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Improvement in antioxidant functionality and shelf life of *yukwa* (fried rice snack) by turmeric (*Curcuma longa* L.) powder addition

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ABSTRACT

The physico-chemical, oxidative and sensory characteristics of fried rice snack, *yukwa* with different amounts of turmeric powder (*Curcuma longa*) were investigated. The moisture content of the pallet ranged from 16.47% to 19.84%. After frying the pallet, a slight decrease in the degree of expansion was obtained with increasing turmeric powder content. The textural properties of *yukwa* were not changed until the turmeric powder content reached 5%; however, over 8% addition induced a decrease in the hardness and an increase in the crispiness. Oxidative deterioration was effectively inhibited by turmeric powder addition, and more turmeric powder in *yukwa* led to higher free radical scavenging activity. Based on the sensory characteristics, a 5% addition of turmeric powder was the most acceptable for the *yukwa* product. In the correlation results among variables, the moisture content of the pallet proved to be the most important factor for *yukwa* quality.

1. Introduction

Yukwa is a traditional fried waxy rice snack in Korea, of which the texture and flavor are generated during the deep-fat frying process. Recently, this fried snack was chosen as the most preferred snack among Korean commercial snacks in consumers' sensory profiles (Rhee, Lee, & Kim, 2013).

Frying is one of the most popular cooking methods for foods; however, the oils and fats used for frying undergo physical and chemical deterioration, which affects the fried foods and the storage stability of the products (Fauziah, Razali, & Nor-Aini, 2000). Lipid oxidation is a major deteriorative reaction in frying oils and fried foods, and often results in a significant loss of quality (Alexander, 1978) and negative changes in the functional and nutritive values (Pearson, Gray, Wolzak, & Horenstein, 1983). Moreover, highly oxidized oils may also produce polyaromatic hydrocarbons that are regarded as carcinogens (FAO/WHO, 1988). As one of the ways to solve these problems, there have been trials to prevent deterioration of *yukwa* using different puffing media instead of oil, such as hot-air puffing (Shin, Kim, Chung, & Lee, 1990), roast puffing (Yang, Kim, & Chun, 2008) or vacuum puffing (Shen, Han, & Ryu, 2014).

Antioxidants have been used as food additives to prevent the oxidative deterioration of fats and oils in processed foods. However, due to limitations on the use of synthetic antioxidants and enhanced public awareness of health issues, the need for health-promoting natural antioxidants has increased (Nanditha & Prabhasankar, 2009). For these reasons, several natural antioxidants, such as *Angelica keiskei* (Kim & Kim, 2001), *Lycii fructus* powders (Park, Yang, & Cho, 2012), or green tea (Shen et al., 2014) have been used for *yukwa* preparation, and the addition of these antioxidants was proven to be effective for preventing oxidative properties.

Turmeric (*Curcuma longa* L.), one of the major spices containing natural antioxidants, is commonly consumed in Asia, and is reported to possess various medicinal properties, including antioxidant, anti-tumor, and anti-inflammatory activities (Tuba & Ilhami, 2008). Lean and Mohamed (1999) reported that turmeric was more antimycotic and antioxidative than other herbs, such as clove, betel leaves and lemon grass, and it was even more effective than BHA and BHT in extending the oxidative shelf-life of processed cakes. Miquel, Bernd, Sempere, Diaz, and Ramiraz (2002) suggested that curcumin, which is a yellow-colored phenolic pigment in turmeric powder, made turmeric powder a strong antioxidant. Tuba and Ilhami (2008) compared the antioxidant activity of curcumin, BHA, BHT, a-tocopherol and trolox and reported that curcumin had a marked antioxidant effect and showed the highest hydrogen peroxide scavenging effect.

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In literatures, only a few trials about anti-oxidative functionality of the product by addition of turmeric powder have been reported including use in butter cake (Lean & Mohamed, 1999), bread (Lim, Park, Ghafoor, Hwang, & Park, 2011), and cookies (Choi, Choi, & Yoo, 2013). In the present study, we added turmeric powder to the *yukwa* at levels up to 10% based on waxy rice flour. The shelf-life of commercial *yukwa* was reported by 30 days at room temperature (Kye, Yoon, & Lee, 1986), or 4 weeks at 30 °C (Shin et al., 1990). Here, we stored the prepared *yukwa* at 50 °C up to 30 days for creating more severe oxidation condition, and the effect of turmeric powder on antioxidant properties during storage as well as on physicochemical and sensory properties of *yukwa* were examined. Additionally, the correlation among variables were also tested.

2. Materials and methods

2.1. Materials

Waxy rice (Japonica cultivar) was obtained from a commercial source in Korea. Soybean, soju (Commercial alcoholic beverage in Korea) and soybean oil were purchased from the local market in Seoul. Turmeric powder harvested from Tripura in India (9.34% moisture content) was purchased from Golden Farm Turmeric Village Co. (Incheon, Korea). All solvents/chemicals used for HPLC measurement were purchased from Sigma Chemical Co. (St. Louis, MO).

2.2. Preparation of yukwa

Waxy rice was steeped at room temperature for 5 days and drained for 3 h over a sieve and then milled (HMF-3100S, Hanil CO., Seoul, Korea). The milled waxy rice flour was passed through a sieve (40 mesh). Soybeans were steeped at room temperature for 4 h and then treated the same as waxy rice. Each level of turmeric powder (0, 2, 5, 8, and 10 g/100 g waxy rice flour, namely, T-0, T-2, T-5, T-8 and T-10, respectively) was substituted for waxy rice flour, and all of the materials including bean powder (3 g/100 g waxy rice flour), soju (18 mL/100 g waxy rice flour), and water (18 mL/100 g waxy rice flour) were mixed to make a dough. The dough was steamed for 20 min and then punched for 5 min using a kneader (Kenwood Mixer KMC 550, Havant, UK). After cooling, the dough was cut into small pallets with average dimensions of 1.5 × 3.5 × 0.5 cm. The pellets were dried for 10 h at 40 °C in an oven (WFO-700 W, Tokyo Rikakikai. Co., Tokyo, Japan) and were then fried by successive two-stage deep-frying: 100 ± 1 °C for 30 s and 160 ± 2 °C, for 60 s. After cooling, the *yukwa* were put in a plastic bag and stored at 50 °C incubator (Sanyo, MIR-162, Osaka, Japan) until analyzed.

2.3. Physical analysis

The moisture content of the pallets was determined by the gravimetric method. The texture analysis of *yukwa* was evaluated using a Texture Analyzer (TX-XT2, Stable Micro Co., Surrey, UK). The hardness was determined from the max force (g), and crispiness was calculated from the peak number after test. A knife blade (HDP/3 PB probe) was used to measure the compression mode, and the optimal test conditions were 100 g force with Pre/Test/Post speed of 2.5, 2.0, and 10.0 mm/s, respectively. Each test was reported as the mean of 10 repetitions. Color analysis of the *yukwa* was performed using a Chroma Meter (CR-300, Minolta Co., Ltd, Osaka, Japan). The colorimeter was standardized with a white plate (L^* = 96.60, a^* = 0.24, b^* = 1.97). The expansion degree was determined from the volume ratio of the *yukwa* and pellets. The volume of *yukwa* and pellets was determined using a seed displacement method (AACC, 2000), and the expansion degree was calculated by the follow equation:

$$\text{expansion degree} = \frac{\text{Volume of } yukwa \text{ after the expansion (mL)}}{\text{Volume of pellets before the expansion (mL)}}$$

2.4. Oxidative properties of yukwa during storage

From the prepared *yukwa*, oil was extracted at 0, 15 and 30 storage days, respectively. The fried *yukwa* base (50 g) was crushed and added to a chloroform:methanol (2:1) mixture (125 mL) and stirred for 30 min without light at room temperature. The mixture was immediately filtered through Whatman No. 1 filter paper to extract the oil. The residue was treated two more times using the same procedure. After combining the filtrates, 1/4 distilled water was added, followed by vigorous shaking and then stored in a refrigerator. The chloroform layer was separated and dehydrated with sodium sulfate anhydrous and then concentrated in a rotary vacuum evaporator at 40 °C. The acid and peroxide values of *yukwa* stored for 30 days at room temperature were measured using the extracted oil (Park et al., 2012).

2.5. Radical scavenging activity by 2,2′-diphenyl-1-picrylhydrazyl (DPPH) method

The DPPH scavenging activity was determined by Blois' method (1958). DPPH was dissolved in 99% ethanol, and the experiments were performed on freshly prepared solutions. In this assay, a reaction mixture containing 0.2 mL of sample solution was added to 0.8 mL of a 0.2 mM DPPH solution, and the resulting solution was then mixed by vortex. Samples were stored at 37 °C for 30 min. DPPH radical scavenging activity was determined by measuring the absorbance at 517 nm with a spectrophotometer (Ultrospec 3000, Pharmacia Biotech, Cambridge, England). The scavenging activity of DPPH radicals was calculated using the following equation:

$$\text{DPPH radical scavenging capacity (\%)} = \frac{A_o - A}{A_o} \times 100$$

where A_o is the absorbance of the control solution (containing only DPPH) and A is the absorbance of the DPPH solution with sample.

2.6. HPLC analysis for curcumin content

The total curcumin content in *yukwa* was analyzed by the method of Lee and Choung (2011) using an Ultimate 3000 HPLC System (Thermo Fisher Scientific Co., Ltd, MA, USA) and an Acclaim 120 column (C18, 5 μm, 6 × 150 mm, Dionex, Sunnyvale, CA, USA). The mobile phase consisted of 2% CH_3COOH in water (A) and 2% CH_3COOH in ACN (B), and the gradient elution was: 10% B (0–3 min), 20% B (8 min), 25% B (13 min), 35% B (18 min). The injection volume was 20 μL and peak was detected at 420 nm.

2.7. Scanning electron microscopy (SEM)

The microstructure of *yukwa* was obtained by environmental scanning electron microscopy (ESEM, XL-30 FEG, FEI Co., Eindhoven, Netherlands) with an acceleration voltage of 10 kV and a thin Au Pb conductive coating.

2.8. Sensory evaluation

Sensory evaluation for *yukwa* without syrup coating was determined by 25 panels. The panels were provided with *yukwa* samples

and asked to evaluate their appearance, flavor, taste, texture, and overall acceptance. All samples were coded and presented in a randomized arrangement. Sensory assessment was analyzed using a seven-point hedonic scale (1 means extremely dislike and 7 means extremely like).

2.9. Statistical analysis

The data were analyzed using the Statistic Analysis System (Ver. 20.0, SPSS Inc., Chicago, IL, USA) package software for analysis of variance (ANOVA). Duncan's multiple range tests were used to detect the significance of differences at $p < 0.05$. All experiments were performed in triplicate. Correlation among variables was also analyzed.

3. Results and discussion

3.1. Physical properties

The moisture content of the pallet, the expansion degree, the color and the textural properties of *yukwa* containing different amounts of turmeric powder are shown in Table 1. The moisture content of the pellets ranged from 16.47% to 19.84%, and the value significantly decreased when the turmeric powder level increased over 5%. Moisture in dough gradually forms pores by transforming from liquid to vapor in the frying process, which have a significant effect on the volume of *yukwa* (Kang, Lee, & Ryu, 2001). If the water content of the pallet is too high, the formation of uniform cells is decreased, whereas an insufficient water content decreases the pore formation, preventing expansion (Kang & Ryu, 2002; Park, Ku, & Mok, 1995). The adequate pellet moisture for high expansion of *yukwa* has been reported as 17–18% (Kang & Ryu, 2002).

The expansion degree is an important factor for *yukwa* product because the texture and mouth feel depend on its expanded volume (Shen et al., 2014). There was no significant difference between control and *yukwa* with 2% turmeric powder (T-2); however, increasing turmeric powder over 5% significantly decreased the expansion degree. It might be expected that the network formation by air cell was inhibited by the turmeric powder addition, resulting in a denser inner structure. Similarly, the addition of green tea powder (Kim & Kim, 2001; Shen et al., 2014) or citrus peel powder (Bae, Lee, & Kim, 2002) for *yukwa* preparation resulted in decreased expansion ratio, showing same tendency with this result.

The color property of *yukwa* was affected by the amount of turmeric powder added. Because turmeric powder has a predominant yellow color (L^* 63.39, a^* 22.56 and b^* 71.50), its addition significantly affected the color of product (Fig. 1). The lightness of *yukwa* decreased with increased turmeric powder, and the redness (a value) and yellowness (b value) dramatically increased from −0.96 to 6.68 and 6.85 to 65.60, respectively.

The hardness of *yukwa* was not changed upon addition of up to 5% turmeric powder, and the value slightly decreased with over 8% turmeric powder. For the hardness of *yukwa*, however, contrary to this result, an increasing tendency has been reported when substitution material content increased: Lycii fructus powder (Park et al., 2012), citrus peel powder (Bae et al., 2002), and green tea powder (Shen et al., 2014). Because the variation of inner structure could induce a change of textural characteristics (Siddiq et al., 2009), these powder substitutions of waxy rice flour could change the food system during frying and thereby affect the texture of the product. Crispiness, which is measured by the peak number and is related to the air cell size and the air cell uniformity, did not change with the addition of up to 5% turmeric powder; however, the value significantly increased with over 8% addition. The texture of *yukwa* is influenced by a number of variables, such as the material added, the frying temperature, the frying method, and the water content of the pallet. In this experiment, higher crispiness and lower hardness were obtained as the turmeric powder content increased, and this might be expected that the crispier surface of *yukwa* was crushed when measuring the texture, resulting in the hardness decreased.

3.2. The oxidative properties

The oxidative properties of *yukwa* containing turmeric powder stored for 30 days at 50 °C are shown in Table 2. The acid values in *yukwa* were not different among samples with/without turmeric powder at 0 day; however, as the storage days increased, the difference became prominent. At 15 days of storage, the addition of 2% turmeric powder did not change the acid value when compared to control (T-0); however, the addition of over 5% turmeric powder decreased the values in *yukwa*. At 30 days of storage, the acid value of the control was 2.27; and all of the samples containing turmeric powder showed significantly lower values than that of the control. The acid value of *yukwa* with 10% turmeric powder (T-10) was decreased to less than half of the value of the control. The decreasing effect on the acid value in other fried snacks (*Majakgwa*) containing turmeric powder was also reported by Choi et al. (2013). Because the acid value in *yukwa* must be lower than 2.0 (mg KOH/g) (MFDS, 2015), the addition of turmeric powder (even a 2% addition) could effectively increase the storage stability of *yukwa* over 30 days even at 50 °C .

Peroxides are the major initial reaction products of lipid oxidation and are responsible for primary oxidation (Ramadan, Amer, & Sulieman, 2006). The peroxide values (PV) of the samples are shown in Table 2. At 0 day, similar PV values were observed in the control and the *yukwa* samples with 2 and 5% turmeric powder added; however, the addition of over 8% turmeric powder significantly lowered the PV compared to the control. Choi et al. (2013) measured the PV of *Majakgwa*, which is another type of fried Korean snack made of wheat flour, and reported that the addition of over 6% turmeric powder significantly decreased the PV value, even

Table 1
Physical properties of *yukwa* containing different turmeric powder.

Sample[1]	M.C (%)	Expansion degree	Color properties			Textural properties	
			L	*a*	*b*	Hardness (g)	Crispiness
Turmeric powder	9.34 ± 0.32	–	63.39 ± 1.67^{d}	22.56 ± 0.96^{a}	71.50 ± 0.95^{a}		
T-0	19.84 ± 0.29^{a}[2]	9.60 ± 2.50^{a}	75.02 ± 2.01^{a}	−0.96 ± 0.13^{d}	6.85 ± 1.74^{d}	1402.39 ± 110.01^{a}	44.67 ± 5.03^{c}
T-2	19.35 ± 0.38^{ab}	6.24 ± 2.06^{ab}	71.59 ± 1.34^{b}	−8.33 ± 0.92^{f}	60.78 ± 6.95^{c}	1300.42 ± 209.07^{a}	49.33 ± 10.07^{c}
T-5	18.29 ± 0.16^{bc}	4.97 ± 1.57^{b}	65.87 ± 3.15^{c}	−2.86 ± 1.05^{e}	62.35 ± 4.26^{bc}	1578.05 ± 75.37^{a}	53.00 ± 12.12^{c}
T-8	17.35 ± 1.09^{cd}	3.93 ± 0.20^{b}	66.47 ± 2.24^{c}	1.83 ± 2.37^{c}	65.57 ± 1.96^{b}	1002.02 ± 45.76^{b}	83.67 ± 4.73^{b}
T-10	16.47 ± 1.37^{d}	4.44 ± 0.87^{b}	63.46 ± 3.05^{d}	6.68 ± 1.99^{b}	65.60 ± 2.52^{b}	988.00 ± 209.28^{b}	107.00 ± 13.00^{a}

[1] T-0, T-2, T-5, T-8 and T-10 mean *yukwa* containing 0, 2, 5, 8 and 10 g turmeric powder/100 g waxy rice flour, respectively.
[2] Values are means ± standard deviation of triplicate determinations. Means with different letters within a column are significantly different ($p < 0.05$).

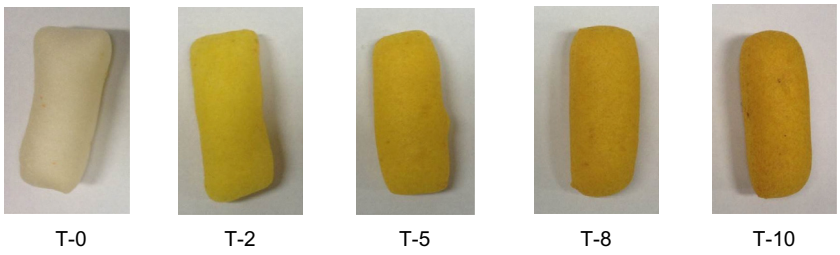

Fig. 1. *Yukwa* containing different amount of turmeric powder. T-0 (Control), T-2, T-5, T-8 and T-10 mean *yukwa* containing 0, 2, 5, 8 and 10 g turmeric powder/100 g waxy rice flour, respectively.

Table 2
Oxidative properties of *yukwa* containing different amount turmeric powder during storage days.

Sample[1]	Acid values (mg KOH/g)			Peroxide values (meq/g)			DPPH (%)		
	0 day	15 day	30 day	0 day	15 day	30 day	0 day	15 day	30 day
T-0	0.14 ± 0.03^{a}[2]	0.28 ± 0.08^{a}	2.27 ± 0.06^{a}	9.18 ± 1.02^{a}	12.34 ± 1.26^{a}	69.2 ± 8.55^{a}	29.86 ± 2.50^{b}	21.39 ± 1.42^{c}	12.82 ± 0.16^{d}
T-2	0.17 ± 0.05^{a}	0.25 ± 0.01^{ab}	1.23 ± 0.08^{b}	6.80 ± 0.59^{ab}	10.62 ± 0.26^{b}	54.74 ± 1.60^{b}	26.87 ± 0.64^{b}	22.50 ± 6.04^{c}	18.26 ± 4.32^{cd}
T-5	0.17 ± 0.03^{a}	0.17 ± 0.03^{bc}	1.27 ± 0.15^{b}	6.46 ± 1.56^{ab}	9.14 ± 0.40^{c}	38.21 ± 2.89^{c}	44.27 ± 0.74^{a}	31.26 ± 0.16^{b}	21.37 ± 4.21^{c}
T-8	0.12 ± 0.03^{a}	0.13 ± 0.03^{bc}	1.20 ± 0.10^{bc}	4.76 ± 1.56^{b}	8.67 ± 0.39^{c}	29.27 ± 3.10^{d}	49.05 ± 1.17^{a}	40.84 ± 1.17^{a}	35.00 ± 6.88^{b}
T-10	0.08 ± 0.03^{a}	0.12 ± 0.03^{c}	1.05 ± 0.05^{c}	4.08 ± 2.04^{b}	7.93 ± 0.3^{c}	20.77 ± 4.39^{e}	48.48 ± 2.16^{a}	43.66 ± 1.27^{a}	45.89 ± 0.52^{a}

[1] T-0, T-2, T-5, T-8 and T-10 mean *yukwa* containing 0, 2, 5, 8 and 10 g turmeric powder/100 g waxy rice flour, respectively.
[2] Values are means ± standard deviation of triplicate determinations. Means with different letters within a column are significantly different ($p < 0.05$).

at 0 days of storage. The order of hydrogen peroxide scavenging effect was reported as follows: curcumin > trolox > BHT > BHA ≈ α-tocopherol by Tuba and Ilhami (2008), and from the results, it could be assured that turmeric powder containing curcumin has a strong antioxidant effect. As the number of storage days increased, the PV also increased, and there was a significant difference between the control and the samples with turmeric powder. At 30 days of storage, a significant increase in PV was observed for all samples; however, the value decreased with increasing turmeric powder content. In the "Standards and Specifications for *yukwa*" in Korea, PV is regulated to be lower than 40 meq/g (NAQS, 2012; MFDS, 2015). In this experiment, a greater than 5% addition of turmeric powder could effectively increase the storage ability of *yukwa* up to 30 days even at 50 °C.

The antioxidant properties of *yukwa* with different amounts of turmeric powder were tested with respect to their DPPH radical scavenging effect, and the results are shown in Table 2. DPPH is one of the few stable organic nitrogen free radicals and has been widely used to determine the free radical scavenging ability of various samples (Staszewski, Pilosof, & Jagus, 2011). At 0 storage day, the DPPH value was the lowest in the control, and addition of turmeric powder improved the scavenging effect for all storage days. The control was 29.86%, and the value increased to 48.48% upon addition of 10% turmeric powder (T-10), which is approximately two times higher than that of the control.

Upon addition of up to 5% turmeric powder (T-0, T-2, and T-5), as the number of storage days increased, the % radical scavenging decreased from 29.86 to 12.82, 26.87 to 18.26, and 44.27 to 21.37, respectively, however, for the 8% addition at 15 days of storage and the 10% addition at 15 and 30 storage days, the % radical scavenging was maintained. Because a high correlation between the total phenolic materials and the DPPH values was measured (Kevers et al., 2007), therefore, the improved antioxidant properties of *yukwa* with turmeric powder were due to the high functional phenolic compound in turmeric powder, curcumin.

3.3. Curcumin content in yukwa

Because phenolic materials are heat unstable and reactive compounds (Cheynier, 2005), frying can induce a loss of curcumin. By frying, considerable reduction in the antioxidant activity of red- and purple-fleshed potatoes was reported (Brown, Durst, Wrolstad, & Jong, 2008). The curcumin content in the turmeric powder used in this experiment was 4.78 mg/g. The content in *yukwa* was measured as 0, 0.07, 0.16, 0.22, and 0.24 mg/g for T-0, T-2, T-5, T-8 and T-10, respectively, showing higher amount with increasing levels of turmeric powder added (Fig. 2). Despite the loss of the total phenol content during frying, some amount was maintained in *yukwa*, improving anti-oxidative functionality.

3.4. Internal structure by SEM

Fig. 3 shows the internal structure in cross-sections of *yukwa* containing turmeric powder. The interior cells in the control (without turmeric powder) were large and distinct; however, the size decreased and became less obvious with increasing turmeric powder content, resulting in a compact and dense shape. This result was similar to that of *yukwa* containing green tea powder (Shen

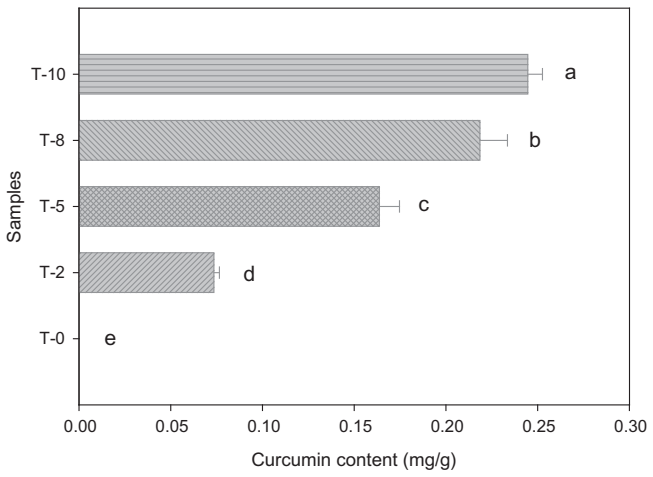

Fig. 2. Curcumin contents in *yukwa*. T-0 (Control), T-2, T-5, T-8 and T-10 mean *yukwa* containing 0, 2, 5, 8 and 10 g turmeric powder/100 g waxy rice flour, respectively. Different letters (a–e) indicate significant differences ($p < 0.05$).

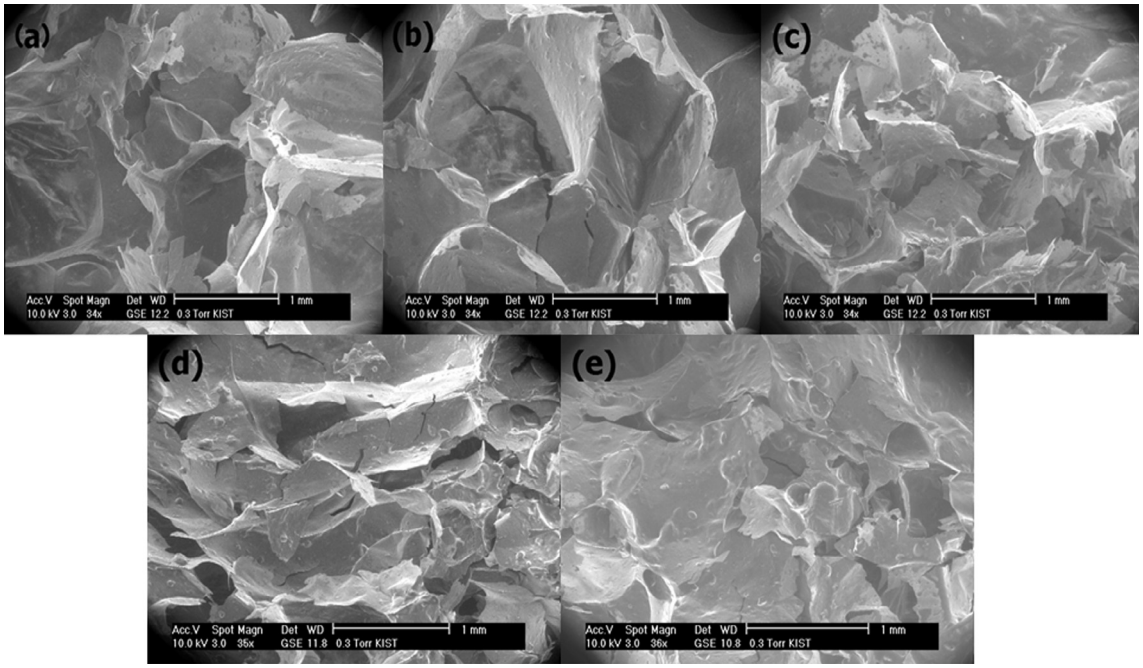

Fig. 3. Scanning electron micrographs of cross-sections of *yukwa* (a) T-0 (Control), (b) T-2, (c) T-5, (d) T-8, (e) T-10, indicating 0, 2, 5, 8 and 10 g turmeric powder/100 g waxy rice flour, respectively.

Table 3
Sensory characteristics of *yukwa* containing different amount turmeric powder during storage days.

Sample[1]	Overall acceptability	Appearance	Flavor	Taste	Texture
T-0	5.40 ± 1.47[a]	5.90 ± 1.29[NS2]	4.95 ± 1.15[NS]	5.15 ± 1.81[a]	5.90 ± 1.71[a]
T-2	5.20 ± 1.44[a]	5.50 ± 1.19	4.90 ± 1.45	4.60 ± 1.45[ab]	6.00 ± 1.45[a]
T-5	5.30 ± 1.42[a]	5.15 ± 1.35	4.80 ± 0.89	4.95 ± 1.57[ab]	6.30 ± 1.03[a]
T-8	4.35 ± 1.87[b]	5.35 ± 1.04	4.65 ± 1.60	4.25 ± 1.55[bc]	4.85 ± 1.63[b]
T-10	3.65 ± 1.23[b]	5.25 ± 1.29	4.35 ± 1.53	3.45 ± 1.19[c]	4.70 ± 1.59[b]

[1] T-0. T-2, T-5, T-8 and T-10 mean *yukwa* containing 0, 2, 5, 8 and 10 g turmeric powder/100 g waxy rice flour, respectively.Values are means ± standard deviation of triplicate determinations. Means with different letters within a column are significantly different ($p < 0.05$).
[2] NS means no significant differences ($p < 0.05$).

et al., 2014), indicating that materials added to waxy rice flour for *yukwa* preparation negatively affect the pore formation.

3.5. Sensory results

The sensory results of *yukwa* with turmeric powder are shown in Table 3. Although the color of *yukwa* was clearly distinguishable among samples, as shown in Fig. 1, the preference for appearance was not significantly different. The flavor of *yukwa* was also not different with different contents of turmeric powder. In terms of taste, the control and samples with up to 5% turmeric powder did not show any difference. Over 8% addition turmeric powder, however, significantly decreased the taste preference of *yukwa* due to the bitter taste of turmeric powder. For texture, up to 5% turmeric powder also did not affect the *yukwa* texture; however, over 8% addition decreased the texture preference.

The results of the sensory test revealed that the addition of turmeric powder up to 5%/100 g waxy rice flour for *yukwa* was acceptable. *Yukwa* with over 8% turmeric powder was rated lower in overall acceptability because excessive amounts of volatiles, curcumin in turmeric powder in this experiment, can negatively affect the taste of food (Drewnowski & Gomez-Carneros, 2000).

3.6. Correlation among variables

The correlation among variables was analyzed, and the results are shown in Table 4. The physicochemical properties of the product were highly correlated with the sensory quality. Among sensory variables, overall acceptability was positively correlated with hardness ($r = 0.886$) and negatively correlated with crispiness ($r = -0.995$). The moisture content of pallets showed strong correlations with the oxidative and textural properties. A higher moisture content decreased crispiness ($r = -0.950$) and increased the acid value ($r = 0.970$, at 15 days) and peroxide values ($r = 0.947$, 0.9505 and 0.988 at 0, 15 and 30 storage days, respectively). A higher moisture content also had a negative correlation with DPPH ($r = -0.913$, -0.965 and -0.902 at 0, 15 and 30 storage day, respectively), suggesting that the moisture content of the dough for *yukwa* was a main factor influencing *yukwa* quality. The *L* value was correlated with the oxidative properties. A higher *L* value means lower turmeric powder addition in *yukwa* and was related to higher acid ($r = 0.962$ at 15 storage days) and peroxide values ($r = 0.913$, 0.986 and 0.949 at 0, 15 and 30 storage days, respectively) and lower DPPH values.

4. Conclusions

Turmeric powder, which contains the strong antioxidant known as curcumin, was added to *yukwa* with different amount, and the quality of the product was evaluated. With the addition of turmeric powder, the expansion degree of *yukwa* decreased with over 5% addition, and the color was significantly changed to lower lightness and higher yellowness. The addition of turmeric powder also

Table 4
Coefficients of correlation among sensory, physical, textural and oxidative variables for *yukwa* containing turmeric powder.

Varaible	Sensory			Physical properties				Textural properties		Acid value (AV)			Peroxide value (PV)		
	OA[1]	Color	Flavor	MC[2]	ED[3]	L	b	Hard	Crisp	AV-0	AV-15	AV-30	PV-0	PV-15	PV-30
MC	0.919*	0.741	0.960**	1											
Hard	0.886*	0.167	0.744	0.701	0.580	0.437	−0.381	1							
Crisp	−0.995**	−0.520	−0.981**	−0.950*	−0.678	−0.789	0.541	−0.853	1						
AV-0	0.913*	0.138	0.866	0.758	0.350	0.736	0.827	−0.904*		1					
AV-15	0.807	0.827	0.866	0.970**	0.897*	0.962**	−0.754	0.589	−0.855	0.608	1				
AV-30	0.786	0.891*	0.638	0.731	0.839	0.829	−0.992**	0.441	−0.606	0.216	0.760	1			
PV-0	0.890*	0.800	0.883*	0.947*	0.903*	0.913*	−0.863	0.724	−0.887*	0.607	0.934*	0.891*	1		
PV-15	−0.72	0.906*	0.858	0.950*	0.895*	0.986**	−0.868	0.545	−0.825	0.521	0.972**	0.881*	0.966**	1	
PV-30	0.890*	0.800	0.925*	0.988**	0.880*	0.949*	−0.793	0.696	−0.919*	0.673	0.976**	0.821	0.983**	0.978**	1
DP[4]-0	−0.720	−0.738	−0.795	−0.913*	−0.814	−0.900*	0.581	−0.485	0.784	−0.601	−0.963**	−0.574	−0.807	−0.883*	−0.891*
DP-15	−0.970**	−0.548	−0.954*	−0.965**	−0.753	−0.811	0.554	−0.843	0.986**	−0.875	−0.903*	−0.600	−0.897*	−0.848	−0.937*
DP-30	−0.963**	−0.514	−0.986**	−0.902*	−0.527	−0.771	0.499	−0.746	0.962**	−0.884*	−0.773	−0.585	−0.824	−0.781	−0.859

* $p < 0.05$.
** $p < 0.01$.
[1] OA means overall acceptability.
[2] MC means moisture content.
[3] ED means expansion degree.
[4] DP means DPPH value.

changed the textural properties of *yukwa*, resulting in increased hardness and decreased crispiness, especially with over 8% addition. In the microscopic images obtained by E-SEM, the internal structure of *yukwa* was flattened and crushed with increasing turmeric powder. As expected, a strong prevention effect of turmeric powder on *yukwa* oxidation was proved by the DPPH radical scavenging activity. Oxidative deterioration measured by AV, PV and DPPH was effectively inhibited by increased turmeric powder content. Based on the results of the physicochemical and sensory tests, the 5% turmeric powder addition is the most acceptable for *yukwa* preparation, and it showed almost 1/2 numerical value for acid and peroxide values, and 2 times higher free radical scavenging effect than those of control at 30 storage day. With the addition of turmeric powder to *yukwa*, the functional properties and shelf life are significantly improved.

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