



Effect of green tea powder on the quality attributes and antioxidant activity of whole-wheat flour pan bread



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ABSTRACT

The effects of green tea powder (GTP) on the quality attributes and antioxidant activity of whole-wheat flour (WWF) pan bread were studied. Crumb hardness, cell diameter, and chewiness of WWF pan bread increased at higher GTP levels, whereas specific volume and brightness showed a reverse trend. At the 1.00 g GTP/100 g flour addition level, hardness, resilience and specific volume of WWF pan bread were not significantly affected, but antioxidant activity increased by 1.00 mM TE/g sample. In the storage test, GTP greatly inhibited the production of peroxide, as determined by peroxide value (PV), in WWF pan bread. After 8 days of storage at room temperature, the PV of the lipid fraction of WWF pan bread without GTP (control) increased by 0.35 mg/100 g, while the PV of bread with the addition of 1.00 g GTP/100 g flour increased by 0.14 mg/100 g. These results suggest that the addition of GTP at the 1.00 g/100 g flour level effectively increases the antioxidant activity, and significantly reduces the production of peroxide during storage, while at the same time maintaining the baking quality of WWF pan bread.

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1. Introduction

Pan bread is one of the most widely consumed grain products in the world. Whole-wheat flour (WWF) pan bread is preferred by more consumers because of its high dietary fiber and bioactive substances, which not only reduce cholesterol levels but also decrease the risk of colon cancer (Lynnette & Philip, 1996; Okarter & Liu, 2010). To meet the growing demand for healthy and low-calorie foods, the development of bread products made with WWF, with its high content of dietary fiber and unsaturated fatty acids, could be an effective way to promote high-fiber food consumption and improve dietary patterns (Niu, Hou, Lee, & Chen, 2014; Mozaffarian, Lee, & Kennedy, 2013). However, the unsaturated fatty acids in WWF are susceptible to oxidation under high temperatures and/or light conditions, which decreases the nutritional value and makes the product unpalatable. The overall antioxidative capacity of whole wheat bread was reduced during storage as the lipid hydroperoxides were peaked after 2–3 weeks of storage (Jensen, Oestdal, Clausen, Andersen, & Skibsted, 2011). The addition of shortening in bread formulation could also contribute to

the oxidation and might be considered as a source of oxidation products.

The oxidation of unsaturated fatty acids, monitored by peroxide value (PV), UV spectrophotometry, or high performance size exclusion chromatography of polar compounds of the lipid fraction (Bilancia, Caponio, Sikorska, Pasqualone, & Summo, 2007; Caponio, Gomes, Pasqualone, & Summo, 2007), reduces the shelf life of food products (Zhou, Chen, Zhang, Jiang, & Cao, 2002). Flour bleaching agent (i.e., benzoyl peroxide), bread improver (i.e., potassium bromate) and preservatives (i.e., calcium propionate) are frequently added to bread to improve quality and extend shelf life. However, such kinds of chemical additives may lead to acute or chronic poisoning (Varriano, Hsu, & Mahdi, 1980). At the same time, the requirements of consumers (in terms of flavor, nutrition and health) have become more stringent.

Tea is one of the most popular beverages in the world, and its strong antioxidant activity has drawn increasing attention in recent years (Mildner-Szkudlarz, Zawirska-Wojtasiak, Obuchowski, & Gośliński, 2009). Many researchers have reported that green tea contains antioxidant compounds (Karori, Wachira, Wanyoko, & Ngure, 2007), and have confirmed that green tea has stronger antioxidant ability than black tea (Lee, Lee, & Lee, 2002). Additionally, tea can prolong the shelf life of food products without

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affecting their organoleptic or nutritional qualities (McKay & Blumberg, 2002; Wang, Provan, & Helliwell, 2000). These biological properties are believed to result mainly from the functions of catechins (a major type of tea polyphenols that exhibits high antioxidant activity). Green tea powder (GTP) is powder-formed green tea leaves (ground powder, not instant tea powder), and retains almost all of the catechins of fresh tea leaves. In addition to bioactive components, GTP is a rich source of cellulose, proteins and vitamins. As a natural ingredient, GTP has been incorporated into a wide range of foods, such as biscuits, ice cream, and beverages (Liang & Lu, 2013), but it has never been used in pan bread, especially WWF pan bread.

The aims of this study were to investigate the quality characteristics of WWF pan bread with the addition of GTP at 0.00 g, 1.00 g, 2.00 g, 3.00 g, and 4.00 g/100 g flour levels, and to evaluate the antioxidant activity of GTP and its effect on the quality of pan bread. Additionally, a storage test at 37 °C (90 °F) and 65% relative humidity was conducted to evaluate the production of peroxide in the WWF pan bread.

2. Materials and methods

2.1. Materials

Hard white WWF was kindly provided by Ardent Mills (Denver, CO). Protein, moisture, lipids and ash contents of the flour were 12.70 g/100 g (14% mb), 8.70 g/100 g, 2.50 g/100 g (14% mb), and 1.60 g/100 g (14% mb), respectively. GTP was provided by Shao Xing Royal Tea Village Co. Ltd. (Shao Xing, Zhejiang Province, China). The mean particle size of GTP was 90 µm as measured by the laser particle-size analyzer (Haoyu Technology Co. LTD, Dan Dong, Liaoning Province, China). GTP was stored at 5 °C (40 °F) without light until further use. The contents of total phenolic, catechins, protein, vitamins C and E, and cellulose in GTP were 17.20 g/100 g, 12.90 g/100 g, 23.20 g/100 g, 0.80 g/100 g, and 24.10 g/100 g (dry basis), respectively. The antioxidant capacity of catechins is 1.46 mM TE/g.

2.2. Dough mixing properties

Dough characteristics were determined using the Mixolab (Chopin Technologies Inc. Paris, France). In the “Chopin+” protocol (AACC International Approved Method 54–60.01), the dough weight is 75 g, and the target consistency (C1) is 1.1 Nm (± 0.05 Nm). The mixing tank temperature was maintained at 30 °C (86 °F) by a circulating water bath, and the mixing speed was 80 rpm. The time required to achieve C1 (T1), stability time, the torque of starch gelatinization (C3), the torque of hot gel stability (C4), and the torque of starch retrogradation in the cooling phase (C5) were measured.

2.3. Preparation of whole-wheat flour pan bread containing green tea powder

WWF breads were prepared according to the AACC International Approved Method 10-10B with some modifications. Bread formulation was: WWF (187.98 g, 14% mb), water (166.00 g), shortening (6.00 g), sugar (12.00 g), salt (3.00 g), non-fat dry milk (2.00 g), Lesaffre instant dry yeast (2.00 g), malted barley flour (0.40 g). GTP was added at the levels of 0.00, 1.00, 2.00, 3.00, and 4.00 g/100 g flour. WWF, GTP, and other dry ingredients were blended in a Swanson mixer (National Mfg. Co. Lincoln, NE) for 1 min. Water and shortening were added and mixed for ~6 min until the dough fully developed. The dough was divided into two 170 g pieces, placed in two lightly greased stainless steel bowls, and fermented in a

fermentation cabinet (National Mfg. Co. Lincoln, NE) for 180 min at 30 °C (86 °F) and 85% RH. The fermented dough had its first punch at 105 min of fermentation, and its second punch at 155 min of fermentation. After 180 min of fermentation, the dough was molded with an Oshikiri molder (WFS, Oshikiri Machinery LTD, Tokyo, Japan), and placed into the baking pan and proofed for 60 min at 30 °C (86 °F) and 85% RH. The proofed bread dough was then baked at 204 °C (400 °F) for 26 min. After 60 min cooling at room temperature, bread was measured for volume and specific volume (volume divided by weight), and then cut mechanically into 20 mm-thick slices using a BIZERBA Bread Slicer (Model B100, Bizerba GmbH & Co. KG, Balingen, Germany) for crumb texture, color intensity and morphology measurement tests. The bread-making trials were replicated three times.

2.4. Pan bread quality analysis

2.4.1. Volume and specific volume

After cooling to room temperature for 60 min, bread weight was measured using a balance scale (Mettler Toledo, Schwerzenbach, Switzerland). Loaf volume and specific volume (volume divided by weight) were determined using a Bread Volume Measurer (Model: BVM-L370, TexVol Instruments AB, Viken, Sweden).

2.4.2. Color intensity and morphology of bread crumb

Color intensity was measured using the C-Cell (Model: CC.400.01; Calibre Control International Ltd. Warrington, UK) and was expressed as brightness, L^* , a^* , and b^* values. The lightness value (L^*) represents the black-white colors; a^* represents the green-red colors; and b^* represents the blue-yellow colors. Morphology of crumb grain was characterized by cell number, cell diameter, and wall thickness. The above-mentioned analysis was conducted in 10 replicates.

2.4.3. Texture profile analysis

The texture profile analysis (TPA) of bread was conducted using a TA-XTPlus Texture Analyzer (Texture Technologies Corp. NY) according to the method described by Fan, Yu, and Wang (2014). The bread slice (20 mm thickness) was placed on a flat Lexan plate and compressed to 30% of its original thickness at a speed of 3.0 mm/s using a 1 in (25 mm) diameter cylindrical acrylic probe (Model: TA-3); the compression was paused for 5 s after 30% compression. Hardness, springiness, chewiness and resilience were measured.

2.4.4. Antioxidant activity and peroxide value

Bread slices were packaged in plastic bags and sealed with an Impulse Heat Sealer (Model: MP-20, Midwest Pacific, Rocky Mount, NC). Slices in plastic bags were stored in an environment chamber (National Mfg Co. Lincoln, NE) at 37 °C and 65% RH for 8 d according to the procedure of Ren, Chen, and Jing (2011). Each treatment had three sets of bagged bread slice samples, and two slices were taken from each set at 0, 4 and 8 d, respectively. They were cooled for 20 min at -40 °C, followed by freeze-drying for 12 h at -80 °C. Later, the freeze-dried samples were ground to pass through a 60-mesh sieve for measuring antioxidant activity and peroxide value (PV).

2.4.4.1. Antioxidant activity. The antioxidant activity of the bread with different added amounts of GTP was determined by the 2, 2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) assay method (Bae, Lee, Hou, & Lee, 2014). ABTS solution (7 mmol/L) was prepared by dissolving ABTS (Sigma Aldrich, St. Louis, MO) in deionized water, and was allowed to react with 2.45 mM potassium persulfate in the dark at room temperature for 16 h. The ABTS solution was diluted with phosphate-buffered saline (0.01 mol/L, pH

7.4) until the absorbance reached 0.700 ± 0.020 at 734 nm. The ABTS reagent (1 mL) was added to the extract (0.01 mL) and was then incubated at 30 °C (86 °F) for 6 min. The absorbance was measured at 734 nm using a spectrophotometer (DU 730, Beckman Coulter Inc. Fullerton, CA). The antioxidant activity was expressed as Trolox equivalents (TE) per gram of sample on a dry weight basis.

2.4.4.2. Peroxide value. Each bread slice (200 g, freeze-dried) was placed in a 500 mL conical flask, and 240 mL petroleum ether (Shanghai Biological Co. LTD, Shanghai, China) was added. After 14–18 h extraction, the solution was distilled for 15 min with a rotary evaporator to remove petroleum ether. The residue was air-dried for 1 h at 50 °C (122 °F), and lipids were obtained. The lipids (3–5 g) were dissolved in 30 mL chloroform and glacial acetic acid solution (V:V = 2:3), and allowed to react for 3 min in the dark. Then 80 mL of distilled water was added along with 1 mL starch indicator (10 g/L), and the solution was titrated with 0.01 N sodium thiosulfate standard solution (Shanghai Biological Co. LTD, Shanghai, China). PV was calculated using the following equation: $PV (\text{mg}/1000 \text{ g}) = 1000(V - V_0) \times 0.1269 \times C (\text{mol}/\text{L})/W$ (Zhang, Li, & Qian, 2011). V (mL) is the volume of the sodium thiosulfate standard solution used for titration, and V_0 (mL) is the volume of the sodium thiosulfate standard solution used for the blank test. C is the concentration of the sodium thiosulfate standard solution, and W is the weight of lipids.

2.4.5. Statistical analysis

All measurements were performed at least in triplicate, and bread making trials were replicated three times. Statistical analyses were carried out with DPS software (V.9.50, DPS Institute, China) for Windows using one-way analysis of variance (ANOVA). $P < 0.05$ was considered to be significant using Duncan's test.

3. Results and discussion

3.1. Effect of green tea powder on whole-wheat flour dough properties

The effect of GTP on WWF dough properties is shown in Table 1. There were significant differences ($P < 0.05$) in development time (T1), C3, and C5 between the control flour (no GTP) and the flour groups with added GTP. There were also significant differences ($P < 0.05$) in stability time and C4 between the control flour and the flour groups containing 2–4% added GTP. T1 refers to the dough development time; stronger flour typically has longer development time, but it is also affected by dough hydration rate. Higher fiber content in GTP-fortified flour groups was likely responsible for longer T1 as fiber competed for water and delayed gluten development during mixing. Stability time represents the mixing tolerance of dough, and the dough seemed to become stronger with increasing GTP addition. C3 represented the maximum torque of

dough in the heating stage, and GTP significantly reduced C3 compared to the control, which may be attributed to the gelation properties of the protein in tea. C4 indicated the hot-gel stability of dough, which became stronger with increasing GTP addition. C5 related to starch retrogradation in the cooling phase, which became greater with increasing GTP addition. GTP contains 23.2% protein, which may be involved in gluten development. However, GTP is a complex system containing not only protein but also phenolic antioxidants (catechins, 12.90 g/100 g) and dietary fiber (cellulose, 24.10 g/100 g), which exert different effects on the quality of pan bread. Wang and Zhou (2004) reported that there was a possible interaction between phenolic antioxidants and wheat protein via hydrogen bonding during dough preparation as green tea extract was added. Emmambux and Taylor (2003) noted that catechin is a monomeric flavanol, and it was not involved in protein-proanthocyanidin cross-linking in sorghum. The increased cellulose content in dough would also alter dough's water absorption, causing reduced water availability to gluten and poor viscoelastic properties (Sivam, Sun, Quek, & Perera, 2010). Therefore, the net outcome of dough properties is determined by the interactions of individual GTP components with flour constituents.

3.2. Effect of green tea powder on specific volume of whole-wheat flour pan bread

There was a general trend indicating a decline in WWF bread specific volume with increasing GTP levels, but no significant difference ($P > 0.05$) in specific volume was observed between the

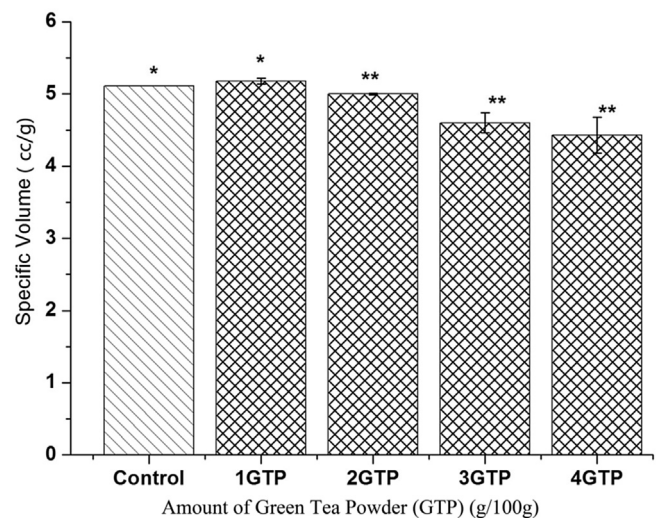


Fig. 1. Specific volume of whole-wheat flour pan bread with the addition of different amounts of green tea powder (GTP). Control: 0.00 g GTP/100 g flour; 1–4GTP: 1.00–4.00 g GTP/100 g flour. *: not a significant difference ($P > 0.05$); **: significant difference ($P < 0.05$).

Table 1
Effect of green tea powder (GTP) on Mixolab properties of flour^{a,b,c}.

GTP amount (g/100 g flour)	T1 (min)	Stability time (min)	C3 (Nm)	C4 (Nm)	C5 (Nm)
Control (0)	4.53 ± 0.05c	7.29 ± 0.29d	1.71 ± 0.02a	1.35 ± 0.04c	1.99 ± 0.06c
1GTP	7.25 ± 0.32b	7.15 ± 0.57d	1.61 ± 0.01d	1.36 ± 0.01bc	2.11 ± 0.02 b
2GTP	8.18 ± 0.50ab	7.88 ± 0.13c	1.62 ± 0.01cd	1.38 ± 0.02abc	2.25 ± 0.06a
3GTP	8.80 ± 1.37a	9.62 ± 1.33b	1.64 ± 0.01bc	1.40 ± 0.02ab	2.30 ± 0.02a
4GTP	7.46 ± 0.57b	10.45 ± 1.02a	1.65 ± 0.02b	1.41 ± 0.01a	2.29 ± 0.05a

^a Values are means of 3 determinations ± SD. Same letters within a column indicate no significant difference ($P > 0.05$).

^b Control: 0 g GTP/100 g flour; 1–4 GTP: 1–4 g GTP/100 g flour.

^c T1: time required to achieve water absorption (development time); C3: starch gelatinization peak; C4: hot gel stability; C5: starch retrogradation in the cooling phase.

bread with 1.00 g GTP/100 g flour and the control bread sample (Figs. 1 and 3). As GTP was increased to 2.00–4.00 g GTP/100 g flour, all three breads had a significantly smaller specific volume ($P < 0.05$) than the control bread and the bread with 1.00 g GTP/100 g flour; however, there were no significant differences among the three highest GTP addition levels.

The volume reduction of WWF pan bread with the addition of GTP appeared to contradict to dough property results as measured by Mixolab because the stability time was increased with the GTP amount (Table 1). In a recent study, Girard, Castell-Perez, Bean, Adrianos, and Awika (2016) confirmed that catechin had some positive effect, although weaker than sorghum proanthocyanidin, on improving gluten elasticity in dough because of its monomeric structure. It is possible that the addition of catechin could have contributed to the bread volume improvement if its functionality is well maintained during baking process, but high temperatures lead to the oxidation of catechins (Ananingsih, Sharma, & Zhou, 2013; Wang, Zhou, & Jiang, 2008). In addition, GTP also contains 24.10 g/100 g cellulose that could have profound effect on bread making results. There are three possible mechanisms that caused smaller loaf volume in the present study. First, GTP diluted gluten, and reduced the interactions among fiber components, fat, water and gluten. According to Anil (2007), bread volume was reduced after the addition of hazelnut fiber. This was possibly caused by the fiber weakening the dough structure and reducing CO₂ gas retention. Second, the increased fibers vigorously competed for water during bread making, and less water was available for the development of the starch-gluten network, resulting in an underdeveloped gluten network and reduced loaf volume (Kaack, Pedersen, & Laerke, 2006). Third, catechins could also have exhibited behavior that inhibits yeast activity leading to decreased gas production (Mildner-Szkudlarz, Zawirska-Wojtasiak, Szwengiel, & Pacyński, 2011).

3.3. Effects of green tea powder on whole-wheat flour pan bread color, morphology and structure properties

3.3.1. Whole-wheat flour bread crumb color

The color results of WWF pan bread with different amounts of added GTP are shown in Figs. 2 and 3. All color data were expressed by Hunter L*, a*, and b* values corresponding to lightness, greenness, and yellowness, respectively. The results show that the color of bread crumb was affected by GTP addition. In general, the brightness was reduced (Fig. 2a), and the L*, a*, and b* values decreased, with increasing GTP levels (Fig. 2b, c, Fig. 2d). The values of a* were reduced to nearly 0 with the addition of 4.00 g GTP/100 g flour, as bread crumb became greenish in color.

GTP contains approximately 1 g chlorophyll/100 g, which can present a green color even when partially reduced in the baking process. The brightness of bread crumb was affected by brown substances resulting from the oxidation of the catechins to generate some deep-colored materials, such as theaflavins, thearubigins, and theabrownines, during high temperatures in the baking process. At the same time, the chlorophyll broke down and produced magnesium chlorophyll, which is also brown in color (Wan, 2007).

3.3.2. Whole-wheat flour pan bread morphology and structure

Cell refers to the pore structure in the crumb. Images of the bread crumb were scanned by C-Cell, and the total cell number, cell-to-total area ratio, cell diameter, and cell wall thickness were measured. The results of image analysis showed that the total cell number was reduced, and the wall thickness became greater, with increased GTP levels, but there was no significant difference ($P > 0.05$) in the total cell number, average diameter, or wall thickness at the level of 1.00 g GTP/100 g flour compared to the

control (Table 2). During mixing, trapped air forms gas cells that act as nucleation sites for the CO₂ gas subsequently generated by yeast activity during proofing. The cellulose content in the dough increased with increasing levels of GTP, so less water was available for optimal gluten development. The dough could not trap the gas molecules, which coalesce to form large-diameter cells; the average cell diameter increased, even to the extent of forming a hole during the processes of proofing and baking. Thus, the number of cells decreased, and the average diameter of cells and the cell-to-total area ratio increased (Table 2).

3.4. Effect of green tea powder on textural properties of whole-wheat flour pan bread

Crumb hardness is commonly used as an indicator of bread staling, and it is negatively correlated with bread quality (Wang, Zhou, & Isabelle, 2007). The hardness of pan bread showed an increasing trend with the amount of GTP added (Table 3); however, there was no significant difference ($P > 0.05$) among the control, 1.00 g GTP/100 g flour and 2.00 g GTP/100 g flour groups. Significant differences ($P < 0.05$) were observed when comparing the control to the 3.00 g GTP/100 g flour and 4.00 g GTP/100 g flour groups, as hardness increased by 24.7% and 35.0%, respectively. With the increasing of GTP, cellulose would intertwine to form a more compact mesh structure. Similar to bread hardness, the chewiness of pan bread gradually increased with the GTP content. Chewiness is also negatively correlated with pan bread quality. There was no significant difference in resilience value between the control and the GTP groups. Zhang et al. (2009) reported that the bread resilience was associated with Mixolab C4 and C5 values (starch gelatinization and retrogradation characteristics). The addition of GTP significantly ($P < 0.05$) increased C4 and C5 values in GTP flour groups, but the differences were not large (Table 1). As the bread texture was measured on the day of production, there was little impact of starch retrogradation on texture. If the GTP fortified bread is stored for more than one day, the increases in hardness and chewiness values and decrease in resilience value may be larger as starch staling will take the effect. Bonnand, Dela, and Lefebvre (2010) reported that the addition of insoluble wheat fiber resulted in stiffer dough, most likely through a filler-like effect in the dough matrix. Kaack et al. (2006) compared the functional properties of five fiber fractions by baking wheat bread in which 0, 4, 8 and 12 g/100 g of the wheat flour was substituted with dry potato pulp. The result was that fiber had a detrimental effect on bread quality when the substitution level was more than 8 g/100 g of the wheat flour. The detrimental effect was mainly due to increased hardness and gumminess.

3.5. Antioxidant activity and peroxide value of whole-wheat flour pan bread during storage

The antioxidant activity and composition of the pan bread after baking with 1.00 g GTP/100 g flour was determined. The contents of lipids, phenolic compounds and total catechins were 2.31 g/100 g, 10.66 g/100 g and 7.74 g/100 g (dry basis), respectively, and the antioxidant capacity of catechins was 1.14 mM TE/g. As shown in Fig. 4a, 1.00 GTP breads had significantly higher ($P < 0.05$) antioxidant activities than the control, and 2.00–4.00 GTP breads had significantly higher ($P < 0.05$) antioxidant activity than 1.00 GTP bread, but there were no significant differences ($P > 0.05$) among the 2.00–4.00 g GTP breads. The antioxidant activity of the control bread was 5.42 mM TE/g sample, while it was 6.42 mM TE/g sample for the bread with 1.00 g GTP/100 g flour, an increase of 18.45% in antioxidant ability. GTP is itself a type of natural antioxidant; in addition, there are other antioxidants in green tea, such as vitamin

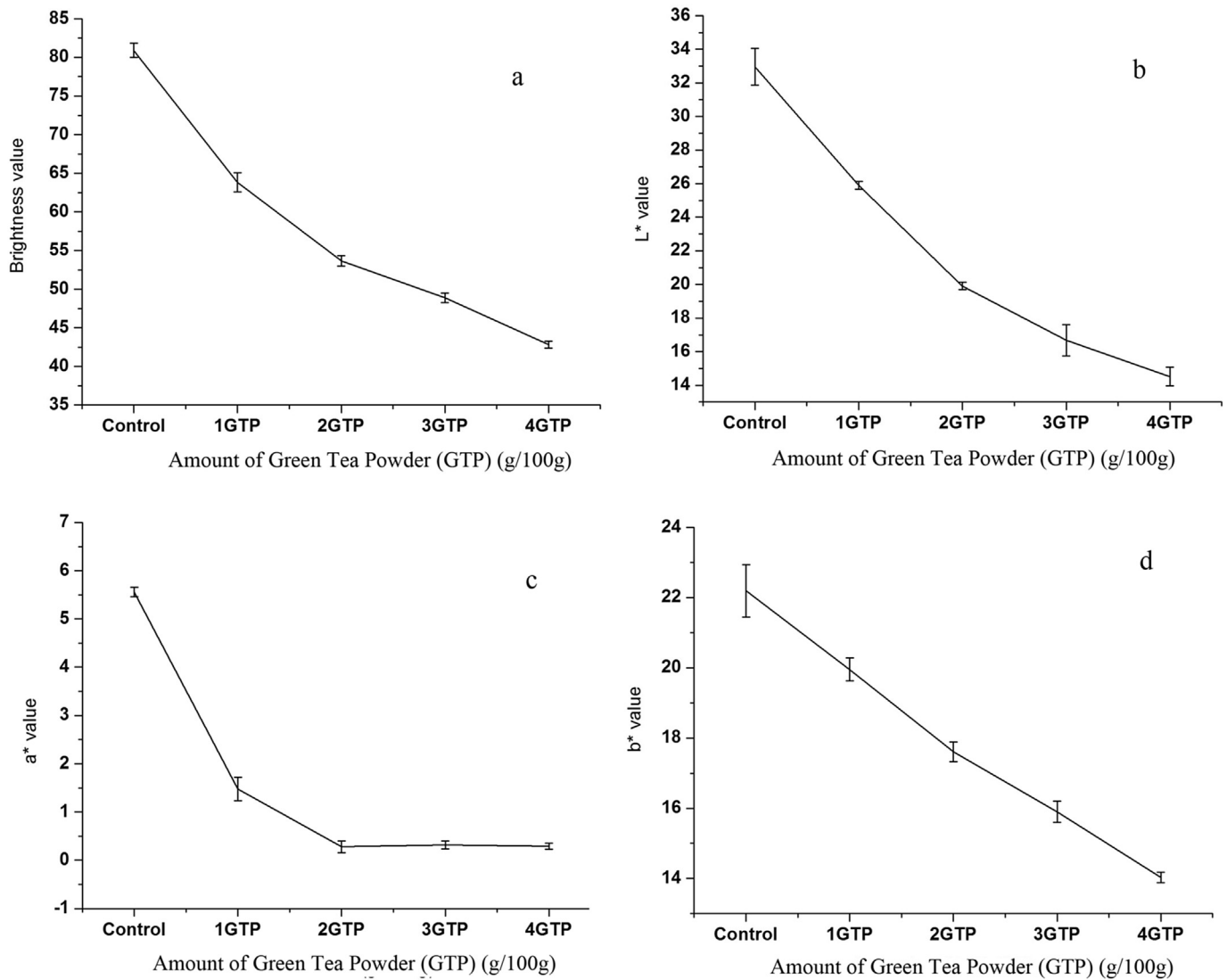


Fig. 2. Crumb color of whole-wheat flour pan bread with the addition of different amounts of green tea powder (GTP). (a) Crumb grain brightness; (b) L* value of crumb grain; (c) a* value of crumb grain; (d) b* value of crumb grain. L*: lightness; a*: red/green complementary colors; b*: yellow/blue complementary colors. Control: 0.00 g GTP/100 g flour; 1–4GTP: 1.00–4.00 g GTP/100 g flour.

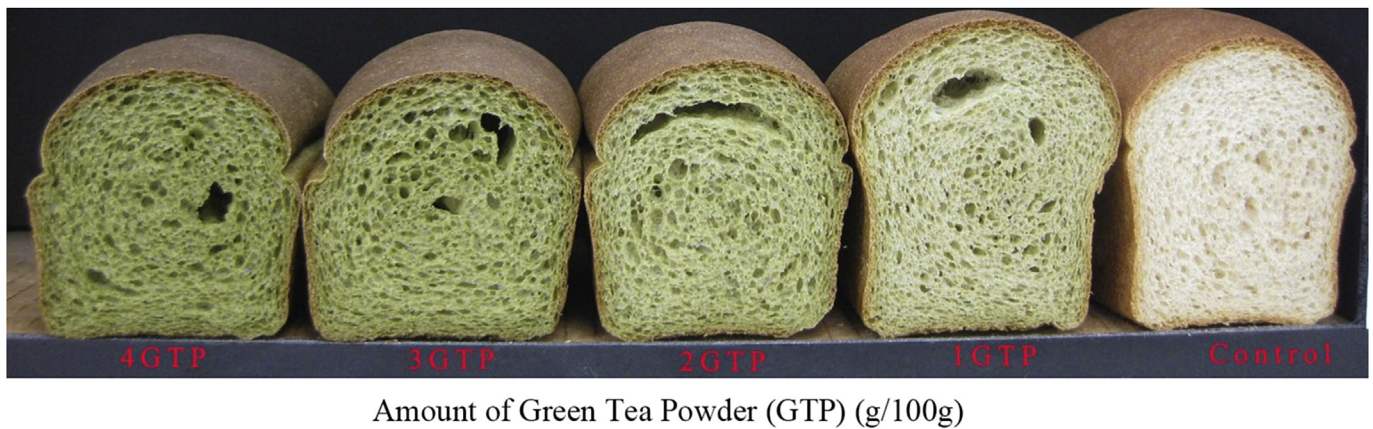


Fig. 3. Whole-wheat flour pan breads with the addition of different amounts of green tea powder (GTP). Control: 0.00 g GTP/100 g flour; 1–4GTP: 1.00–4.00 g GTP/100 g flour.

Table 2Morphology and crumb structure of whole-wheat flour pan bread with the addition of different amounts of green tea powder (GTP)^{a,b}.

GTP amount (g/100 g flour)	Cell-to-total area ratio (%)	Average diameter (mm)	Total cell number	Wall thickness (mm)
Control (0)	21.93 ± 0.42c	1.52 ± 0.42b	4854 ± 64a	0.44 ± 0.01c
1GTP	42.30 ± 1.71b	1.73 ± 0.01b	4638 ± 59a	0.44 ± 0.02c
2GTP	53.90 ± 0.20a	2.22 ± 0.05a	3064 ± 11b	0.49 ± 0.02b
3GTP	54.05 ± 0.35a	2.26 ± 0.01a	2879 ± 38c	0.59 ± 0.00a
4GTP	54.90 ± 0.21a	2.22 ± 0.02a	2875 ± 9c	0.62 ± 0.00a

^a Values are means of 3 determinations ± SD. Same letters within a column indicate no significant difference ($P > 0.05$).^b Control: 0 g GTP/100 g flour; 1–4 GTP: 1–4 g GTP/100 g flour.**Table 3**Effects on texture profile of whole-wheat flour pan bread with different ratios of GTP^{a,b}.

GTP amount (g/100 g flour)	Hardness (N)	Chewiness (N)	Resilience
Control (0)	2.19 ± 0.11c	1.78 ± 0.21c	0.41 ± 0.02a
1GTP	2.28 ± 0.03c	1.84 ± 0.00c	0.39 ± 0.01ab
2GTP	2.38 ± 0.12c	2.22 ± 0.10b	0.39 ± 0.01ab
3GTP	2.73 ± 0.12b	2.32 ± 0.11ab	0.38 ± 0.00b
4GTP	2.96 ± 0.21a	2.49 ± 0.14a	0.39 ± 0.01ab

^a Values are means of 3 determinations ± SD. Same letters within a column indicate no significant difference ($P > 0.05$).^b Control: 0 g GTP/100 g flour; 1–4 GTP: 1–4 g GTP/100 g flour.

C, carotenoids, and selenium. Mildner-Szkudlarz et al. (2009) found that green tea extract had an excellent antioxidant effect on biscuit lipid stability, and inhibited hydrogen peroxide formation by approximately 47%–73%, and formation of secondary oxidation products by approximately 3.5%. The antioxidant capacity of catechins reduced from 1.46 mM TE/g to 1.14 mM TE/g in 1.00 g GTP bread after baking, because high temperatures led to the oxidation of catechins and affected their antioxidant properties (Ananingsih et al., 2013; Wang et al., 2008). It was suggested these compounds could be microencapsulated for incorporation in bread to preserve their antioxidative capacity (Pasrija, Ezhilarasi, Indrani, & Anandharamakrishnan, 2015). The antioxidant capacity of GTP is mainly due to the presence of epigallocatechin-3-gallate (EGCG), which would be oxidized in the baking process and combined with

protein in flour, and resulting in loss of antioxidant capacity (Cao et al., 2012). In addition, the antioxidant capacity of GTP is evaluated by removing free radical reaction. The number of free radicals was fixed in the amount of bread, so an excess of GTP in the bread did not show stronger antioxidant capacity.

Peroxide value (PV) has been selected to monitor lipid oxidation in this study, because storage time was short and limited oxidation was expected. The PV of WWF pan bread is shown in Fig. 4b. During 8 d storage, the PV of all breads increased, but the control bread had a much faster increase in PV than the GTP breads, which suggests that GTP was very effective in controlling the rate of peroxide production. Unsaturated fatty acids in WWF pan bread can be easily oxidized during storage and cause the formation of off-flavors and bitter taste in bread (Jensen, Osetdal, Skibsted, Larsen, & Thybo, 2011). GTP is a powerful antioxidant; its antioxidant ability is much higher than butylated hydroxyanisole (BHA) and ascorbic acid (Mildner-Szkudlarz et al., 2009). Our study clearly indicated that GTP delayed the unsaturated fatty acid oxidation of WWF pan bread and demonstrated its ability to extend the shelf life of bread.

4. Conclusion

In the present study, GTP was added in WWF pan bread to examine its influence on dough and bread quality and antioxidant activity. Mixolab results showed that GTP significantly increased T1 (development time), stability time, and C5 (starch retrogradation), but significantly decreased C3 (starch pasting viscosity). At the 1.00 g GTP/100 g flour addition level, both specific volume and

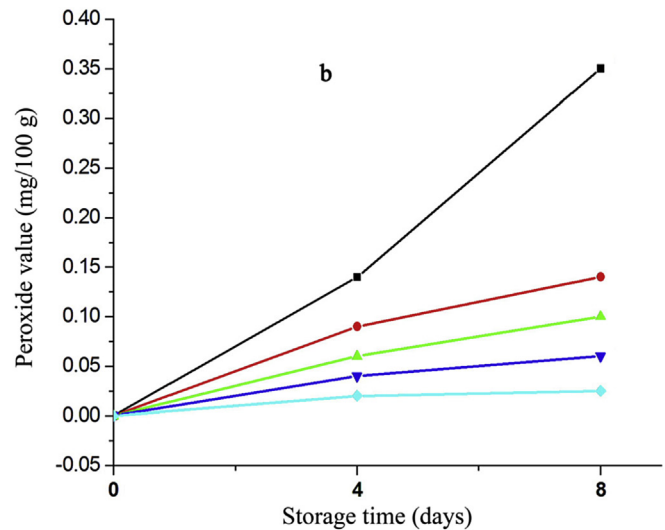
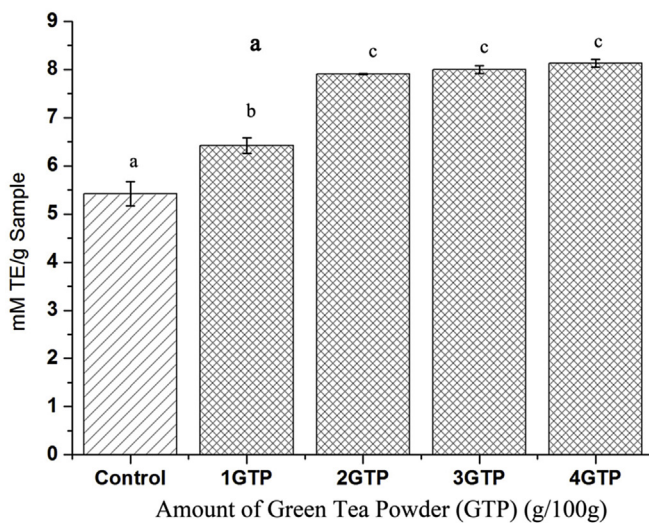


Fig. 4. Antioxidant activity and peroxide value (PV) of whole-wheat flour pan bread with the addition of different amounts of green tea powder (GTP). (a): Antioxidant activities; (b) Peroxide value (PV) of pan bread during 8 days of storage at room temperature. a: Control: 0.00 g GTP/100 g flour; 1–4GTP: 1.00–4.00 g GTP/100 g flour. Different letters above column bars indicate significant difference at $P < 0.05$. b: → Control: 0.00 g GTP/100 g flour; → 1GTP: 1.00 g GTP/100 g flour; → 2GTP: 2.00 g GTP/100 g flour; → 3GTP: 3.00 g GTP/100 g flour. → 4GTP: 4.00 g GTP/100 g flour.

crumb hardness of bread did not show significant changes compared to the control; however, at 3.00 g GTP/100 g flour or higher addition levels, bread quality was negatively affected by GTP in both volume and texture.

GTP had an excellent antioxidant effect on pan bread and increased the antioxidant activity by 18.5% at the 1.00 g GTP/100 g flour addition level, and the more added GTP, the higher the antioxidant ability of pan bread, but at 2.00–4.00 g GTP/100 g flour addition levels, there was no significant difference in bread antioxidant activity ($p > 0.05$). During 8 d storage of WWF pan bread at room temperature, GTP demonstrated significant effectiveness in reducing the rate of peroxide accumulation in bread at a minimum addition level of 1.00 g GTP/100 g flour.

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