Effects of newly developed waxy rice flour on the quality characteristics and oxidative stability of Korean traditional fried cookie, *Yakgwa*

HyunJin Kim¹ · Junhee No¹ · Malshick Shin¹

Received: 3 May 2018 / Revised: 18 June 2018 / Accepted: 1 July 2018 / Published online: 24 July 2018
© The Korean Society of Food Science and Technology and Springer Science+Business Media B.V., part of Springer Nature 2018

Abstract The effects of waxy rice flour (WRF) in substitution for wheat flour (WF) on the oil absorption, structure, texture and oxidative stability of traditional Korean fried cookies, *Yakgwa*, were investigated. Fried cookie prepared with WF showed the greatest oil absorption (20.66%), however, the oil absorption reduced as the ratio of WRF substitution increased. The fried cookies prepared with WRF in substitution for WF showed the reduced oil absorption and increased oxidation stability. In addition, the cookies still maintained a layered structure with crispiness and softness. Also, when white WRF was used, the fried cookie showed the increased oxidative stability and reduced oil absorption decreased compared to when brown WRF was used. WRF can be used as a substitute for WF at a percentage of up to 75% and can improve the structure and oxidative stability of *Yakgwa* during storage. Substitution of WRF for WF significantly improves the structure and oxidative stability of *Yakgwa*.

Keywords Korean fried cookie · Waxy rice flour · Oil absorption · Structure · Oxidative stability

Introduction

Korean traditional cookies are classified into seven different types, which are *Yumilgwa*, *Suksilgwa*, *Gwapyeon*, *Dasik*, *Gwapyeon*, *Yeot Gangjeong*, and *Jeonggwa*, based on their ingredients and cooking methods used (Kim and

Kim, 2001). *Yakgwa* is a type of *Yumilgwa* which is a flower-shaped fried cookie made with wheat flour (WF), sesame oil, honey, and rice wine (Park et al., 1992). Sesame oil prevents gluten formation and lubricates in dough making (Mamat and Hill, 2014). *Yakgwa* is widely consumed because its recipe is similar to that of Western-style cookies, pie crust and pastry with its soft and crispy texture.

It is reported that shortening surrounds the proteins and the starch granules of wheat flour, isolating them from the water, thereby breaking the continuity of protein and starch structure (Mamat and Hill, 2014); however, the effect of oil on Korean fried cookie has not been reported yet. Although there are many preparation methods for making *Yakgwa* dough, the high quality *Yakgwa* with a layered structure is prepared by kneading and folding of dough in the same direction. However, the protein and starch granules of wheat flour are covered with sesame oil and the oil prevents gluten from being formed from the wheat dough during kneading with water (Larsson, 1982; Lásztity et al., 1996; Shih and Daigle, 2002). Starch granules are surrounded by oil, and the amylose–lipid complex can be formed after temperature increases.

Deep fat frying is a very complex process which includes initial heating, surface boiling, falling rate, and bubble end point. The oil uptake and the moisture loss were found to be interrelated with both as linear functions of the square root of frying time (Gamble et al., 1987). The higher frying temperature leads to faster moisture loss from the fried products; the lower frying temperature leads to more oil adsorption (Budžaki and Šeruga, 2005). The traditional method for making fried cookie involves two steps: fried at a lower temperature at 110–120 °C and then fried again at 150–160 °C (Lee et al., 2012). The oil content of commercial *Yakgwa* prepared from wheat flour ranges from 20

✉ Malshick Shin
msshin@chonnam.ac.kr

¹ Department of Food and Nutrition, Chonnam National University, Gwangju 61186, Republic of Korea

to 30% (Kim and Kim, 2001; Park et al., 2017). Therefore, *Yakgwa* is a high-calorie food and undergoes lipid oxidation during storage.

In recent years, consumer trends are slowly moving towards low-fat or defatted healthier foods, creating the need to reduce lipid content in end products. For this reason, many scientists and manufacturers have tried to improve the quality of fried cookie by using health functional natural food materials. Healthy *Yakgwa* can be made by reducing oil absorption and oxidation.

Rice flour, including waxy rice flour (WRF), absorbs less oil during frying than wheat flour and it does not contain gluten (Nakamura and Ohtsubo, 2010; Shih and Daigle, 1999). Waxy rice flour retards starch retrogradation, but shows a sticky texture, and therefore, waxy rice flour has been used for manufacturing high valued *Yakgwa*. But in general, dry and wet milled waxy rice flours are difficult to be used as a substitute for wheat flour of *Yakgwa* dough. As such, the newly developed waxy rice flour (Kim and Shin, 2014; Shin et al., 2010), which is prepared from dry milled using soaked waxy rice grains and can absorb water and be made into dough more easily, is used as a substitution. Interestingly, Korean cookie prepared using waxy rice flour can be easily developed into a swollen structure with tiny air cells and a crispy texture. A mixture of wheat flour with waxy rice flour has been shown to improve the storage stability and textural properties of muffins and waffles with increasing percentages of waxy rice flour (Johnson, 1990; Kim et al., 1991). To improve the nutritional and functional qualities, brown waxy rice flour, which has a higher dietary fiber content and more phytochemicals, antioxidants, and minor nutrients compared to white waxy rice flour, can be used instead of waxy rice flour (Pereira-Caro et al., 2013; Tuncel and Yilmaz, 2011).

Some researchers have reported an increase in health functionality of *Yakgwa* that contains various functional food materials (Kim and Chung, 2000; Kim et al., 2011; Lee and Kim, 2002; Yun and Kim, 2005).

Therefore, the objectives of this study were to improve Korean traditional fried cookie, *Yakgwa* by using different percentages of white and brown waxy rice flours substituted for wheat flour and to investigate oil absorption, color values, structure, textural properties, and the oxidative stability of *Yakgwa* during storage.

Materials and methods

Materials

A Korean waxy rice cultivar, *Boseokchal*, was obtained from the Department of Rice and Winter Cereal Crops,

NICS, Rural Development Administration, Iksan, Jeonbuk, Korea. All-purpose wheat flour (CJ Cheiljedang Co. Ltd., Gyeongnam, Korea), sesame oil (Saessack Co. Ltd., Incheon, Korea), honey (Gavo Farms Co. Ltd., Jeonnam, Korea), salt (CJ Cheiljedang Co. Ltd., Gyeongnam, Korea), pepper (Woomtree Co. Ltd., Gyeonggi, Korea), and distilled liquor, soju (Bohae Co. Ltd., Jeonnam, Korea) were purchased from a local supermarket. Soybean oil for frying (CJ Cheiljedang Co. Ltd., Gyeonggi, Korea) was purchased from the local market prior to the experiments.

Preparation of brown and white waxy rice flours

Brown and white waxy rice flours were prepared using the method described by Kim and Shin (2014) and Shin et al. (2010). Brown and white waxy rice grains were washed three times in water and were soaked at 20 ± 2 °C for 12 and 6 h, respectively. After soaking, the wet grains were dried at 18 ± 3 °C until 12% moisture content was achieved. Dried grains were milled using a pin mill with a built-in 120-mesh sieve (Pung-Jin Food Machinery Co. Ltd., Gyeonggi, Korea). Brown and white waxy rice flours were stored at 4 °C until use.

Preparation of fried cookie

Korean fried cookie, *Yakgwa* was prepared by modification of the traditional method proposed by Lee et al. (2012). Flour blends were made with a different percentage of wheat flour to brown and white waxy rice flours. The percentage tested were 100:0, 50:50, 30:70, and 25:75. It was difficult to form *Yakgwa* dough with 100% waxy rice flour. The maximum percentage of substitution of waxy rice flour was determined to be 75%. The flour blend (200 g) was mixed with pepper (0.2 g), salt (1.25 g), sesame oil (44 g), honey (40 g), and soju (46 g) to make *Yakgwa* dough (Table 1). The flour blend mixed with pepper and salt was passed through a stainless steel flour sieve sifter. Sesame oil was added to the sifted flour mixture, which was then mixed well and passed through a 40-mesh sieve. Honey and soju were added to the greasy flour mixture to make *Yakgwa* dough. The dough was kneaded repeatedly and folded seven times, and then, it was allowed to rest for 20 min at room temperature. The *Yakgwa* dough was placed inside a rectangular mold (length $\times$ width $\times$ height: 20.00 $\times$ 25.00 $\times$ 1.20 cm) and rolled out until it reached a height of 1.20 cm. The dough was cut into pieces of 2.50 $\times$ 2.50 $\times$ 1.20 cm in size and its surface was pierced with a fork for even frying. Fresh soybean oil was used for frying each treated *Yakgwa* dough. Six pieces of *Yakgwa* dough were fried in soybean oil (1500 g) in a deep fat fryer (Hamilton Beach, Southern Pines, NC USA) at a constant temperature of 110 °C for

Table 1 Formulations of *Yakgwa* prepared with different percentages/proportions of brown and white waxy rice flours substituted for wheat flour (unit: g)

Flour blend ¹	Wheat flour	Brown waxy rice flour	White waxy rice flour	Salt	Black pepper	Sesame oil	Honey	Distilled liquor
WF	200	–	–	1.25	0.2	44	40	46
BWRF50	100	100	–	1.25	0.2	44	40	46
BWRF70	60	140	–	1.25	0.2	44	40	46
BWRF75	50	150	–	1.25	0.2	44	40	46
WWRF50	100	–	100	1.25	0.2	44	40	46
WWRF70	60	–	140	1.25	0.2	44	40	46
WWRF75	50	–	150	1.25	0.2	44	40	46

¹WF, BWRF, and WWRF: wheat flour, brown waxy rice flour, and white waxy rice flour, respectively. 50, 70 and 75 indicate substitution percentages/proportions of BWRF or WWRF for WF. For example, BWRF50 means wheat flour: brown waxy rice flour = 50:50

25 min. The fried *Yakgwa* dough was then directly transferred into a frying oil heated to 150 °C and fried for additional 5 min. After frying, excess oil was drained on a strainer. The fried *Yakgwa* was placed on an oil-absorbing paper in the dark for 24 h to remove extra oil, and then, it was transferred to a glass container and stored at a 23 °C incubator (Daihan Labtech, Co. Ltd., Namyangjusi, Korea) for 20 days.

Determination of oil absorption

The oil absorption rate of fried *Yakgwa* was determined using the Soxhlet extraction method (AOAC, 2000). *Yakgwa* powder (5 g) placed in a cylinder containing filter paper was extracted with a Soxhlet apparatus using ethyl ether for 16 h. After removing the solvent, the weight of the flask containing the extracted oil was measured, and the oil absorption was calculated using the following equation:

$$\text{Oil absorption (\%)} = \frac{W - W_0}{S} \times 100$$

W = weight of the flask after oil extraction (g)

W₀ = weight of the empty flask (g)

S = weight of *Yakgwa* powder (g)

Properties of *Yakgwa* during storage

Yakgwa storage

Yakgwa (control, C) and oil-removed *Yakgwa* samples were prepared by storing for 24 h in the dark at room temperature (0 day), for 20 days in a 23 °C incubator (Daihan Labtech Co., Ltd, Namyangjusi, Gyeonggi-do, Korea).

Sample preparation

All seven types of *Yakgwa* were ground in a food blender (DA 3000-A, Daesung Artlon, Pajusi, Gyeonggi-do, Korea) and passed through a 100-mesh sieve (Chunggye Co., Seoul, Korea). *Yakgwa* powder was placed in a customized food grade resealable zipper aluminum foil lined flexible packaging bag (Xiongxin Xuri Paper-Plastic Packaging Co. Ltd., Baoding City, Hebei, China) to protect it from light and oxygen, and then, it was stored in a refrigerator.

Morphology and moisture loss of *Yakgwa*

The surface, external, and internal shapes of the *Yakgwa* samples were visualized using a digital camera (Kento, Canon, Tokyo, Japan). A cross-section of each type of *Yakgwa* was obtained by cutting through the middle of the samples. The moisture loss was calculated by calculating the difference between the moisture content of the *Yakgwa* dough and that of *Yakgwa* powder (AACCI, 2012).

Hardness and fracturability

The hardness and fracturability of the *Yakgwa* samples were analyzed using a Texture Analyzer (TA-XT plus, Surrey, England). A one-bite compression test was carried out using a blade set probe (2.5 × 70 × 80 mm). The conditions were as follows: deformation rate, 40%; pre-test, test and post-test speeds, 1 mm/s. The hardness obtained from force (kg) at maximum peak at the 1st bite compression and fracturability measured the length (mm) to maximum point before fracture.

Determination of lipid oxidation

Yakgwa powder (5 g) was placed in a volumetric flask and 100 mL of solvent was added (diethyl ether: ethyl alcohol = 2:1). The flask was sealed with an aluminum foil to block out light and stirred using a magnetic bar (φ 8 × 41 mm) for 1 h.

The sample was filtered by vacuum filtration with Whatman No. 2 filter paper. One drop of phenolphthalein was added to the filtrate, followed by titration using a 0.1 N potassium hydroxide solution ($f = 1.000$) until a faint pink color was detected.

$$\text{Acid value} = \frac{(\text{KOH volume} - \text{blank})}{S} \times 5.611 \times f$$

S = Sample weight (g)

f = 0.1 N potassium hydroxide of the titer

Yakgwa powder (1 g) was placed in a volumetric flask, and 25 mL of acetic acid and chloroform (3:2, v/v) were added to dissolve the oil in the powder. A saturated potassium iodide solution (1 mL) was added to the sample mixture, which was then allowed to stand in the dark. After 10 min, soluble starch (1 mL) was added to the flask and the sample solution was titrated using a 0.01 N sodium thiosulfate solution ($f = 1.000$) until the solution became colorless.

$$\text{Peroxide value} = \frac{(a - b) \times f}{s} \times 10$$

a = Volume of 0.01 N sodium thiosulfate used for titration of the sample (mL)

b = Volume of 0.01 N sodium thiosulfate used for titration of the blank (mL)

S = Sample weight (g)

f = 0.01 N sodium thiosulfate of the titer

Thiobarbituric acid (TBA) reagent was prepared as follows: TBA (1.675 g) in glacial acetic acid (150 mL) was heated at 100 °C, HCl (5 mL) was added, and then, the two acids were mixed well. The TBA reagent solution was transferred into a volumetric flask (250 mL) and calibrated with glacial acetic acid. *Yakgwa* powder (1 g) was placed in a triangular flask, and then, benzene (10 mL) and TBA reagent (10 mL) were added to the flask and the contents were stirred continuously for 4 min. The sample solution was filtered and boiled for 30 min in a boiling water bath. After being cooled for 10 min, the absorbance of the sample solution was measured at 530 nm using a UV–Vis spectrophotometer (UV–Vis Spectrophotometer, Optizen Pop, Mecasys Co., Ltd, Daejeon, Korea). The TBA value was calculated using the following equation:

$$\text{TBA} = \frac{(A - B) \times 3 \times 100}{S}$$

A: Absorbance of the sample solution at 530 nm

B: Absorbance of the blank at 530 nm

S: Sample weight (g)

Statistical analysis

All experiments were analyzed at minimum in triplicate and the data were expressed as the mean $\pm$ standard deviation. The data were analyzed by the analysis of variance (ANOVA) and Duncan's multiple range test for significance at the $p < 0.05$ level using SPSS 12.0 (SPSS Inc., Chicago, IL, USA).

Results and discussion

Oil absorption

When the wheat flour and sesame oil were mixed, the oil covered the surface of the flour particles. The oil coating prevented the development of a gluten network because the oil interfered with the hydrations of wheat flour proteins to form gluten, although the *Yakgwa* dough was kneaded. Table 2 shows the oil absorption and moisture loss of *Yakgwa*. *Yakgwa* dough had 13.3% oil content, but there may be an uptake of oil during deep frying. It was reported that the oil uptake is primarily a surface phenomenon involving an equilibrium between adhesion and drainage of oil during the post frying process (cooling period) (Bouchon et al., 2003; Budžaki and Šeruga, 2005). The oil absorption of seven *Yakgwa* samples are shown in Table 2. *Yakgwa* prepared with wheat flour had the highest oil absorption (20.66%), and the oil absorption was significantly different among the samples ($p < 0.05$). *Yakgwa* made with waxy rice flour blends had a lower oil absorption value than *Yakgwa* made with wheat flour, and oil absorption decreased with an increasing waxy rice flour percentage. *Yakgwa* prepared with white waxy rice flour (WWRF) (from 15.25 to 11.67%) exhibited 3% less oil absorption capacity than *Yakgwa* prepared with BWRf (from 18.14 to 15.04%). *Yakgwa* prepared with Brown waxy rice flour (BWRf) blends (BWRf50, 70, and 75) contained more dietary fiber and protein than *Yakgwa* prepared with WWRF blends. These results were similar to the results of Lee et al. (2012) and Shih and Daigle (2002). Shih and Daigle (2002) reported when cake donuts were prepared using WF, long grain rice flour and WF, the WRF donut had the lowest oil uptake (11.8%) and the WF donut the highest (23.6%). Lee et al. (2012) reported that WRF reduced the oil absorption rate of *Yakgwa*. The increase in oil uptake of *Yakgwa* prepared with BWRf caused an increase in protein and dietary fiber content (Nakamura and Ohtsubo, 2010; Shih and Daigle, 1999). The protein contents of seven *Yakgwa* prepared with different flour blends differed based on the ratio of WF to WRF. The protein content of the flour blends decreased in the following order: WF > BWRf > WWRF. The oil absorption rate was found to be related to the protein content of *Yakgwa*

Table 2 Oil absorption and moisture content of *Yakgwa* prepared with different percentages/proportions of white and brown waxy rice flours substituted for wheat flour during storage

Flour blends ¹		Moisture loss (%) of Con ²		Moisture loss (%) of 0 day sample
WF	20.66 ± 0.08 ^{a2}	8.16 ± 0.11 ^{a3}		7.15 ± 0.09 ^a
BWRF50	18.14 ± 0.30 ^b	5.78 ± 0.17 ^b		6.52 ± 0.08 ^b
BWRF70	15.27 ± 0.04 ^c	5.98 ± 0.16 ^b		4.48 ± 0.14 ^f
BWRF75	15.04 ± 0.10 ^c	5.39 ± 0.10 ^d		4.13 ± 0.01 ^g
WWRF50	15.25 ± 1.09 ^c	5.29 ± 0.26 ^c		6.05 ± 0.05 ^c
WWRF70	12.00 ± 0.15 ^d	5.31 ± 0.09 ^c		5.26 ± 0.01 ^d
WWRF75	11.67 ± 0.67 ^d	5.36 ± 0.06 ^c		4.72 ± 0.05 ^c

Data represents mean ± SD

¹WF, BWRF, and WWRF: wheat flour, brown waxy rice flour, and white waxy rice flour, respectively. 50, 70, and 75 indicate the substitution percentages/proportions of waxy rice flour for wheat flour. *Yakgwa* was measured before (C) and after the removal of frying oil (0 day sample)²Con means immediately fried *Yakgwa* without removing the extra oil³Values accompanied by lowercase superscripts in the same column differ significantly ($p < 0.05$) according to Duncan's multiple range test

prepared with different flour blends. However, the starch content of *Yakgwa* prepared with WRF was higher than that of *Yakgwa* prepared with WF, as WRF starch composed of amylopectin cannot form the amylose–lipid complex. Interactions between lipid and protein and between lipid and starch in the *Yakgwa* dough also affected the oil absorption rate during frying (Larsson, 1982; Lásztity et al., 1996; Shih and Daigle, 2002). When the oil absorption is composed of three oil fractions: structural oil (absorbed during frying), penetrated surface oil (suctioned during cooling), and surface oil (Bouchon et al., 2003), the oil absorption of *Yakgwa* was assumed structural oil and penetrated surface oil. After frying in a fryer (oil temperature at 150 °C), the fried products were placed on an oil-absorbing paper in the dark for 24 h to remove extra oil. From this procedure, surface oil and a part of penetrated surface oil should be removed. Consequently, the oil absorption of *Yakgwa* increased due to structural oil and penetrated surface oil. The complicated chemical interactions between WF and WRF in the dough as well as between water loss and oil absorption during frying and cooling were not understood clearly. Nevertheless, the use of WRF reduced the oil absorption of *Yakgwa*, and WWRF was more effective at reducing oil absorption of *Yakgwa* than BWRF.

Moisture loss

The moisture loss of *Yakgwa* samples is shown in Table 2. The moisture loss of *Yakgwa* differed significantly based on the type of flour blends used ($p < 0.05$). The moisture loss and the oil uptake were found to be interrelated and both had linear functions (Gamble et al., 1987). The moisture loss of the 100% wheat flour-containing *Yakgwa* (Korean traditional cookie) ranged from 6.57 to 8.66% and it was the highest among the seven types of *Yakgwa*

samples. The moisture loss was positively related to the oil absorption. The oil absorption depends on the amount of water removed (Bouchon et al., 2003; Shih and Daigle, 2002) and this result showed the same trend. The moisture loss decreased with an increasing WRF percentage. It was not a linear relationship between the moisture loss and the oil absorption of WWF substitution of *Yakgwa*.

Morphology

The surface and internal shape of *Yakgwa* samples during storage are shown in Fig. 1(A), (B). The interior and exterior of the *Yakgwa* sample turned dark brown during storage. *Yakgwa* made with WRF had a more viscous and softer texture than *Yakgwa* made only with WF. Consequently, *Yakgwa* made with WRF and WF blends also formed a thin, layered structure with a crispy texture like a *Yakgwa* made only with WF [Fig. 1(B)]. These morphological and textural traits are found in high-quality traditional *Yakgwa* (Lee et al., 2012). There was no difference between the surface of *Yakgwa* made with WRF and WF blends and that of *Yakgwa* made with 100% WF [Fig. 1(A)]. However, the interior shape and fragility differed between *Yakgwa* made with 100% WF and that made with a WRF blend. The gap between the layers and the fragility increased with an increasing WRF percentage and *Yakgwa* made with BWRF was more fragile than that made with WWRF [Fig. 1(B)]. The gap between the layers may have increased with an increasing WRF percentage as a result of increased compactness owing to the formation of a waxy rice film in WRF-containing *Yakgwa*, as a film would have made it harder for the steam to be released through the sealed layers, leading to more fragile layers. Lee et al. (2012) reported the feasibility of producing waxy rice-containing *Yakgwa* when WRF was milled using dry and wet methods and substituted for WF at a percentage of

Fig. 1 The surface (A) and internal (B) appearance of *Yakgwa* prepared with different percentages/proportions of white and brown waxy rice flour substituted for wheat flour and stored at 23 °C for 20 days. WF, BWRF, and WWRF: wheat flour, brown waxy rice flour, and white waxy rice flour, respectively. 50, 70, and 75 indicate

substitution percentages/proportions of waxy rice flour for wheat flour. *Yakgwa* was photographed before (C) and after the removal of frying oil (0 day sample), and it was stored at 23 °C for 5, 10, and 20 days

30%. In this study, the newly developed WRF could be substituted for WF at a percentage of up to 75% because of the better processing quality of WRF using the new method compared to dry and wet milling methods. It was impossible to increase the WRF percentage in the commercial *Yakgwa* because of using dry milled waxy rice flour. Therefore, it was found that the milling method of waxy rice is an important factor in the manufacturing of waxy rice flour containing *Yakgwa*.

Textural properties

Changes in the hardness of *Yakgwa*, as evaluated with a compression test using a texture analyzer, are shown in Table 3. The hardness of *Yakgwa* with 100% WF remained

the same before or after the extra oil was removed, but it increased during storage. WRF reduced the hardness of *Yakgwa*, especially BWRF reduced the hardness more than WWRF. The WF *Yakgwa* held the protein-oil complex densely unlike the WRF-containing *Yakgwa*. In the WRF-containing *Yakgwa*, the hardness also increased during storage, but it decreased with an increasing WRF percentage. The quality of *Yakgwa* was influenced by oil absorption, rancid odor, crispiness, softness, roasted flavor, and sweetness. In particular, reduction in gluten content caused by the addition of WRF will improve the result in terms of food allergies and atopy (Capriles and Arêas, 2014). The gap between the layers inside the structure may affect the textural properties, hardness, and fracturability of the final product.

Table 3 Hardness and fracturability of *Yakgwa* prepared with different percentages/proportions of white and brown waxy rice flours substituted for wheat flour during storage

Flour blend ¹	Con	Storage time (days)			
		0	5	10	20
<i>Hardness (kg)</i>					
WF	3.53 ± 0.11 ^{a2C3}	3.78 ± 0.25 ^{aC}	6.86 ± 0.52 ^{aAB}	7.36 ± 0.63 ^{aA}	6.33 ± 0.14 ^{aB}
BWRF50	1.75 ± 0.12 ^{eB}	1.90 ± 0.15 ^{dB}	2.06 ± 0.26 ^{dAB}	2.31 ± 0.31 ^{dA}	2.31 ± 0.32 ^{cA}
BWRF70	2.10 ± 0.14 ^{dB}	2.47 ± 0.26 ^{cA}	2.08 ± 0.21 ^{dB}	2.58 ± 0.30 ^{dA}	1.38 ± 0.14 ^{dC}
BWRF75	1.41 ± 0.14 ^{fBC}	1.77 ± 0.27 ^{dB}	2.16 ± 0.28 ^{dA}	1.57 ± 0.29 ^{eBC}	1.25 ± 0.26 ^{dC}
WWRF50	2.85 ± 0.26 ^{bC}	4.06 ± 0.18 ^{aB}	6.28 ± 0.38 ^{bA}	6.13 ± 0.16 ^{bA}	6.08 ± 0.41 ^{aA}
WWRF70	2.63 ± 0.36 ^{bcC}	3.24 ± 0.17 ^{bB}	3.22 ± 0.22 ^{cB}	3.48 ± 0.12 ^{cAB}	3.70 ± 0.29 ^{bA}
WWRF75	2.44 ± 0.28 ^{cC}	3.08 ± 0.19 ^{bB}	2.98 ± 0.48 ^{cBC}	3.96 ± 0.21 ^{cA}	3.37 ± 0.52 ^{bB}
<i>Fracturability (mm)</i>					
WF	14.96 ± 0.32 ^{aA}	12.48 ± 0.50 ^{bD}	13.92 ± 0.10 ^{aB}	13.60 ± 0.52 ^{aBC}	13.11 ± 0.52 ^{bCD}
BWRF50	7.94 ± 0.61 ^{eB}	7.91 ± 0.50 ^{cB}	8.99 ± 0.33 ^{cA}	8.63 ± 0.30 ^{cAB}	8.83 ± 0.56 ^{cA}
BWRF70	8.92 ± 0.59 ^{dA}	6.62 ± 0.96 ^{dB}	8.96 ± 0.65 ^{cA}	4.68 ± 0.70 ^{dC}	3.83 ± 0.55 ^{eC}
BWRF75	9.01 ± 0.46 ^{dA}	8.73 ± 0.42 ^{cA}	8.83 ± 0.82 ^{cA}	3.94 ± 0.24 ^{cC}	7.39 ± 1.20 ^{dB}
WWRF50	13.79 ± 0.57 ^{bA}	13.08 ± 0.68 ^{aAB}	12.20 ± 0.10 ^{bC}	12.78 ± 0.10 ^{bBC}	13.12 ± 0.51 ^{bAB}
WWRF70	12.22 ± 0.41 ^{cB}	12.51 ± 0.74 ^{abB}	14.57 ± 0.51 ^{aA}	12.82 ± 0.74 ^{bB}	14.46 ± 0.55 ^{aA}
WWRF75	13.47 ± 0.32 ^{bcAB}	13.78 ± 0.43 ^{aA}	13.83 ± 0.49 ^{aA}	13.07 ± 0.51 ^{abB}	14.14 ± 0.36 ^{aA}

Data represents mean ± SD

¹WF, BWRF, and WWRF: wheat flour, brown waxy rice flour, and white waxy rice flour, respectively. 50, 70, and 75 indicate the substitution percentages/proportions of waxy rice flour for wheat flour. *Yakgwa* was measured before (Con) and after the removal of frying oil (0 day sample) and stored 5, 10, and 20 days

²Values accompanied by lowercase superscripts in the same column differ significantly ($p < 0.05$) according to Duncan's multiple range test

³Values accompanied by capital letter superscripts in the same row differ significantly ($p < 0.05$) according to Duncan's multiple range test

The quality of the Korean fried cookie with a layered structure is affected by textural properties, especially crispiness or fracturability. The fracturability of *Yakgwa* prepared with different substitution percentages of WWRF and BWRF during storage is shown in Table 3. Fracturability indicates the distance from the starting point to the point of fracture in the *Yakgwa* sample (mm). Fracturability is influenced by the thickness of the layers, the number of layers, and oil absorption. Fracturability was higher in 100% WF and WWRF-containing *Yakgwas* than in BWRF-containing *Yakgwa* regardless of the substitution percentage. The trend of fracturability was different from that of hardness. Although the 100% WF *Yakgwa* showed increased hardness with increasing storage days, the fracturability maintained during storage. Generally, it is known that consumers like soft and crispy *Yakgwa*. The 100% WF *Yakgwa* was not soft, but it showed crispiness. WWRF-containing *Yakgwa* was harder than BWRF-containing *Yakgwa*, but the former was crispier than the latter. The protein content of WF and dietary fiber content of BWRF affected the textural properties of *Yakgwa*. In terms of textural properties, the 70 and 75% WWRF-containing

Yakgwa samples revealed high qualities such as softness and crispiness during storage. Generally, *Yakgwa* is coated with a mixture of rice syrup, honey, and ginger juice, which is called *Jibcheong*, to protect it from lipid oxidation and to improve its sensory properties as well as storage stability.

Lipid oxidation during storage

The frying temperature used to prepare fried cookie is different from that used to prepare fried foods in general. The high oil content is due to the coating with sesame oil and frying at a low temperature, which promotes hydrolysis and oxidation. Therefore, prevention of lipid oxidation is very important for controlling storage stability as lipid oxidation causes changes in the color, flavor, taste, texture and quality of *Yakgwa* (Han et al., 1994; Shih and Daigle, 1999).

Acid value, or the level of free fatty acids in oil, is an important parameter used to evaluate the quality of oil (Zhang et al., 2015). Changes in the acid values of *Yakgwa* made with different percentages of WRF substituted for

WF during storage except after frying (Con) are shown in Fig. 2. At the initial stage after frying, the acid value of 100% WF *Yakgwa* was 0.56 mg KOH/g and the acid values of WRF50, WRF70 and WRF75 *Yakgwa* samples were 0.90 mg KOH/g, 1.06 mg KOH/g, and 1.12 mg KOH/g, respectively. After removing the extra oil for 24 h, the acid values decreased to 70% of WF, 60% of BWR50, 50% of WWR50, 43–45% of BWR70 and 75, and 32–35% of WWR70 and 75, respectively. *Yakgwa* substituted with WWR exhibited a greater decrease in acid value than that

Fig. 2 Changes in lipid rancidity of *Yakgwa* prepared with different percentages/proportions of white and brown waxy rice flours substituted for wheat flour during storage [acid value (A), peroxide value (B) and TBA value (C)]. WF, BWR50, and WWR50: wheat flour, brown waxy rice flour, and white waxy rice flour, respectively. 50, 70, and 75 indicate substitution percentages/proportions of waxy rice flour for wheat flour. *Yakgwa* was measured before (C) and after the removal of frying oil (0 day sample), and it was stored at 23 °C for 5, 10, and 20 days

substituted with BWR50. The acid value decreased with increasing WRF percentages and it increased from 5 day of storage to 10 day of storage, but it decreased after storage for 20 days (Fig. 2). The lack of amylose in waxy rice may have contributed to its lower oil uptake compared to that of amylose-containing rice because amylose tends to form a complex [structure] and is more compatible with oil. Additionally, dough formulation that have a strong water holding capacity is more effective in resisting the penetration of oil during frying (Shih and Daigle, 2002).

Changes in the peroxide values of *Yakgwa* made with different percentages of WRF substituted for WF are shown in Fig. 2. The peroxide value serves as a useful indicator of the extent of lipid oxidation and it directly measures lipid peroxides, which are the primary products of lipid oxidation (Shantan and Decker, 1994). The initial peroxide values of WF *Yakgwa* and BWR50 *Yakgwa* samples were 10.46 and 11.43 meq/kg, respectively, and they were not significantly different from each other.

The initial peroxide values of BWR70 and WWR50 *Yakgwa* samples were 6.46 and 4.46 meq/kg, while the initial peroxide values of BWR75, WWR70, and WWR75 *Yakgwa* samples were 0.00 meq/kg each. *Yakgwa* samples made with WWR had lower peroxide values than those made with BWR or 100% WF. It might be caused from the fact that BWR contains higher levels of unsaturated fatty acids, protein, and dietary fiber than WWR. Lee et al. (1992) reported that the acid and peroxide values of WRF-containing *Yakgwa* were not statistically different after 45 days of storage at room temperature or in a refrigerator. After 90 days of storage, the acid value increased, but the peroxide values changed irregularly, because peroxide degrades easily into small carbonyl compounds.

The TBARS assay measures malondialdehyde concentration and lipid oxidation during short-term storage of food (Brewer et al., 1992). Changes in TBARS levels of *Yakgwa* made with different percentages of WRF during storage are presented in Fig. 2. TBARS levels are affected by storage temperature, fatty acid composition, oxidative activity, and antioxidant levels (Park, 1997). TBARS levels were increased in *Yakgwa*s made with 100% WF and BWR50, but were decreased in *Yakgwa*s made with other WRF blends stored for 5 days. The maximum value was seen in *Yakgwa* stored for 10 days. The TBARS levels in all *Yakgwa* samples decreased after 20 days of storage. However, the lipid oxidation pattern differed according to the analytical method. The oxidation stability of *Yakgwa* increased in the following order: WWR substitution > BWR substitution > 100% WF. The lipid oxidation stability increased with increasing substitution percentages of each type of WRF. Based on these results, it was discovered that it is possible to reduce the amount of

lipid needed to make wheat flour products by substituting rice flour for wheat flour.

Acknowledgements This research was supported by Grants from the globalization of Korean foods R&D program, funded by the Ministry of Food, Agriculture, and Rural Affairs.

Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest.

References

- AACC International. Approved Methods of Analysis. 11th ed. St. AACC International, Paul, MN <https://doi.org/10.1094/AACCIntMethod> Accessed Feb. 20 2017 (2012)
- AOAC. Official Methods of Analysis. 17th ed. Association of Official Analytical Chemists. Washington DC (2000)
- Bouchon P, Aguilera JM, Pyle DL. Structure oil-adsorption relationships during deep-fat frying. *J. Food Sci.* 68: 2711–2716 (2003)
- Brewer MS, Ikins WG, Harbers CAZ. TBA values, sensory characteristics, and volatiles in ground pork during long-term frozen storage effects of packaging. *J. Food Sci.* 57: 558–580 (1992)
- Budžaki S, Šeruga B. Moisture loss and oil uptake during deep fat frying of “Kroštula” dough. *Eur. Food Res. Technol.* 220: 90–95 (2005)
- Capriles VD, Arêas AG. Novel approaches in gluten-free breadmaking: Interface between food science, nutrition, and health. *Compr. Rev. Food Sci. F.* 13: 871–890 (2014)
- Gamble MH, Rice P, Selman JD. Relationship between oil uptake and moisture loss during frying of potato slices from c.v. record U.K. tubers. *Int. J. Food Sci. Technol.* 22: 233–241 (1987)
- Han MJ, Rhee YK, Bae EA. Stability and flavor of *Yakgwa* fried on soybean, cottonseed and rice bran oils. *J. Korean Soc. Food Cult.* 9: 335–340 (1994)
- Johnson FCS. Characteristics of muffins containing various levels of waxy rice flour. *Cereal Chem.* 67: 114–118 (1990)
- Kim IH, Chung KH. The effect of functional chitosan ingredients on quality of *Yakgwa* products. *J. Chitin Chitosan* 5: 57–64 (2000)
- Kim EM, Kim HS. A study on setting the shelf life of commercial Korean traditional cookies; rice *Yoogwa*, sesame *Yoogwa* and *Yakgwa*. *Korean J. Food Cook. Sci.* 17: 229–236 (2001)
- Kim JH, Lee KH, Lee YS. A study on quality of rice-*Yakgwa*. *Korean J. Food Cook. Sci.* 7: 41–49 (1991)
- Kim JM, Shin M. Effects of particle size distributions of rice flour on the quality of gluten-free rice cupcakes. *LWT - Food Sci. Technol.* 59(1): 526–532 (2014)
- Kim JY, Shin DE, Jang KH, Kang WW. Quality characteristics of *Yakgwa* added with vegetable power. *Korean J. Culinary Res.* 17(1): 218–225 (2011)
- Larsson K. Some effects of lipids on the structure of foods. *Food Microstruct.* 1: 55–62 (1982)
- Lásztity R, Békés F, Örsi F, Smied I, Ember-Kárpáti M. Protein-lipid and protein-carbohydrate interaction in the gluten complex. *Period. Polytech. Chem.* 40: 29–40 (1996)
- Lee SY, Kim MA. Effect of sucrose fatty acid ester on *Yakgwa* quality. *J. Korean Soc. Food Cult.* 17: 260–266 (2002)
- Lee HS, Park MW, Jang MS. Effect of waxy rice flour on the quality and acceptability of *Yakgwa* during storage. *J. Korean Soc. Food Cultm* 7: 213–222 (1992)
- Lee AS, Yoo MJ, Lee MJ, Cho YS, Yoon K, Chung KR, Kim HJ. Courtesy Food and Korean Set Menu. EG Co. pp. 144–145 (2012)
- Mamat H, Hill SE. Effect of fat types on the structural and textural properties of dough and semi-sweet biscuit. *J. Food Sci. Technol.* 51: 1998–2005 (2014)
- Nakamura S, Ohtsubo K. Influence of physicochemical properties of rice flour on oil uptake of tempura frying batter. *Biosci. Biotech. Bioch.* 74(12): 2484–2489 (2010)
- Park KM. Studies on the lipid rancidity and rheology of *Yakgwa* during storage. *Korean J. Food Cook. Sci.* 13: 609–616 (1997)
- Park JS, Lee HA, Lee KA. Effects of glutinous rice flour substitution levels on physicochemical and sensory properties of *Yakgwa*. *Korean J. Food Cook. Sci.* 33: 285–291 (2017)
- Park KM, Lee JH, Yum CA. Studies on the experimental cookery and the preservation of the traditional Korean fried cookie, *Yakgwa*. *Korean J. Food Cook. Sci.* 8: 297–307 (1992)
- Pereira-Caro G, Cros G, Yokota T, Crozier A. Phytochemical profiles of black, red, brown, and white rice from the Camargue region of France. *J. Agr. Food Chem.* 61: 7976–7986 (2013)
- Shantan NC, Decker EA. Rapid, sensitive, iron-based spectrophotometric methods for determination of peroxide values of food lipids. *J. AOAC Int.* 77: 421–424 (1994)
- Shih F, Daigle K. Oil uptake properties of fried batters from rice flour. *J. Agr. Food Chem.* 47: 1611–1615 (1999)
- Shih F, Daigle K. Preparation and characterization of low oil uptake rice cake donuts. *Cereal Chem.* 79: 745–748 (2002)
- Shin M, Gang DO, Song JY. Effects of protein and transglutaminase on the preparation of gluten-free rice bread. *Food Sci. Biotechnol.* 19: 951–956 (2010)
- Tuncel NB, Yilmaz N. Gamma-oryzanol content, phenolic acid profiles and antioxidant activity of rice milling fraction. *Eur. Food Res. Technol.* 233: 577–585 (2011)
- Yun GY, Kim MA. The effect of green tea powder on *Yakgwa* quality and preservation. *J. Korean Soc. Food Cult.* 20(1): 103–112 (2005)
- Zhang W, Li N, Feng Y, Su S, Li T, Liang B. A unique quantitative method of acid value of edible oils and studying the impact of heating on edible oils by UV-Vis spectrometry. *Food Chem.* 185: 326–332 (2015)