Physical, textural and sensory characteristics of legume-based gluten-free muffin enriched with waxy rice flour

Duyun Jeong¹ · Hyun-Jung Chung¹

Received: 11 May 2018 / Revised: 8 July 2018 / Accepted: 24 July 2018 / Published online: 11 August 2018
© The Korean Society of Food Science and Technology and Springer Science+Business Media B.V., part of Springer Nature 2018

Abstract Physical, textural, and sensory characteristics of the gluten-free muffins made of mungbean and cowpea flours enriched with waxy rice flour were investigated. Amylose content and pasting viscosity of legume-waxy rice flour blend (1:1) were lower than that of wheat flour. The number and area of gas cells of muffin containing legume flour was lower than that of control muffin with wheat flour. Legume-based muffins had low lightness value due to the presence of color components. Weight of the muffins containing legume was higher than that of control muffin, but their height and volume were lower than control. Legume-based muffins had greater crude ash and protein contents than control. Compared with control, muffin containing legume flour had significantly higher hardness and gumminess. In sensory evaluation, overall acceptance of muffin containing *Okdang* cultivar of cowpea was the highest among legume-based muffins, which was comparable to control muffin.

Keywords Gluten-free muffin · Legume flour · Waxy rice flour · Quality characteristics

Introduction

The market for gluten-free products that are nutritious and palatable is growing as more people are choosing a gluten-free diet out of necessity or personal preference (Gao et al.,

2018). Celiac disease is a life-long autoimmune disorder derived from the ingestion of gluten in susceptible patients (Kennedy and Feighery, 2000). The celiac patients have a classic symptoms in the malabsorption of some nutrients such as iron and soluble vitamins, chronic diarrhea, and abdominal distention. Gluten-free product was initially designed for people diagnosed with celiac disease. Currently, the increased interest in gluten-free products is motivated by health concerns to avoid wheat in the diet (Nachay, 2010). However, baked products without gluten have technical problems such as quality defect, crumbling texture, and rapid staling since gluten is a major structural forming protein in bakery products contributing to the viscoelastic characteristics of dough (Goswami et al., 2015). As a result, there has been extensive studies including the addition of native and modified starches, various animal and vegetable proteins, and food hydrocolloids into a gluten-free formulation, in an effort to mimic the properties of gluten and improve the structure, mouthfeel, acceptability and storage stability (Lazaridou et al., 2007; Moore et al., 2006; Nunes et al., 2009; Renzetti et al., 2008; Ribotta et al., 2004).

The popularity of gluten-free baked products such as bread, biscuits, cakes, muffins and pastries has increased. Muffin is very popular sweet baked products highly appreciated by consumers due to its good taste and spongy texture (Shevkani et al., 2015). Traditionally, muffin is made of wheat flour, sugar, vegetable oil, egg, and milk, and thus persons with celiac disease are unable to consume this type of baked product since its ingestions cause intestinal damage. Gluten-free muffins may serve as a useful method for nutritional improvement in diets in gluten-intolerant individuals. Incorporation of non-gluten protein may facilitate gluten-free foods (Matos et al., 2014). Several studies investigating gluten-free muffins

✉ Hyun-Jung Chung
hchung@jnu.ac.kr

¹ Division of Food and Nutrition, Chonnam National University, 77 Yongbong-ro, Buk-gu, Gwangju 61186, South Korea

sought to improve the structure, mouth feel, acceptability, and nutritional quality of the final products with various grains such as rice flour, millet, buckwheat, sorghum, common bean, and pea (Matos et al., 2014; Minarro et al., 2012).

Legumes are important grain for food and feed since they contain large amounts of proteins and carbohydrates (Chung et al., 2008). Legume protein is an inexpensive ingredient for protein enrichment of gluten-free cereal bakery products due to its amino acid composition complementary to cereals, almost absence of allergic gluten proteins, beneficial health effects and lower cost compared with animal proteins (Gularte et al., 2012; Matos et al., 2014). Legumes have been known to decrease blood glucose response and prevent diabetes and hyperlipidemia due to the reduced bioavailability, low glycemic response, high amylose content, intact cell structure, and high viscous soluble dietary fiber components (Chung et al., 2008; Tharanathan and Mahadevamma, 2003). However, gluten-free baked products containing cereals or legumes often were defective in quality and expensive due to the amount of ingredients used to replace gluten (Gallagher et al., 2004; Mir et al., 2016). In addition, a limited number of studies investigated the properties of legume-based gluten-free muffin.

The present study was focused to evaluate the chemical composition, physical properties, texture, and sensory evaluation of gluten-free muffin prepared with different species (cowpea and mungbean) and cultivars of Korean legumes enriched with waxy rice flour.

Materials and methods

Materials

Mungbean (*Sohyun*, *Dahyun*, and *Jangan* cultivar) and cowpea (*Seowon*, *Yeonbun*, and *Okdang* cultivar) were provided by the Rural Development Administration (Jeonju, Korea). Waxy rice (*Baekokchal* cultivar), wheat flour, sugar (CJ Co., Seoul, Korea), butter (Lotte Co., Seoul, Korea), baking powder (SL Food, Seoul, Korea), milk (Maeil Dairies Co., Seoul, Korea), salt (Daesang Co., Seoul, Korea), and egg were purchased from the local grocery market (Gwangju, Korea).

Preparation of legume and waxy rice flours

Mungbean and cowpea were washed and steeped in distilled water (500 g in 750 mL) for 6 h at room temperature. After soaking, the mungbean and cowpea were ground using a mechanical grinder (DA5500, Daesung Artlon Co., Seoul, Korea), dried overnight at 45 °C to a moisture

content less than 10%, and sieved through a sieve (100 mesh). The mungbean and cowpea flours were heated at 120 °C for 30 min to remove their undesirable off-flavors and improve the texture of muffin but ensuring that the heating time does not result in dextrinization of flour due to its limited moisture content. Chiu et al. (1999) reported that thermal treatment of flour or starch could improve the textural characteristic of product and remove an undesirable taste and off-flavors. In our preliminary test, the thermal treatment condition at 120 °C for 30 min was achieved to reduce the off-flavor and to minimize the color change during heating.

Waxy rice grains were soaked in distilled water (500 g in 1500 mL) for 4 h at room temperature (25 °C). The soaked rice was drained for 1 h and dried in a convection oven (25 °C) for 12 h to produce semi-wet rice grains. The semi-wet rice grains were ground into fine flour using a mechanical grinder (DA5500, Daesung Artlon Co., Seoul, Korea) and then passed through a 100 mesh sieve.

Properties of legume and waxy rice flour blends

The apparent amylose content of wheat flour and legume-waxy rice flour (1:1) blends were determined using a colorimetric method (Williams et al., 1970). The flours were mixed with 0.5 N KOH solution and the suspension was heated for 10 min in a boiling water bath. After cooling, an aliquot of the solution was neutralized by adding 0.5 N HCl and iodine reagent (0.2% I₂ + 2.0% KI). The absorbance of the color developed solution was measured using a spectrophotometer (Optizen Pop, Mecasys Co., Daejeon, Korea).

The pasting properties of wheat flour and legume-waxy rice flour (1:1) blends were analyzed by using a Rapid Visco-Analyzer (RVA 4500-TecMaster, Newport Scientific, Warriewood, Australia). The flour suspension (7%, w/w) was held at 50 °C for 1 min, raised to 95 °C at a rate of 6 °C/min, held at 95 °C for 5 min, cooled to 50 °C at 6 °C/min, and held at 50 °C/min for 2 min with a constant rotating speed of the paddle (160 rpm). Peak viscosity, breakdown, setback, final viscosity, and pasting temperature were determined from the viscograms.

Thermal properties of wheat flour and legume-waxy rice (1:1) flour blends were determined using a differential scanning calorimeter (DSC4000, PerkinElmer Inc., Waltham, MA, USA). The flour (6.66 mg, db) and 13.32 µL of distilled water were loaded into a stainless steel pan and hermetically sealed. The sample pans were heated from 5 to 150 °C at a heating rate of 5 °C/min. An empty pan was used as a reference. The onset (T_o), peak (T_p) and conclusion (T_c) gelatinization temperatures and gelatinization enthalpy (ΔH) were determined using the DSC thermograms.

Muffin preparation

Muffins were prepared according to Chung et al. (2010) with little modification. The gluten-free muffins were made by replacing the wheat flour with legume (mungbeans or cowpeas) and waxy rice flour blends (1:1). In the preliminary test, the muffin made with legume flour-waxy rice flour (1:1) blend exhibited greater texture and overall acceptability in sensory evaluation among muffins made with flour blends ranging from 0 to 100%. Muffin formulation containing wheat flour alone served as the control sample. The ingredients used in muffin preparation were 200 g wheat flour (or 100 g legume flour, 100 g waxy rice flour), 100 g butter, 120 g sugar, 120 g egg, 100 g milk, 13 g baking powder, and 2 g salt.

Muffin batter was prepared by blending butter, salt, and sugar for 3 min with a wire whip. Egg was added and mixed for 5 min. Wheat flour (or legume flour-waxy rice flour blends), baking powder, and milk were then added and mixed with wire whip for 1 min. The batter (60 g) was poured into the muffin cup (5.5 cm diameter, 4.5 cm height) and baked at 170 °C for 25 min in a preheated baking oven (FDO-7104B, Daeyoung Bakery Machinery Co., Seoul, Korea). The muffins, after baking, were cooled to room temperature on a rack to avoid moisture condensation on their surface. The muffins from each formulation were prepared at least three times on different days with 5 muffins in each bath.

Properties of legume flour-based muffins

The proximate composition of muffins made from wheat flour and legume-waxy rice (1:1) flour blends was analyzed using the AOAC methods (2000): moisture (Method 925.09), crude fat (Method 969.24), crude protein (Method 950.48), and crude ash (Method 923.03).

The muffin was cut vertically and images of the cut surface of the crumb were captured using a digital camera (Samsung NX 3000, Seoul, Korea). Muffin volume was measured using the seed replacement method, muffin weight was determined using a balance, and muffin height was measured with a digital caliper from the highest point of the muffin to the bottom.

The muffin sample was cut in the center. The crumb color of muffin samples was determined in terms of L^* (lightness), a^* (redness), and b^* (yellowness) values using a colorimeter (SpectraMagic NX, Konica Minolta, Tokyo, Japan).

The textural properties of the muffin were measured using a texture analyzer (TA-XT + , Stable Micro Systems, Surrey, UK). The muffin was cut in cubes (20 × 20 × 20 mm) from the center of the muffin. A double compression test (texture profile analysis mode)

was performed with a cylinder probe (20 mm diameter) and 50% compression of its original height at a speed of 1.0 mm/s with 5 s interval between the two compression cycles. The hardness, adhesiveness, springiness, cohesiveness, and gumminess were determined from the curves.

The sensory characteristics of muffins were determined by 24 trained panelists (3 male, 21 female, ages 20–25). Sensory attributes including color, taste, flavor, texture, and overall acceptance were evaluated using a seven point hedonic scale, ranging from 1 (dislike extremely) to 7 (like extremely).

Statistical analysis

All tests in this study were performed in triplicate. Differences between factors were evaluated using a one way analysis of variance (ANOVA) and statistical analyses were carried out with Duncan's multiple range test ($p < 0.05$) to compare means using SAS software system (Version 9.2, SAS Institute Inc., Cary, NC, USA).

Results and discussion

Amylose content and pasting viscosity of flours

The amylose content of wheat flour and blends of legume and waxy rice flours is presented in Table 1. As expected, the wheat flour exhibited the highest amylose content (24.3%), whereas the amylose content of legume-waxy rice flour blends ranged between 6.1 and 9.6% (Table 1). Incorporation of waxy rice flour considerably decreased the amylose content of flour blends. Considering the starch content in legume seeds (~ 45%) and the amylose content in waxy rice starches (< 2%), the observed amylose content of legume starches may be in the range of 30–40%, which is similar to those have been reported with cowpea and mungbean starches (Hoover et al., 2010; You et al., 2014). The amylose content of mungbean-waxy rice flours (MS-WR, MD-WR, and MJ-WR) was relatively higher than that of cowpea-waxy rice flours (CS-WR, CY-WR, and CO-WR).

Pasting profiles of legume-waxy rice flour blends were apparently different from that of wheat flour (Table 1). All legume-waxy rice flour blends had substantially low pasting temperature, peak viscosity, setback, and final viscosity compared with wheat flour (Table 1). The pasting viscosity of flours is mainly due to the swelling of starch granules (Vandeputte et al., 2003). The setback and final viscosity indicates the degree of re-association of the starch chains, which may relate to the amount of leached amylose during heating. The legume containing higher amylose content exhibit a lower degree of swelling and amylose leaching

Table 1 Effect of legumes on amylose content, pasting properties and thermal properties of flour

Flour	Amylose content (%)	Pasting temperature (°C)	Peak viscosity (mPa·s)	Breakdown (mPa·s)	Setback (mPa·s)	Final viscosity (mPa·s)	T _o (°C)	T _p (°C)	T _c (°C)	ΔH (J/g)
Wheat	24.3 ± 0.9 ^a	85.9 ± 0.0 ^a	2620 ± 2 ^a	1195 ± 19 ^a	1780 ± 7 ^a	3205 ± 7 ^a	55.4 ± 0.3 ^d	61.9 ± 0.3 ^c	69.1 ± 0.3 ^d	7.0 ± 0.2 ^{bc}
MS-WR	8.4 ± 0.1 ^c	70.1 ± 0.3 ^c	1098 ± 29 ^d	336 ± 14 ^b	545 ± 29 ^a	1307 ± 29 ^e	65.3 ± 0.2 ^{ab}	72.2 ± 0.1 ^{ab}	80.0 ± 0.2 ^c	6.7 ± 0.0 ^{cd}
MD-WR	8.8 ± 0.2 ^c	70.3 ± 0.0 ^c	1149 ± 12 ^d	291 ± 19 ^c	679 ± 4 ^d	1537 ± 4 ^d	65.2 ± 0.0 ^b	72.2 ± 0.1 ^{ab}	80.1 ± 0.3 ^c	5.7 ± 0.0 ^e
MJ-WR	9.6 ± 0.2 ^b	70.1 ± 0.2 ^c	1003 ± 29 ^e	288 ± 21 ^c	531 ± 26 ^a	1246 ± 26 ^e	65.4 ± 0.1 ^{ab}	72.5 ± 0.4 ^a	80.9 ± 0.3 ^b	6.5 ± 0.1 ^d
CS-WR	6.1 ± 0.2 ^e	70.3 ± 0.0 ^c	1551 ± 14 ^c	185 ± 12 ^d	732 ± 15 ^c	2098 ± 15 ^c	64.2 ± 0.0 ^c	72.0 ± 0.1 ^b	80.1 ± 0.2 ^c	7.1 ± 0.3 ^b
CY-WR	8.0 ± 0.2 ^{cd}	70.9 ± 0.3 ^b	1498 ± 51 ^c	149 ± 8 ^d	844 ± 70 ^b	2194 ± 70 ^b	65.4 ± 0.3 ^{ab}	72.4 ± 0.1 ^{ab}	82.4 ± 0.5 ^a	7.9 ± 0.1 ^a
CO-WR	7.8 ± 0.0 ^d	70.9 ± 0.3 ^b	1770 ± 46 ^b	310 ± 24 ^{bc}	811 ± 56 ^b	2271 ± 56 ^b	65.6 ± 0.1 ^a	72.4 ± 0.1 ^{ab}	80.5 ± 0.0 ^{bc}	7.8 ± 0.1 ^a

Data followed by the different letter in the same column are significantly different ($p < 0.05$)

T_o, onset gelatinization temperature; T_p, peak gelatinization temperature; T_c, conclusion gelatinization temperature; ΔH, gelatinization enthalpy

MS-WR mungbean *Sohyun*-waxy rice (1:1) flour blend; MD-WR mungbean *Dahyun*-waxy rice flour blend; MJ-WR mungbean *Jangan*-waxy rice flour blend; CS-WR cowpea *Seowon*-waxy rice flour blend; CY-WR cowpea *Yeonbun*-waxy rice flour blend; CO-WR cowpea *Okdang*-waxy rice flour blend

than wheat, which could explain the low pasting viscosity of legume-waxy rice flour blends (Hoover et al., 2010). The lower pasting temperature of legume-waxy rice flour blends than wheat flour could be attributed to the presence of waxy rice flour in flour blends. Jongsutjarittam and Charoenrein (2013) reported that the pasting temperature of waxy rice flour was substantially lower than that of wheat flour because the crystallinity of wheat starch (35.5%) was higher than that of waxy rice starch (18.5–23.8%). The increasing levels of protein in legume-waxy rice flour than in wheat flour might be attributed to lower paste viscosities because of the starch dilution effect in the presence of more proteins and a greater stability of the starch granules induced by protein–starch interactions (Shevkani et al., 2015; Tharanathan and Mahadevamma, 2003).

The mungbean-waxy rice flour blends (MS-WR, MD-WR, and MJ-WR) exhibited substantially lower peak viscosity, setback, and final viscosity than cowpea-waxy rice flour blends (Table 1). The mungbean has lower starch yield when compared with cowpea (Hoover et al., 2010). A greater starch yield in cowpea may directly contribute to its higher swelling during heating, and thereby, higher peak viscosity in cowpea cultivars than mungbean cultivars. The amylose content of mungbean flour was higher than that of cowpea flour (Table 1). Hoover et al. (2010) also reported that the amylose content in cowpea (25.8–33.0%) was higher than that in mungbean (33.0–45.3%). The amylose in starch could restrict granular swelling, which also explains the higher peak viscosity in cowpea-waxy rice flour blends than mungbean-waxy rice flour blends.

Mungbean and cowpea flours showed significant difference among the cultivars with respect to pasting characteristics (Table 1). Among the mungbean cultivars, *Dahyun* (MD-WR) had the highest pasting viscosity and final viscosity. Among the cowpea cultivars, *Okdang* (CO-WR) had the highest pasting viscosity and final viscosity, whereas the pasting temperature was not significantly different among the cultivars. This difference in pasting properties among the cultivar could be attributed to their flour composition and characteristic of starches and proteins (Singh et al., 2014).

Gelatinization properties

The gelatinization properties of wheat flour and blends between legume and waxy rice flours are also presented in Table 1. The onset, peak, and conclusion temperatures (T_o , T_p , and T_c , respectively) for gelatinization of wheat flour were significantly lower than those of blends involving legume and waxy rice flours (Table 1). This difference in gelatinization temperatures may be due to starch structure and protein content (Kaur and Singh, 2005). The

gelatinization temperature represents the degree of crystal perfection in the starch granules (Eliasson and Gudmunsson, 1996). Thus, higher gelatinization temperature in legume-waxy rice flours than wheat flour indicates a high degree of crystalline stability because of the high amylose content in starch and great amount of protein content in legume. Similarly, Emmambux and Taylor (2013) reported that legume starches had higher gelatinization temperature than cereal starches. Interestingly, the gelatinization temperature of legume-waxy rice flours was significantly higher than that of wheat flour, whereas the pasting temperature showed the opposite trend (Table 1). Gelatinization is defined as the disruption of molecular orders and pasting is the phenomenon following gelatinization in the dissolution of starch, involving granular swelling and leaching of molecular components from the granules although pasting is not exactly distinct from gelatinization (Thomas and Atwell, 1999). Gelatinization and pasting in wheat flour occur in sequence, while pasting overlaps as a continuation of gelatinization in legume-waxy rice flour. In flour blends of legume and waxy rice, the starch gelatinization occurred at a relatively high temperature by the presence of legume flour, while the pasting process began before gelatinization end due to the rapid swelling by waxy rice flour. This heterogeneity with granules in legume-waxy rice flour induce a broader gelatinization temperature ranges compared with wheat flour (Table 1).

Gelatinization enthalpy is the property of starch in flour and reflects the overall amount of crystallinity of starch (Tester and Morrison, 1990). Cowpea-waxy rice flour showed higher gelatinization enthalpy than mungbean-waxy rice flour. The greater gelatinization enthalpy of cowpea-waxy rice flour as compared to mungbean-waxy rice flour may be attributed to their lower amylose content since starch with lower amylose content could have more crystalline structure (Jane et al., 1999).

Chemical composition and physical characteristics of muffin

The chemical composition of legume-waxy rice flour blend muffins along with control muffin is presented in Table 2. The legume-based muffins had slightly higher moisture content than control muffin. The legume flours generally contain greater protein and dietary fiber contents than wheat flour (Tharanathan and Mahadevamma, 2003). These components contribute to greater water holding capacity in the composite flour, and therefore, contribute to greater moisture content in muffins containing legume flours (Hallen et al., 2004). As expected, the legume-based muffins showed higher protein content than control muffins, which could be attributed to the higher protein content of legume flours than wheat flour. The muffin made with

Table 2 General composition of legume-based gluten-free muffins

Muffin	Moisture (%)	Crude protein (%)	Crude fat (%)	Crude ash (%)
Con	31.7 ± 0.3 ^b	4.8 ± 0.1 ^c	16.0 ± 0.4 ^{bc}	1.5 ± 0.1 ^b
MS-WR	32.9 ± 0.1 ^a	7.4 ± 0.3 ^{ab}	15.6 ± 0.4 ^{bc}	2.0 ± 0.1 ^a
MD-WR	32.2 ± 0.7 ^{ab}	7.3 ± 0.1 ^b	14.6 ± 0.4 ^c	1.7 ± 0.1 ^{ab}
MJ-WR	32.0 ± 0.1 ^{ab}	7.2 ± 0.1 ^b	17.0 ± 0.2 ^{ab}	1.9 ± 0.2 ^a
CS-WR	31.8 ± 0.7 ^b	7.6 ± 0.1 ^a	17.7 ± 0.5 ^a	2.0 ± 0.0 ^a
CY-WR	33.0 ± 0.4 ^a	7.5 ± 0.0 ^{ab}	17.2 ± 0.6 ^{ab}	1.9 ± 0.0 ^a
CO-WR	32.1 ± 0.3 ^{ab}	7.6 ± 0.8 ^a	16.8 ± 0.6 ^{ab}	1.9 ± 0.0 ^a

Data followed by the different letter in the same column are significantly different ($p < 0.05$)

Con muffin made with wheat flour; *MS-WR* muffin made with mungbean *Sohyun*-waxy rice (1:1) flour blend; *MD-WR* muffin made with mungbean *Dahyun*-waxy flour blend; *MJ-WR* muffin made with mungbean *Jangan*-waxy flour blend; *CS-WR* muffin made with cowpea *Seowon*-waxy flour blend; *CY-WR* muffin made with cowpea *Yeonbun*-waxy flour blend; *CO-WR* muffin made with cowpea *Okdang*-waxy flour blend

cowpea flour had slightly higher protein content than the muffin containing mungbean flour (Table 2), which may be attributed to the differential protein content among legume species. The lipid content of muffins containing cowpea was greater than that of control muffin, whereas the muffin containing mungbean flour showed specific trends in lipid content when compared with control muffin. Marginally greater ash content in legume-waxy rice flour blend muffins when compared with control muffin may be attributed to the rich mineral content in legume (Jood et al., 1988). Enhanced nutritional value was observed in terms of protein and mineral contents in legume-based muffins compared with control muffin.

A vertical section of the muffins revealed differences in loaf volume, gas cells, and crumb color (Fig. 1). The control muffin showed a stable network structure with homogeneous gas cells, while the muffins prepared with legume-waxy flour blend showed tunnels formation with unequal air bubbles and a lower number of air bubbles compared with control muffin. In addition, a highly denser matrix was occasionally observed in some places of crumb, which could be due to the addition of waxy flour. Zambrano et al. (2004) reported the formation of tunnels with unequal cells in crumb with addition of guar and xanthan gums due to reduced gluten content. Interestingly, the cowpea-waxy rice flour blend muffins contained relatively greater number of air cells than mungbean-waxy rice flour

Fig. 1 Cross-sectional images of legume-based gluten-free muffins. (A) muffin made with wheat flour; (B) muffin made with mungbean *Sohyun*-waxy rice (1:1) flour blend; (C) muffin made with mungbean *Dahyun*-waxy flour blend; (D) muffin made with mungbean *Jangan*-

waxy flour blend; (E) muffin made with cowpea *Seowon*-waxy flour blend; (F) muffin made with cowpea *Yeonbun*-waxy flour blend; (G) muffin made with cowpea *Okdang*-waxy flour blend

blend muffins, showing more spongy and light structure. Compared with control muffin, the legume-based muffins showed a higher degree of collapse on the surface with low loaf volume (Fig. 1). Similarly, Mohammed et al. (2012) observed that bread containing chickpea had reduced loaf volume because the chickpea flour suppressed the production of steam during baking as a result of its great water holding capacity. The muffin containing *Okdang* cultivar of cowpea showed a lower degree of collapse on the surface with a similar surface in control muffin (Fig. 1).

Muffin color is an important parameter for muffin quality assessment (Shevkani et al., 2015). The L^* , a^* , and b^* values for crumb color showed significant differences among the tested muffins (Table 3). The muffins made with legume-waxy rice flour blends had significantly lower lightness (L^*) than control muffin. Similarly, the bread crumb color turned darker due to higher levels of legume flours (Hallen et al., 2004). The redness (a^*) of muffins made of cowpea-waxy rice flour blends was higher than that of muffin made with mungbean-waxy rice flour blends or control muffins, while the cowpea-waxy rice flour blend muffins exhibited lower yellowness (b^*) than those prepared with mungbean-waxy rice flour blend or control muffins. This difference in muffin color was attributed to the original color imparted by individual pigments and the color developed during baking (Matos et al., 2014). The significantly lower L^* of legume-waxy rice flour blend muffins when compared with control muffin may be due to the presence of pigment in legume flours. The difference in redness and yellowness between muffins containing mungbean flours and cowpea flours was also related to the difference in original color of two varieties used in this study. Hallen et al. (2004) reported that the cowpea containing bread showed an increased Maillard reaction during baking due to its rich lysine content, resulting in darkening

of bread. This increased Maillard reaction also contributed to the decreased lightness of legume-based muffins.

The weight, height and volume of muffins are presented in Table 3. The weight of control muffin (49.5 g) was lower than that of legume-based muffins (50.3–53.3 g), which was consistent with moisture content in muffins (Table 2). Similarly, Mohammed et al. (2012) found a decrease in baking loss by the incorporation of chickpea in wheat flour to bread formulation, suggesting that the greater moisture content in chickpea-enriched muffins may be attributed to the higher capacity of chickpea protein to retain water than wheat gluten. Goswami et al. (2015) also reported that the decrease in weight loss of muffin containing millet flour could be due to the limited moisture evaporation during baking by the enhanced water binding capacity. Among the legume cultivars, the CY-WR and CO-WR muffins showed marginally higher weight (lower baking loss) than the other legume-containing muffins (Table 3).

The height and volume of control muffin were 4.8 cm and 125.0 mL, respectively, whereas general decreases in height and volume occurred when the muffin was made with legume-waxy rice flour blends (Table 3). This result could be related to the absence of the wheat gluten in legume-waxy rice flour blend muffins. Similarly, Mohammed et al. (2012) reported the decrease in bread volume by increasing the level of chickpea in bread, which was attributed to the decreased elasticity of dough. El-Adawy (1997) also found that legume flour addition decreased bread volume, which was probably due to the combined effects of gluten dilution and disruption of the gluten network structure by the addition of legume protein. The decrease in height or volume of muffin containing legume flour may be attributed to fewer air cells, poor gas cell stability by dilution of gluten, and lower viscosity of

Table 3 Color values and physical characteristics of legume-based gluten-free muffins

Muffin	L^*	a^*	b^*	Weight (g)	Height (cm)	Volume (mL)
Con	82.3 ± 0.5 ^a	− 0.1 ± 0.1 ^c	27.5 ± 1.1 ^a	49.5 ± 0.3 ^d	4.8 ± 0.1 ^a	125.0 ± 5.0 ^a
MS-WR	54.4 ± 0.2 ^c	0.5 ± 0.1 ^d	26.1 ± 1.6 ^a	51.7 ± 0.1 ^{bc}	4.0 ± 0.1 ^{cd}	110.0 ± 10.0 ^c
MD-WR	53.4 ± 0.5 ^d	0.6 ± 0.6 ^d	26.2 ± 0.4 ^a	51.8 ± 0.6 ^{bc}	4.1 ± 0.1 ^{cd}	110.0 ± 0.0 ^c
MJ-WR	54.2 ± 0.6 ^c	0.4 ± 0.5 ^d	21.3 ± 1.3 ^b	50.3 ± 0.1 ^{cd}	3.9 ± 0.1 ^d	106.7 ± 2.9 ^c
CS-WR	45.5 ± 0.4 ^e	8.9 ± 0.2 ^a	14.8 ± 0.4 ^d	51.7 ± 0.3 ^{bc}	4.3 ± 0.0 ^{bc}	115.0 ± 0.0 ^{bc}
CY-WR	58.6 ± 0.4 ^b	4.2 ± 0.2 ^c	18.6 ± 0.8 ^c	53.3 ± 2.0 ^a	4.1 ± 0.0 ^{cd}	115.0 ± 0.0 ^{bc}
CO-WR	54.7 ± 0.3 ^c	6.7 ± 0.1 ^b	19.7 ± 2.1 ^c	52.0 ± 0.6 ^{ab}	4.5 ± 0.0 ^b	120.3 ± 2.9 ^{ab}

Data followed by the different letter in the same column are significantly different ($p < 0.05$)

L^* , lightness; a^* , yellowness; b^* , redness

Con muffin made with wheat flour; MS-WR muffin made with mungbean *Sohyun*-waxy rice (1:1) flour blend; MD-WR muffin made with mungbean *Dahyun*-waxy flour blend; MJ-WR muffin made with mungbean *Jangan*-waxy flour blend; CS-WR muffin made with cowpea *Seowon*-waxy flour blend; CY-WR muffin made with cowpea *Yeonbun*-waxy flour blend; CO-WR muffin made with cowpea *Okdang*-waxy flour blend

legume flour during heating (Shelke et al., 1990). Therefore, decrease in muffin height and volume indicates less air bubble and poor air bubble retention capacity, which was consistent with the number and size of air cells found in the muffin section (Fig. 1), and the reduced leavening of muffins by low pasting viscosity (Table 1). Interestingly, the muffins prepared using cowpea-waxy rice flour blends were slightly higher height and larger volume than the muffins prepared with mungbean-waxy rice flour blends. Greater protein content and pasting viscosity in cowpea flour than mungbean flour (Tables 1 and 2) contributes to the increased height and volume of muffins prepared from cowpea flour. Shevkani et al. (2015) reported that the protein increased muffin volume by increasing batter viscoelasticity and promoting stability of air bubbles in the batter. Goswami et al. (2015) suggested that the decrease in the height of the muffin containing millet flour might be related to the reduced pasting viscosity of the muffin batter containing millet flour. Among the legume cultivars, the *Okdang* cultivar of cowpea contributed to the highest muffin height and volume, which were relatively close to that of control muffin, and this muffin exhibited more resistance to surface collapse as shown in Fig. 1.

Textural and sensory characteristics

The texture of control muffin significantly different with that of muffins prepared from legume flours (Table 4). Hardness was the lowest in the control muffin (174.6 g), whereas hardness of muffins containing legume flour ranged from 440.5 to 663.7 g, which was significantly lower than that of control muffin (Table 4). Gularte et al. (2012) also reported that the incorporation of legume flours in rice based cakes significantly increased the hardness. Hellen et al. (2004) found an increase in hardness by the incorporation of cowpea flour in the bread due to the more

compact bread with a more dense structure. Mohammed et al. (2012) reported that the chickpea-enriched bread showed increased crumb hardness when compared with wheat flour bread possibly due to the thickening of the crumb well and hardening of the crumb structure by the protein addition. The increase in the hardness of muffin containing legume may be attributed to a decrease in the number and size of muffin air bubbles as shown in Fig. 1, thereby increasing the force needed for compression. The hardening in muffin containing legume flour could be associated with a decrease in wheat gluten content and greater water absorption capacity due to its greater protein and fiber contents, which results in the reduction in gluten-forming network structure and low ability of the muffin to enclose air, resulting in a dense structure (Gularte et al., 2012). Among the legume species, the cowpea flour yields greater hardness in muffin than mungbean flour. Cowpea flour contains greater protein content than mungbean flour, leading to greater crumb firmness. In addition, the lower amylose content of cowpea flour compared with mungbean flour (Table 1) might increase crumb hardness. Kum (1998) also reported that a higher level of amylose content in rice bread resulted in decreased hardness. Among the legume cultivars, the muffin containing *Yeonbun* cultivar of cowpea had the highest hardness, while the muffin containing mungbean *Dahyun* had the lowest hardness (Table 4). Chewiness, which is related to the ease of mastication, showed a similar trend with harness (Table 4). Gularte et al. (2012) also reported higher hardness and chewiness of legume containing gluten-free cakes compared with control cakes prepared from wheat flour.

The muffins made with legume-waxy rice flour blends exhibited higher adhesiveness compared with control muffin, as expected (Table 4), due to the adhesive property by incorporation of waxy rice flour. Cohesiveness and springiness, which are very important qualities in a muffin,

Table 4 Texture parameters of legume-based gluten-free muffins

Muffin	Hardness (g)	Adhesiveness (g.s)	Springiness	Cohesiveness	Chewiness (g)
Con	174.6 ± 9.5 ^f	− 0.7 ± 0.5 ^a	0.80 ± 0.02 ^a	0.54 ± 0.02 ^a	75.5 ± 3.2 ^e
MS-WR	471.6 ± 13.2 ^d	− 7.9 ± 3.9 ^b	0.78 ± 0.02 ^{ab}	0.48 ± 0.02 ^{bc}	178.0 ± 10.1 ^{cd}
MD-WR	440.5 ± 24.1 ^e	− 5.4 ± 3.7 ^b	0.78 ± 0.05 ^{ab}	0.49 ± 0.03 ^b	169.0 ± 13.1 ^d
MJ-WR	482.3 ± 8.2 ^d	− 7.0 ± 3.8 ^b	0.80 ± 0.02 ^a	0.50 ± 0.02 ^b	194.2 ± 7.4 ^{bc}
CS-WR	547.4 ± 14.7 ^b	− 6.1 ± 2.4 ^b	0.77 ± 0.02 ^{ab}	0.47 ± 0.02 ^{bc}	196.9 ± 8.4 ^b
CY-WR	663.7 ± 24.7 ^a	− 7.0 ± 2.8 ^b	0.77 ± 0.04 ^b	0.49 ± 0.01 ^b	247.2 ± 13.5 ^a
CO-WR	525.3 ± 9.1 ^c	− 5.2 ± 3.7 ^b	0.77 ± 0.03 ^b	0.46 ± 0.02 ^c	185.6 ± 9.7 ^c

Data followed by the different letter in the same column are significantly different ($p < 0.05$)

Con muffin made with wheat flour; *MS-WR* muffin made with mungbean *Sohyun*-waxy rice (1:1) flour blend; *MD-WR* muffin made with mungbean *Dahyun*-waxy flour blend; *MJ-WR* muffin made with mungbean *Jangan*-waxy flour blend; *CS-WR* muffin made with cowpea *Seowon*-waxy flour blend; *CY-WR* muffin made with cowpea *Yeonbun*-waxy flour blend; *CO-WR* muffin made with cowpea *Okdang*-waxy flour blend

were marginally higher in control muffin than in legume-containing muffins (Table 4). Springiness is associated with fresh, aerated and elastic products, and cohesiveness is related to denseness and energy required to chew the food piece (Sanz et al., 2009). The higher springiness and cohesiveness in the control muffin reflects higher specific volume and more aerated structure because the gluten protein may result in a stronger and more organized gluten network. Marginally lower springiness and cohesiveness in a legume-containing muffin may be attributed to the inhomogeneity of flour blends. However, marginal differences in springiness and cohesiveness compared with control muffin suggest relatively acceptable quality of texture in legume-based muffins.

Sensory characteristics of muffin

The sensory characteristics of gluten-free muffins containing legume flours are presented in Table 5. No significant differences in color preference score by the panel were observed, although significant differences were detected in the color of muffin appearance (Fig. 1) and instrumental color (Table 3). Most muffins containing legume flours had a relatively lower taste and flavor scores than control muffins (Table 5). This decline in taste and flavor may be attributed to the beany flavor and taste in the legume flours. A lower odor and taste scores over control product were also reported for soybean-based bread due to its beany flavor and taste (Shin et al., 2013). However, some muffins containing legume were found no significant difference in taste and flavor with control muffin. Interestingly, despite muffins containing legume flour having low loaf volume (Table 3) and high instrumental hardness (Table 4), panelists identified a texture score higher than in control muffins (Table 5). The Korean panelists preferred the sticky texture by adding the waxy rice flour to the

muffin and the new texture based on composite flour blend included legume flour. The overall acceptance of muffins containing legume was marginally lower than that of control muffin possibly due to their low taste and flavor. However, most muffins containing legume showed no statistically difference in overall acceptance compared with control muffins. Although the mean sensory scores of legume-containing muffins for various parameters was marginally lower than that of control muffin, the overall results of sensory evaluation yielded acceptable scores by panelists. The muffins containing cowpea flours had relatively greater sensory scores than muffins containing mungbean flours based on all the sensory parameters. The muffin containing *Okdang* cultivar of cowpea was the most preferred by panelists, with the highest scores of color, taste, flavor, texture and overall acceptance, which was related to its greatest height and volume. The muffin containing *Okdang* cultivar of cowpea showed no significant difference in sensory parameters compared with control muffins, indicating a sensory quality comparable to that of the control muffins.

In conclusion, the incorporation of legume flours to develop muffins highly influenced the color, volume, textural, and sensory properties of muffins. The addition of legume flours to muffins resulted in nutritional improvement by enhancing the protein and ash contents compared with the control wheat muffin. The muffins containing legume flour showed a reduced height and volume, and a substantial increase in textural hardness. However, the legume-based muffins were found to be acceptable based on their sensory evaluation scores. Muffins containing cowpea flours exhibited greater quality than the muffins containing mungbean flours. The muffins containing *Okdang* cultivar of cowpea resulted in a sensory quality that was close to the control muffin. Overall, considering the physical, nutritional, textural, and sensory qualities, the

Table 5 Sensory evaluation values of legume-based gluten-free muffins

Muffin	Color of crumb	Taste	Flavor	Texture	Overall acceptance
Con	5.5 ± 1.5 ^a	4.8 ± 1.2 ^a	5.0 ± 1.7 ^a	3.0 ± 1.5 ^b	4.7 ± 1.0 ^a
MS-WR	4.3 ± 1.7 ^a	4.3 ± 1.4 ^a	3.9 ± 1.6 ^{ab}	5.1 ± 1.4 ^a	4.5 ± 0.9 ^a
MD-WR	4.4 ± 1.8 ^a	2.7 ± 1.4 ^b	3.2 ± 1.5 ^b	5.2 ± 1.0 ^a	3.4 ± 0.9 ^b
MJ-WR	4.3 ± 1.8 ^a	2.6 ± 1.5 ^b	2.4 ± 1.3 ^b	4.8 ± 1.3 ^a	3.2 ± 1.3 ^b
CS-WR	4.9 ± 1.3 ^a	3.6 ± 1.6 ^{ab}	4.3 ± 1.6 ^a	4.1 ± 1.3 ^{ab}	3.8 ± 1.0 ^{ab}
CY-WR	4.3 ± 1.6 ^a	3.5 ± 1.5 ^{ab}	3.2 ± 1.3 ^b	4.3 ± 1.4 ^{ab}	3.7 ± 1.1 ^{ab}
CO-WR	5.3 ± 1.2 ^a	4.0 ± 1.5 ^a	4.5 ± 1.5 ^a	5.0 ± 1.1 ^a	4.4 ± 1.0 ^a

Data followed by the different letter in the same column are significantly different ($p < 0.05$)

Con muffin made with wheat flour; *MS-WR* muffin made with mungbean *Sohyun*-waxy rice (1:1) flour blend; *MD-WR* muffin made with mungbean *Dahyun*-waxy flour blend; *MJ-WR* muffin made with mungbean *Jangan*-waxy flour blend; *CS-WR* muffin made with cowpea *Seowon*-waxy flour blend; *CY-WR* muffin made with cowpea *Yeonbun*-waxy flour blend; *CO-WR* muffin made with cowpea *Okdang*-waxy flour blend

legume-waxy rice flour blends exhibits a great potential for application in gluten-free bakery products.

Acknowledgements The Rural Development Administration (Republic of Korea) through “Cooperative Research Program for Agriculture Science and Technology Development (Project No. PJ01183303)” supported this research.

Compliance with ethical standards

Conflict of interest The authors have declared no conflict of interest.

References

- AOAC. Official Methods of Analysis of AOAC Intl. 17th ed. Association of Official Analytical Chemists, Gaithersburg, MD, USA (2000)
- Chiu CW, Schiermeyer E, Thomas DJ, Shah MB, Hanchett DJ, Jeffcoat R. Thermally-inhibited non-pregelatinized granular starches and flours and process for their preparation. U.S. Patent 5,932,017 (1999)
- Chung HJ, Lee SE, Han JA, Lim ST. Physical properties of dry-heated octenyl succinylated waxy corn starches and its application in fat-reduced muffin. *J. Cereal Sci.* 52: 496–501 (2010)
- Chung HJ, Liu Q, Hoover R., Warkentin TD, Vandenberg, B. In vitro starch digestibility, expected glycemic index, and thermal and pasting properties of flours from pea, lentil and chickpea cultivars. *Food Chem.* 111: 316–321 (2008)
- El-Adawy TA. Effect of sesame seed protein supplementation on the nutritional, physical, chemical and sensory properties of wheat flour bread. *Food Chem.* 59: 7–14 (1997)
- Eliasson AC, Gudmunsson M. Starch: physicochemical and functional aspects. pp. 431–503. In: Carbohydrate in Foods. Eliasson AC (ed). Marcel Dekker Inc., NY, USA. (1996)
- Emmambux MN, Taylor JRN. Morphology, physical, chemical, and functional properties of starches from cereals, legumes, and tubers cultivated in Africa: A review. *Starch/Stärke*, 65: 715–729 (2013)
- Gallagher EMD, Gormley TR, Arendt EK. Recent advances in the formulation of gluten-free cereal-based products. *Trends Food Sci. Tech.* 15: 143–152 (2004)
- Gao Y, Janes ME, Chaiya B, Brennan MA, Brennan CS, Prinyawiwatkul WP. Gluten-free bakery and pasta products: prevalence and quality improvement. *Int. J. Food Sci. Technol.* 53:19–32 (2018)
- Goswami D, Gupta RK, Mridula D, Sharma M, Tyagi SK. Barnyard millet based muffins: Physical, textural and sensory properties. *LWT-Food Sci. Tech.* 64: 374–380 (2015)
- Gularte MA, Gomez M, Rosell CM. Impact of legume flours on quality and in vitro digestibility of starch and protein from gluten-free cakes. *Food Bioprocess Tech.* 5: 3142–3150 (2012)
- Hallen E, Ibanoglu S, Ainsworth P. Effect of fermented/germinated cowpea flour addition on the rheological and baking properties of wheat flour. *J. Food Eng.* 63: 177–184 (2004)
- Hoover R, Hughes T, Chung HJ, Liu Q. Composition, molecular structure, properties, and modification of pulse starches: A review. *Food Res. Int.* 43: 399–413 (2010)
- Jane J, Chen YY, Lee LF, McPherson AE, Wong KS, Radosavljevic M, Kasemsuwan T. Effects of amylopectin branch chain length and amylose content on the gelatinization and pasting properties of starch. *Cereal Chem.* 76: 629–637 (1999)
- Jongsutjarittam N, Charoenrein S. Influence of waxy rice flour substitution for wheat flour on characteristics of batter and freeze-thawed cake. *Carbohydr. Polym.* 97: 306–314 (2013)
- Jood S, Chauhan BM, Kapoor AC. (1988). Contents and digestibility of carbohydrates of chickpea and black gram as affected by domestic processing and cooking. *Food Chem.* 30: 113–127 (1988)
- Kaur M, Singh N. Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. *Food Chem.* 91: 403–411 (2005)
- Kennedy NP, Feighery C. (2000). Clinical features of coeliac disease today. *Biomed. Pharmacother.* 54: 373–380 (2000)
- Kum JS. Effects of amylose content on quality of rice bread. *Korean J. Food Sci. Technol.* 30: 590–595 (1998)
- Lazaridou A, Duta D, Papageorgiou M, Bele N, Biliaderis CG. Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulation. *J. Food Eng.* 79: 1033–1047 (2007)
- Matos ME, Sanz T, Rosell CM. Establishing the function of proteins on the rheological and quality properties of rice based gluten free muffins. *Food Hydrocolloid.* 35: 150–158 (2014)
- Minarro B, Albanell E, Aguilar N, Guamis B, Capellas M. Effect of legume flours on baking characteristics of gluten-free bread. *J. Cereal Sci.* 56: 476–481 (2012)
- Mir SA, Shah MA, Naik HR, Zargar IA. Influence of hydrocolloids on dough handling and technological properties of gluten-free bread. *Trends Food Sci. Tech.* 51: 49–57 (2016)
- Mohammed I, Ahmed A, Senge B. Dough rheology and bread quality of wheat-chickpea flour blends. *Ind. Crop. Prod.* 36: 196–202 (2012)
- Moore M, Heinbockel M, Dockery P, Ulmer H, Arendt E. Network formation in gluten-free bread with application of transglutaminase. *Cereal Chem.* 83: 28–36 (2006)
- Nachay K. Gluten-free offering increase. *Food Technol.* 64: 13–14 (2010)
- Nunes MHB, Moore M, Arendt E. Impact of emulsifiers on the quality and rheological properties of gluten-free breads and batters. *Eur. Food Res. Technol.* 228: 633–642 (2009)
- Renzetti S, Dal Bello F, Arendt E. Microstructure, fundamental rheology and baking characteristics of batters and breads from different gluten-free flours treated with a microbial transglutaminase. *J. Cereal Sci.* 48: 33–45 (2008)
- Ribotta P, Ausar S, Morcillo M, Perez G, Beltramo D. Production of gluten-free bread using soybean flour. *J. Sci. Food Agr.* 84: 1969–1974 (2004)
- Sanz T, Salvador A, Baixauli R, Fiszman S. Evaluation of four types of resistant starch in muffins. II. Effects in texture, colour and consumer response. *Eur. Food Res. Technol.* 229: 197–204 (2009)
- Shelke K, Faubion JA, Hoseney RC. The dynamics of cake baking as studied by a combination of viscometry and electrical resistance oven heating. *Cereal Chem.* 67: 575–580 (1990)
- Shevkani K, Kaur A, Kumar S, Singh N. Cowpea protein isolates: Functional properties and application in gluten-free rice muffins. *LWT-Food Sci. Tech.* 63: 927–933 (2015)
- Shin DJ, Kim W, Kim Y. Physicochemical and sensory properties of soy bread made with germinated, steamed, and roasted soy flour. *Food Chem.* 141: 517–523 (2013)
- Singh N, Shevkani K, Kaur A, Thakur S, Parmar N, Virdi AS. (2014). Characteristics of starch obtained at different stages of purification during commercial wet milling of maize. *Starch/Stärke*, 66: 668–677 (2014)
- Tester R, Morrison W. Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose, and lipids. *Cereal Chem.* 67: 551–557 (1990)

- Tharanathan RN, Mahadevamma S. Grain legumes- a boon to human nutrition. *Trends Food Sci. Tech.* 14: 507–518 (2003)
- Thomas DJ, Atwell WA. Eagan press handbook series: Starches. Eagan Press, St. Paul, MN, USA (1999)
- Vandeputte GE, Vermeulen R, Geeroms J, Delcour JA. Rice starches. III. Structural aspects provide insight in amylopectin retrogradation properties and gel texture. *J. Cereal Sci.* 38: 43–52 (2003)
- Williams PC, Kuzina FD, Hlynka I. A rapid colorimetric procedure for estimating the amylose content of starches and flours. *Cereal Chem.* 47: 411–420 (1970)
- You SY, Lim ST, Lee JH, Chung HJ. Impact of molecular and crystalline structures on in vitro digestibility of waxy rice starches. *Carbohydr. Polym.* 112: 729–735 (2014)
- Zambrano F, Despinoy P, Ormenese RCSC, Faria EV. The use of guar and xanthan gums in the production of 'light' low fat cakes. *Int. J. Food Sci. Tech.* 39: 959–966 (2004)