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Quality and antioxidant properties of bread containing turmeric (*Curcuma longa* L.) cultivated in South Korea

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ABSTRACT

Turmeric (*Curcuma longa* L.) powder was used to substitute 0%, 2%, 4%, 6% and 8% of wheat flour for making turmeric wheat breads. Proximate composition, physical quality, functional components (curcumin and total phenols) and antioxidant properties of breads containing turmeric were analysed and compared with those of wheat bread. Hardness, crumb colour *a* and *b* values, curcumin content and total phenolic contents of breads significantly increased with the addition of turmeric powder. Water activity, specific volume and crumb colour *L* value of breads decreased with the addition of turmeric powder. Breads containing turmeric powder also showed good antioxidant activity as tested by the β-carotene-linoleate bleaching assay. A 4% substitution of wheat flour with turmeric powder showed acceptable sensory scores which were comparable to wheat bread. Breads containing turmeric powder can thus be developed as a health-promoting functional food.

1. Introduction

Antioxidants are used as food additives in order to prevent the oxidative deterioration of fats and oils in processed foods. However, due to limitation on the use of synthetic antioxidants and enhanced public awareness of health issues, there is an increasing need of health-promoting natural antioxidants in foods, such as in bakery products (Nanditha & Prabhasankar, 2009). Free radicals can usually be generated by several biological reactions in the body and these are capable of damaging crucial bio-molecules; if they are not scavenged effectively by cellular constituents, they lead to disease conditions. The harmful action of free radicals can be blocked by antioxidant substances, which scavenge the free radicals and detoxify the organisms. Current researches have confirmed that foods rich in antioxidants play an essential role in the prevention of cardiovascular diseases, cancers and neurodegenerative diseases, as well as inflammation and problems caused by cell and cutaneous aging (Fan, Zhang, Yu, & Ma, 2006). Antioxidants are important in the control of degenerative diseases in which oxidative damage has been implicated. There are different plant sources which contain important antioxidants capable of free radical scavenging and they are preferred over synthetic antioxidants such as butylated hydroxy toluene (BHT) and butylated hydroxy anisole (BHA) which are reported to be toxic to human health (Lean & Mohamed, 1999).

Studies have been carried out to find potential sources of natural antioxidants in wheat breads. Fan et al. (2006) evaluated antioxidant property and quality of breads containing *Auricularia auricular* polysaccharide (AAP) flour. The incorporation of AAP in bread markedly increased the antioxidant activity of bread as tested by DPPH free radical scavenging method. HoltekjØlen, Bævre, RØdbotten, Berg, and Knutsen (2008) studied antioxidant properties and sensory profiles of breads in which 40% wheat flour was replaced with barley flour. The incorporation of barley increased the antioxidant properties of the breads and the sensory evaluation showed differences among sensory attributes, depending on the barley variety used. There was a good consistency between the sensory attributes and the amount of phenolics in barley wheat bread. Lin, Liu, Yu, Lin, and Mau (2009) found that the buckwheat could be incorporated into wheat bread to get better functional composition and improved antioxidant properties in bread.

Turmeric (*Curcuma longa* L.) is one of the most popular spices containing natural antioxidants, and is reported to possess numerous medicinal properties including antioxidant, anti-protozoal, anti-tumour, anti-inflammatory and anti-venom activities (Tuba

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& Ilhami, 2008). The major biologically active components of turmeric are curcuminoids which include curcumin, demethoxycurcumin and bis-demethoxy curcumin. Curcumin is a yellow-coloured phenolic pigment and is an effective antioxidant that can scavenges superoxide radicals, hydrogen peroxide and nitric oxide from activated macrophages. Despite of numerous health benefits, not enough research work has been done to promote turmeric powder use in food formulations. However, its use as an antioxidative and antimycotic agent in butter cakes was previously reported (Lean & Mohamed, 1999).

The objectives of this study were to evaluate the physico–chemical, sensory and antioxidant properties of wheat breads made with different levels of turmeric powder.

2. Materials and methods

2.1. Materials

Korean turmeric (*C. Longa* L.) rhizomes, harvested in fall season from Jindo, Chonnam, South Korea, were washed, cleaned, cut into small pieces, dried using forced air drying oven at 40 °C for 2 days, ground to a powder form using blender (KMF-360, Daewoo Co., Seoul, South Korea) and passed through a 150 μm sieve. Wheat flour (protein 12.8%) and sugar were purchased from Cheil Jedang Inc., Incheon, South Korea. Other ingredients were yeast, non-fat dry milk, improver (Seoul Dairy Co., Seoul, South Korea) and salt (Youngjin Foods Inc., Seoul, South Korea). Gallic acid, Folin–ciocalteau reagent, curcumin standard were purchased from Sigma–Aldrich (St. Louis, MO, USA). All other chemicals were analytical grade and purchased from Merck (Darmstadt, Germany).

2.2. Methods

2.2.1. General

Turmeric powder substitution levels were 0%, 2%, 4%, 6% and 8% in wheat flour. The raw materials for bread-baking were weighed according to the formula proportions. 0, 10, 20, 30 and 40 g turmeric powder was incorporated in 1000, 990, 980, 970 and 960 g wheat flour, respectively. Amounts of other ingredients were similar in these different formulations i.e. 80 g sugar, 20 g salt, 20 g yeast, 30 g butter, 20 g non-fat dry milk, 24 g improver and 650 g water.

2.2.2. Bread making

Dough was prepared by using a straight method. Firstly, yeast was dissolved in water at 30 °C followed by the mixing of dry ingredients. Butter was melted and added to other ingredients in the liquid phase containing dissolved yeast. Ingredients were mixed using a professional mixer (K5SS, KitchenAid Inc., St. Joseph, MI, USA) for 2 min at low speed, followed by 6 min mixing at high speed. After complete mixing, dough was placed in the incubator (Daeyung Bakery Machinery Co., Seoul, South Korea) at 30 °C and 85% relative humidity for fermentation. The total duration of the fermentation was 120 min. The dough was taken out of the incubator after initial 70 min fermentation, punched and placed in the incubator again. A second punch was also given 35 min later. The dough was then divided into similar weight pieces and each piece was shaped and placed in incubator for the last 15 min under same incubation conditions. Baking was performed at 220 °C for 20 min in an electric oven (FDO-7104, Electric Deck Oven, Daeyung Bakery Machinery Co., Seoul, Korea). The oven was preheated to set temperatures before placing the dough samples for baking. Afterwards the bread was taken out of the bread cases and cooled to room temperature for 1 h. The crust was removed aseptically, and then the crumb was freeze-dried, ground in a mill and screened through 0.5 mm sieve. Moisture content of powdered bread was 56.2–56.6% and it was used for measuring curcumin, total phenolics and antioxidant activity.

2.2.3. Proximate compositions

The proximate compositions of wheat flour and turmeric powder for moisture, crude protein, crude fat, crude ash and crude fibre were determined by approved methods 44-40, 46-11A, 30-10, 08-01 and 32-07, respectively (AACC, 2000). The nitrogen conversion factor used for crude protein calculation was 6.25. The percentage of nitrogen-free extract was calculated by subtracting the total contents of moisture, crude protein, crude fat, crude ash and crude fibre from 100. Proximate contents of bread and turmeric powder were expressed on a wet basis and dry basis, respectively.

2.2.4. Determination of physical characteristics

The water activity of bread was measured by water activity metre (BT-RS1, Bassersdorf, Switzerland). Moisture in bread was determined using AACC method 44-40 and bread volume was determined by AACC rapeseed displacement method, 10-10B (AACC, 2000). Weights were recorded by using a 2-decimal digital weighing scale. The specific volume of the bread was determined as bread loaf volume divided by bread loaf weight (Penfield & Campbell, 1990). The texture profile analysis (TPA) was carried out to evaluate crumb hardness using a texture analyser (Compac-100, Sun Scientific, Tokyo. Japan). A 35 mm diameter aluminum cylinder probe was used to measure the required compression force. The optimal test conditions were 30–60% deformation, 0.1–2 mm/s cross-head speed and variance coefficient of plunger compressing a sample to 50% of its original height at 0.8 mm/s speed. The dimensions of crumb samples were 40 mm × 40 mm × 30 mm. The data were collected using software, Texture Expert (v 1.22, Texture Technologies, Scarsdale, NY, USA). Crumb colour was measured using a colorimeter (CE-7000, Macbeth, VA, USA), which was calibrated using a white reference tile (lightness (L^*) = 95.91, redness (a^*) = −0.13 and yellowness (b^*) = 2.27).

2.2.5. Determination of curcumin contents

Samples for HPLC analysis were prepared by mixing 1 g of turmeric powder or powdered bread separately in 40 ml of 100% ethanol using vortex mixer followed by extraction in ultrasonic water bath at 50 °C for 3 h. 2 ml filtered extract solution was diluted with 8 ml distilled water and treated with Sep-Pak C-18 cartridge (Waters, Milford, MA, USA). The cartridge was washed with 10 ml distilled water and turmeric dye from cartridge was collected using 20 ml 100% ethanol. The collected solution was concentrated under vacuum at 40 °C and filtered through a 0.45 μm Nylon-66 filter disk. In order to prepare standard solution, 0.05 g of commercial curcumin was dissolved in 100 ml of 100% ethanol and diluted further with ethanol to give a final concentration of 0.1 mg/ml. The standard was filtered through a 0.45 μm Nylon-66 filter disk prior to HPLC analysis.

A modified method (Hiserodt, Hartman, Ho, & Rosen, 1996) was used to quantify curcumin level of bread. An Agilent Series 1100 (Agilent Technologies, Santa Clara, CA, USA) HPLC equipped with a photodiode array detector, a quaternary pump and a manual sample injector was used. A Supelcosil C-18 column (5 μm C_{18}, 250 × 4.6 mm I.D.) from Supelco Inc., Bellefonte, PA, USA was used for separation. The mobile phase for elution consisted of acetonitrile–water–acetic acid (50:49:1 v/v/v). 20 μl of sample and standard solution were injected into HPLC and the flow rate was 1 ml/min. The isocratic elution was monitored at a wavelength of 425 nm for 25 min. The determination of curcumin content involved calculations using concentrations of standard and samples, the purity of commercial curcumin and peak areas of curcumin.

The percentage recovery of curcumin ranged from 84% to 89% and the curcumin concentration was expressed as mg/g.

2.2.6. Determination of total phenolics contents

Total phenolics were determined using the Folin–Ciocalteau method (Singleton, Orthofer, & Lamuela-Raventos, 1999). One gram turmeric powder or powdered bread was homogenised in 80% ethanol at room temperature, centrifuged at 10,000g for 15 min and the supernatant was saved, respectively. The residue was extracted twice again with 80% ethanol and supernatants were pooled. Extract was evaporated at room temperature until dry. Residue was dissolved in 5 ml distilled water. Hundred microliters of this extract was diluted to 3 ml using distilled water and mixed with 0.5 ml Folin–Ciocalteau reagent. After 3 min, 2 ml of 20% sodium carbonate was added followed by thorough mixing. Solutions were heated in a 40 °C water bath for 30 min. Absorbance was measured at 765 nm using spectrophotometer (Optima 2000DV, Perkin-Elmer, Waltham, MA, USA). Gallic acid was used as a standard and results were expressed as mg gallic acid equivalent/100 g (mg GAE/100 g).

2.2.7. β-Carotene-linoleate bleaching assay

Ten grams of powdered bread was extracted with 100 ml 100% ethanol at 25 °C for 24 h along with stirring followed by filtration using Whatman No.1 filter paper. The residues were re-extracted twice as described above. The combined ethanolic extracts were evaporated at 40 °C under vacuum until dry. The antioxidant activity of this dried ethanol extract was assayed according to β-Carotene-linoleate bleaching method developed by Velioglu, Mazza, Gao, and Oomah (1998). BHT was used as standard. β-Carotene (0.2 mg in 1 ml chloroform), linoleic acid (0.02 ml) and Tween 20 (0.2 ml) were transferred into a round bottom flask. The mixture was then added to 0.2 mg of dried ethanolic extract prepared for β-carotene-linoleate bleaching assay or 0.2 ml of standard ethanol (as control). Chloroform was removed at room temperature under vacuum at reduced pressure using a rotary evaporator (Unimax 1020, Heidolph Instruments, Schwabach, Germany). Following evaporation, 50 ml of distilled water was added to the mixture and then shaken vigorously to form an emulsion. Two millilitres aliquots of the emulsion was taken in test tubes and immediately placed in a water bath at 50 °C. The absorbance was read at 20 min intervals for 2 h at 470 nm, using a spectrophotometer (Optima 2000DV, Perkin Elmer, City, State, USA). Degradation rate (DR) was calculated according to first order kinetics, using the following equation (Al-Saikhan, Howard, & Miller, 1995):

$$DR_{sample} \text{ or } DR_{standard} = \text{In}(a/b) \times 1/t$$

where ln is natural log, *a* is the initial absorbance (470 nm) at time 0, *b* is the absorbance (470 nm) at 20, 40, 60, 80, 100 or 120 min and *t* is the initial absorbance (470 nm) at time 0. Antioxidant activity (AA) was expressed as percent of inhibition relative to the control, using the following formula:

$$AA = (DR_{control} - DR_{sample})/DR_{control} \times 100$$

2.2.8. Sensory evaluation

The hedonic test was used to determine the degree of overall liking for the breads. For this study, untrained consumers were recruited among students, staff and faculty at Hankyong National University, Korea. All consumers were interested volunteers and informed that they would be doing bread evaluation. The sensory evaluation was carried out with bread samples within 24 h after baking. The samples were evaluated by 80 consumers (35 males and 45 females, 21–48 years old) each of whom received five samples (3 × 3 × 1 cm) and they were asked to rate samples based on degree of liking or disliking on a nine-point hedonic scale (1: dislike extremely, 5: neither like nor dislike, 9: like extremely). Samples were placed on white plates and identified with random three-digit numbers. Panellists evaluated the samples in a testing area and were instructed to rinse their mouths with water between samples to minimise any residual effect.

2.3. Statistical analysis

Each manufacturing treatment and physico-chemical measurement was carried out in triplicates. The experimental data were subjected to statistical evaluation using analysis of variance (ANOVA) for a completely random design using Statistical Analysis System (SAS Institute, Cary, NC, USA). Duncan's multiple range tests were used to determine the difference among means and the significance was defined at $P < 0.05$.

3. Results and discussion

3.1. Proximate compositions of turmeric powder and wheat flour

Proximate compositions of turmeric powder and wheat flour are presented in Table 1. The protein content of the wheat flour was higher than those of turmeric powder, whereas turmeric powder had higher crude ash and nitrogen-free extract. The ash content in turmeric powder was about four times higher than that of wheat flour, as reported previously by Kang (2007) who found that fresh turmeric contained relatively high levels of minerals (K, P and Ca). However, contents of fat, fibre and moisture were not significantly different.

3.2. The effects of turmeric powder substitution on physical properties of breads

The data on physical properties of bread in presented in Table 2. A significant decrease in water activity was noted with an increase in the turmeric powder level. The moisture contents showed no significant variation. The weight of bread loaf was not significantly different. A significant decrease in bread volume was noted with an increase in the turmeric powder level. The control loaf sample had an average bread volume of 2092 ml, decreasing to 1921, 1837, 1762 and 1629 ml for breads made with 2%, 4%, 6% and 8% turmeric powder, respectively. Similar effect was observed on bread specific volume which decreased with the addition of turmeric powder. The decrease in both loaf volume and specific volume were expected as a result of gluten-free turmeric powder in bread formulation and the addition of turmeric powder reduced the ratio of wheat flour responsible for the formation of network structure. Other researchers have reported that addition of some nonendosperm components of wheat caryopsis also resulted in low specific volume of wheat bread however their effect can not explained only in terms of dilution effect on gluten forming proteins and the precise reason for the decrease in loaf volume caused by their addition is not known (de Kock, Taylor, & Taylor, 1999). Addition of tur-

Table 1
Proximate compositions of turmeric powder and wheat flour[a].

Component (%)	Turmeric powder	Wheat flour
Moisture	14.84 ± 0.19[a]	14.02 ± 0.27[a]
Crude protein	2.85 ± 0.16[b]	12.83 ± 0.11[a]
Crude fat	1.48 ± 0.14[a]	1.52 ± 0.18[a]
Crude fibre	2.60 ± 0.06[a]	2.10 ± 0.03[a]
Crude ash	1.84 ± 0.08[a]	0.43 ± 0.05[b]
Nitrogen-free extract	76.39 ± 1.18[a]	69.10 ± 2.32[b]

[a] Each value is expressed as mean ± SD ($n = 3$) and means having different letter superscripts within a same row are significantly different ($P < 0.05$).

Table 2
Physical properties of breads prepared by the substitution of wheat flour with turmeric powder[a].

Physical characteristics	Substitution level (%)				
	0	2	4	6	8
Water activity	0.955 ± 0.001[a]	0.952 ± 0.002[b]	0.949 ± 0.001[c]	0.946 ± 0.001[d]	0.944 ± 0.001[e]
Moisture contents (%)	56.6 ± 0.2[a]	56.5 ± 0.3[a]	56.5 ± 0.4[a]	56.3 ± 0.3[a]	56.2 ± 0.4[a]
Loaf weight (g)	399.5 ± 2.3[a]	399.9 ± 2.6[a]	400.1 ± 2.9[a]	400.3 ± 2.1[a]	400.6 ± 1.8[a]
Loaf volume (ml)	2092.4 ± 47.7[a]	1921.6 ± 23.1[b]	1837.5 ± 20.3[c]	1762.4 ± 28.4[d]	1629.8 ± 31.6[e]
Specific volume (ml/g)	5.2 ± 0.2[a]	4.8 ± 0.1[b]	4.5 ± 0.1[c]	4.3 ± 0.1[d]	4.0 ± 0.1[e]
Hardness (g/cm^2)	213.1 ± 13.9[e]	229.8 ± 19.2[d]	258.1 ± 12.3[c]	276.1 ± 17.6[b]	299.8 ± 14.8[a]
Crumb colour					
L	88.7 ± 1.3[a]	84.5 ± 1.4[b]	80.3 ± 2.1[c]	77.1 ± 1.2[d]	73.0 ± 1.8[e]
a	1.9 ± 0.5[e]	4.7 ± 0.5[d]	6.4 ± 0.8[c]	8.2 ± 0.9[b]	10.7 ± 0.3[a]
b	12.8 ± 2.5[e]	41.9 ± 2.9[d]	48.3 ± 1.6[c]	56.0 ± 2.5[b]	61.2 ± 1.3[a]

[a] Each value is expressed as mean ± SD ($n = 3$) and means having different letter superscripts within a same row are significantly different ($P < 0.05$).

meric powder had a significant effect on specific volume as was shown by a 23% decrease, from 5.2 to 4.0 ml/g after 8% substitution of wheat flour with turmeric powder.

Results on the hardness of bread showed that it increased with increasing levels of turmeric powder. Different bread samples had uniform weights as mentioned before and the increase in hardness was mainly associated to the reduced loaf volume due to the addition of turmeric powder. The increase in crumb hardness could also be related to an increase in loaf density in the breads (Vittadini & Vodovotz, 2003). The addition of turmeric powder changed the quantity of protein in wheat flour–turmeric powder system and thereby affected the uniform structure in turmeric bread. Siddiq et al. (2009) found that this lack of uniform structure changes the textural characteristics, mainly firmness of breads.

The crumb colour of samples was affected by the replacement of wheat flour with turmeric. For crumb colour, the *L* value decreased significantly however the *a* and *b* values showed significant increase with the addition of turmeric powder, indicating that a darker, redder and yellower crumb was obtained as a result of turmeric powder substitution. The colour change of breads might be related to the fact that turmeric pigments, curcuminoids and phenolic compounds underwent oxidation reaction and sugars participated in caramelisation during baking.

3.3. Curcumin, total phenolics and antioxidant properties

The major bioactives in turmeric are polyphenols, including curcumin, which is well known, besides other polyphenols, for its strong antioxidant activity (Miquel, Bernd, Sempere, Diaz, & Ramiraz, 2002). Curcumin content of turmeric powder used in this study was 2.65 mg/g and as expected, the curcumin was detected only in breads containing turmeric powder (Fig. 1). The curcumin content increased significantly with increasing turmeric powder levels in bread and the highest was found in bread with 8% substitution with turmeric powder. Curcumin is a major bioactive component of turmeric, which has been used as herbal medicine. Curcumin is an effective antioxidant and acts as a superoxide radical scavenger and as a singlet oxygen quencher (Das & Das, 2002; Reddy & Lokesh, 1994). Some studies have pointed out the possible involvement of the β-diketone moiety in the antioxidant action of curcumin, and the H-atom donation from the β-diketone moiety to a lipid alkyl or a lipid peroxyl radical as a potentially more important antioxidant action of curcumin (Masuda et al., 1999; Jovanovic, Steenken, Boone, & Simic, 1999). Since turmeric is a good source of curcumin the substitution of wheat flour in the bread with turmeric powder can result in development of bread with additional health benefits.

The antioxidant and radical scavenging activities are closely related to polyphenols (Alvarez-Jubete, Wijngaard, Arendt, & Gallagher, 2010), the total phenolic contents of turmeric powder and bread samples were also analysed and results are shown in Fig. 2(A). Bread prepared with wheat flour only (no turmeric added) had 30.9 mg GAE/100 g of phenolic compounds, whereas the bread prepared with 8% turmeric powder had 150.5 mg GAE/100 g of those, showing a significant increase in total phenolics in bread. The phenolic content of turmeric powder was 2195 mg GAE/100 g (data not shown). Alvarez-Jubete et al. (2010) reported that wheat seeds and wheat bread contained 53.1 and 29.1 mg GAE/100 g of total phenols, respectively and they were also reported to show DPPH radical scavenging and ferric ion reducing antioxidant activities. Phenolics are quite heat unstable and reactive compounds (Cheynier, 2005) and the baking process might have resulted in some heat damage to phenolic compounds. A comparison of the measured total phenol content in turmeric breads with the expected values suggests that some degradation may have occurred. Reduction of total phenol contents of turmeric powder in turmeric bread were observed following bread making, whereby the reduction extent was 32–54%. However, despite the loss of total phenol content after baking, all breads containing turmeric showed significantly higher phenolic compounds and antioxidant activities when compared with the control.

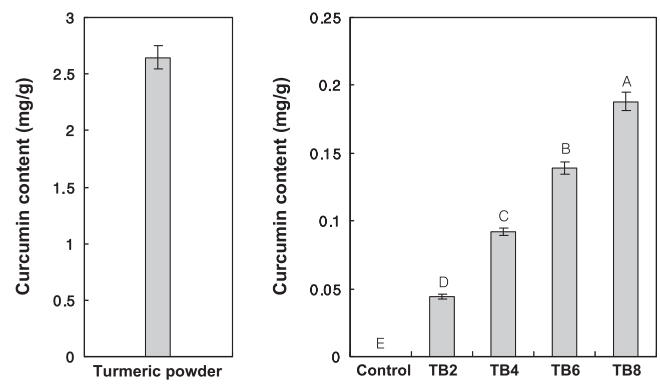

Fig. 1. Curcumin contents of turmeric powder and breads prepared with turmeric powder replacement for wheat flour. Control, TB2, TB4, TB6 and TB8 are breads prepared with 0%, 2%, 4%, 6% and 8% replacement of wheat flour with turmeric powder, respectively. Bars represent standard error of means ($n = 3$) and means with different letters are significantly different ($P < 0.05$).

The antioxidant activities of breads prepared with different levels of substitution of wheat flour with turmeric powder were analysed using the β-carotene bleaching assay and results are shown in Fig. 2(B). The antioxidant activities of breads also increased significantly with increase in turmeric powder substitution. We also determined the antioxidant activity of turmeric powder alone using the β-carotene bleaching assay (Velioglu et al., 1998) and it

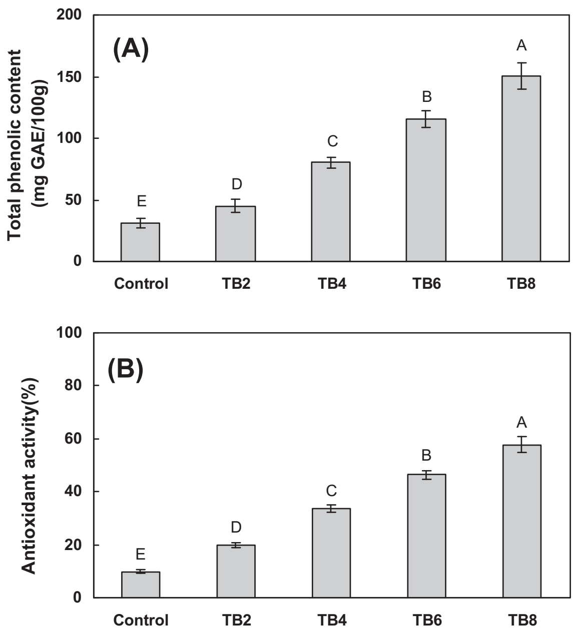

Fig. 2. Total phenolic contents (A) and antioxidant activities (B) of breads containing turmeric powder. Control, TB2, TB4, TB6 and TB8 are breads prepared with 0%, 2%, 4%, 6% and 8% replacement of wheat flour with turmeric powder, respectively. Bars represent standard error of means ($n = 3$) and means with different letters are significantly different ($P < 0.05$).

showed 79.8 ± 0.6% antioxidant activity. Turmeric curcuminoids are reported to have better stability and heating dose not affect the concentration of individual curcuminoids. This characteristic renders turmeric as one of the highly recommended sources of functional food components such as curcumin (Prathapan, Lukhman, Arumughan, Sundaresan, & Raghu, 2009). The Maillard reaction products also possess the antioxidant activities however antioxidants formed during Maillard reaction were found to be unstable when exposed to air (Lingnert & Waller, 1983). The results showed that addition of turmeric powder greatly enhanced the antioxidant activity of bread. The improved antioxidant activity of turmeric bread might be due to the incorporation of phenolic compounds including curcumin, which had been shown to possess strong antioxidant activity (Jayaprakasha, Jaganmohan, & Sakariah, 2006). Tuba and Ilhami (2008) found the total antioxidant activity of curcumin, BHA, BHT, α-tocopherol and trolox as determined by the ferric thiocyanate method in the linoleic acid system, demonstrating that curcumin had a marked antioxidant effect in linoleic acid emulsion. At similar concentrations, the hydrogen peroxide scavenging effect of curcumin and four standard compounds decreased in the order of curcumin > trolox > BHT > BHA ≈ α-tocopherol (Tuba & Ilhami, 2008). We observed that addition of turmeric resulted in significant increase in bioactive contents and antioxidant properties of bread and turmeric bioactives also reported to be heat stable which make turmeric as recommendable source for developing bread with enhanced functional properties.

3.4. Sensory evaluation of bread

The hedonic test was used to determine the degree of liking of breads prepared using different formulations and results are given in Table 3. The crumb colour of bread with 8% turmeric powder had the lowest liking score. Since the colour of turmeric powder was light yellow, 2% substitution of turmeric powder did not interfere with the original colour of the bread made with wheat. The taste and overall acceptability of breads with turmeric powder at substitution levels of 0–4% had the highest liking score. For other sensory characteristics (aroma and texture), no statistically significant difference was observed for all samples. The sensory characteristics liking results pointed out that a partial replacement of wheat flour with up to 4% turmeric powder in breads gives satisfactory overall consumer acceptability. However, bread which contained 6% or 8% turmeric was rated comparatively lower, which might be due to excessive amounts of volatiles and phenolic compounds, which can negatively affect the taste of food (Drewnowski & Gomez-Carneros, 2000). Cross-sectional views of different breads prepared with turmeric powder are presented in Fig. 3. The change in bread

Table 3
Sensory evaluation of breads prepared by the substitution of wheat flour with turmeric powder[a].

Attribute	Substitution level (%)				
	0	2	4	6	8
Crumb colour	7.4^a	7.8^a	4.1^b	2.2^c	1.9^c
Aroma	7.7^a	7.4^a	6.8^a	6.9^a	6.7^a
Taste	7.5^a	7.8^a	6.9^a	4.4^b	4.1^b
Texture	7.4^a	7.5^a	7.1^a	7.1^a	7.3^a
Overall	7.6^a	7.9^a	6.8^a	4.0^b	2.2^c

[a] Nine-point hedonic scale with 1, 5 and 9 representing extremely dislike, neither like nor dislike, and extremely like, respectively. Means with different letter superscript within a same row are significantly different ($P < 0.05$).

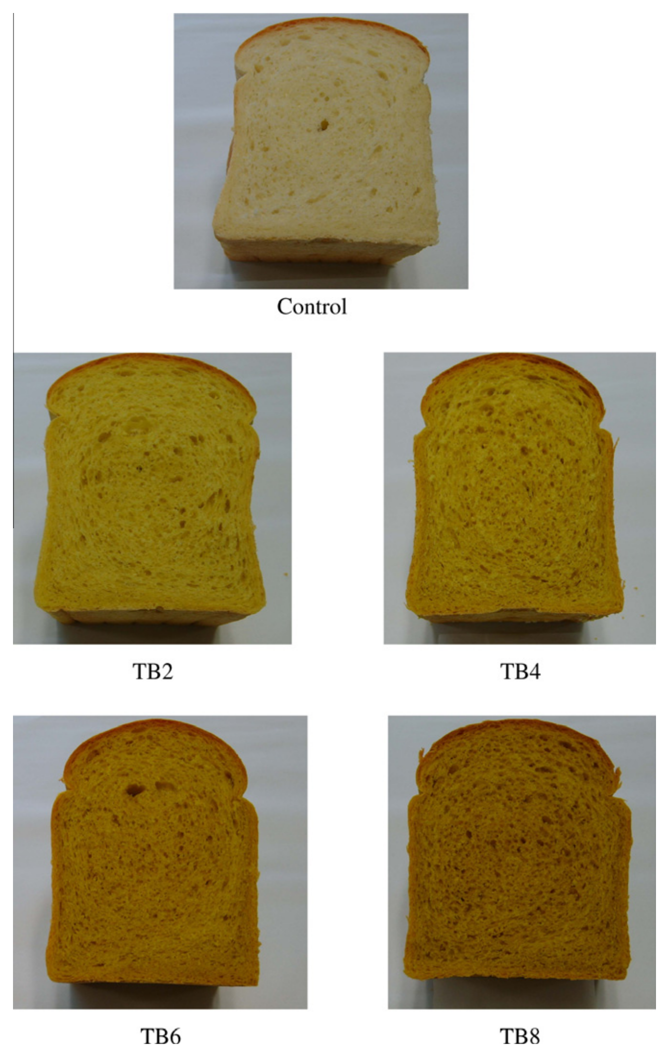

Fig. 3. Cross-sections of the breads prepared with turmeric powder replacement for wheat flour. Control, TB2, TB4, TB6 and TB8 are breads prepared with 0%, 2%, 4%, 6% and 8% replacement of wheat flour with turmeric powder, respectively.

crumb colour is quite evident and with the increase of turmeric powder in bread, crumb colour became darker and yellower.

We may explain that a daily intake of 50 g or two slices of turmeric bread having 4% wheat floor substitution with turmeric powder can deliver approximately 4.6 mg of curcumin and 40.12 mg GAE of total phenolic compounds which can render additional health benefits to human body. The data on exact recommended dosage of these phytochemicals is not available however different *in vitro* and *in vivo* studies have been carried out to analyse their biological effects. Maheshwari, Singh, Gaddipati, and Srimal (2006) summarised various studies that list the biological activities of curcumin in terms of antioxidant activity, wound healing, modulation of angiogenesis and anti-cancer activity. We observed that bread with 4% level of turmeric powder can have significantly higher antioxidant activity (33.7%) than the normal wheat bread (9.9%) as analysed by β-carotene bleaching assay. Lean and Mohamed (1999) documented that turmeric was more antimycotic and anitoxidative than other spices such as clove, betel leaves and lemon grass. They also reported that turmeric was more effective than BHA and BHT in preventing the oxidative shelf-life in processed cakes and those containing turmeric resisted mould growth up to 3 weeks whereas cakes without turmeric showed mould growth after just 1 week. As breads are lower in fat, the addition of turmeric powder is expected to have profound effects of on the shelf-life of bread.

4. Conclusions

In this study, turmeric powder blended wheat bread was developed and analysed for different physical characteristics, bioactive components and antioxidant activities as affected by different substitution levels of turmeric powder in bread. The results showed that up to 4% turmeric powder could be included in a bread formulation without any significant interference with the sensory acceptability of bread. On the other hand, the incorporation of turmeric powder markedly increased the curcumin, total phenolic contents and antioxidant activities of bread. We may also infer that Korean turmeric powder can be effectively incorporated in breads to render higher functional components and antioxidant properties.

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