vivo postprandial glycemic response [49].

It was reported that phenolic compounds in green tea such as catechins inhibited the activity of a-glucosidase and a-amylase which are key enzymes for the digestion of starch. [50,51].

Goh et al. evaluated the effects of GTE on the in vitro digestibility of green tea extract-fortified bread and reported a significant reduction in glucose release from the green tea extract-fortified bread at concentrations of 2% GTE [32].

Considering the effect of GTP on reducing the glycemic response after ingestion of sponge cake, such formulated cake with GTP can be beneficial for reducing the risks of developing type-2 diabetes [52].

4. Conclusion

This study revealed that the consumption of GTP in sponge cake caused a significant reduction in the moisture content, volume, and porosity of samples. In addition, a harder texture and darker color of sponge cake were observed with the addition of GTP. With increasing in the level of GTP, the glycemic potential and antioxidant properties of sponge cake increased significantly. The sensory evaluation results showed that 10% replacement is satisfactory as compared to other GTP levels replacement. In conclusion, this study indicates that 10% flour replacement with GTP can be incorporated in sponge cake to enhance functional properties such as glycemic potential and antioxidant properties.

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article. Raw data were generated during this project, and derived data supporting the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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