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Effects of Processing Conditions on the Physical and Chemical Properties of Buckwheat Grit Cakes

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Buckwheat grit cakes were prepared with a rice cake machine using the following independent variables: tempering moisture contents (15, 17, and 19%, wb), heating temperatures (240, 246, 252, and 258 °C), and heating times (5, 6, 7, and 8 s). Higher moisture, higher heating temperature, or longer heating time produced cakes with a higher cake specific volume. Cakes became lighter in color at a lower heating temperature or a shorter heating time. The hardest cake was produced at 252 °C for 5 s at 19% moisture content. The percent weight loss after tumbling decreased with increasing heating times and heating temperatures. Increased heating time resulted in more expanded products. The average rutin content decreased as the heating temperature or heating time increased. These results suggest that processing conditions, including tempering moisture, heating temperature, and heating time, significantly influenced physical and chemical qualities of buckwheat grit cakes such as specific volume, hardness, integrity, color, internal structure, and rutin content.

KEYWORDS: Buckwheat; *Fagopyrum esculentum*; cake; rutin; puffing; physical properties

INTRODUCTION

Buckwheat (*Fagopyrum esculentum* Moench) is not wheat and is not even a cereal grain, although it is often grouped with other cereal grains because of similarity of cultivation and utilization (*1*). It can be grown in countries such as India, China, Russia, Poland, Brazil, Korea, and Japan as well as in the United States. Most European countries consider buckwheat to be a basic food item employed primarily in the preparation of porridges and soups. In other countries, it is widely used combined with wheat, rice, or corn for bread, noodles, and ethnic foods (*1*−*3*).

Buckwheat seed has the same four basic components as cereal grains. Whole unhulled buckwheat is dark-colored and triangular in shape (*2*). Removal of hulls by impact dehulling releases whole groats. The aleurone, the outermost layer of cells in the endosperm, is a single layer of small cells with thick cell walls (*4*, *5*). Central endosperm cells have thin cell walls and are packed with starch granules (*1*). Buckwheat seed milling fractions are produced by roller-milling the intact achene and sieving the particles into fancy light flour (mainly central endosperm) and grits (coarse granulated product manufactured from the major part of the endosperm).

Buckwheat is a rich source of proteins, trace elements, dietary fiber, and flavonoids. The proteins in buckwheat are the best-known source of high biological value proteins in the plant kingdom. Buckwheat contains all essential amino acids in good proportions, making it closer to being a complete protein than any other plant source (*3*, *5*). For people who struggle with wheat allergies and gluten intolerance, buckwheat is ideal. Buckwheat fiber is free of phytic acid and consists partially of soluble fiber (*4*, *6*). Buckwheat also contains high levels of B vitamins and is rich in phosphorus, potassium, magnesium, iron, and calcium (*3*). Buckwheat is a good source of rutin (*7*, *8*), a substance found to suppress colon tumor incidence, and it reduces the fragility of blood vessels associated with some hemorrhagic diseases or hypertension in humans (*9*).

Cereal and puffed snacks are very popular in America. Many new products are introduced every year. The functional properties of buckwheat create an opportunity for developing a new puffed snack product using a rice cake machine. The objective was to study the effects of various cake-puffing conditions on the physical and chemical properties of buckwheat grit cakes.

MATERIALS AND METHODS

Cake Production. *Materials.* Buckwheat grits (*F. esculentum* Moench) used for this study were purchased from Minn-Dak Growers Ltd. (Grand Forks, ND) through Mid-America Food Sales (Deerfield, IL). The proximate composition of the buckwheat grits is 6.79% crude protein, 1.10% crude fat, 0.40% crude fiber, 0.81% ash, and 10.58% moisture on a wet basis (wb).

Tempering of Buckwheat Grits. To adjust the grit moisture content to desired levels before puffing, water was added to the buckwheat grits and tumbled at 24 rpm for 40 min at ambient temperature in a liquid−solid blender (Patterson-Kelley Co., model LB-10665, East

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Stroudsburg, PA). The moistened buckwheat grits were then unloaded into a bucket and sealed and tempered for an additional 15 h at room temperature.

Puffing of Buckwheat Grit Cakes. The puffing machine used to puff buckwheat grits was a Light Energy rice cake machine (Real Foods Pty Ltd., St. Peters, Australia). The machine was warmed and set at a desired heating temperature and heating time, and the tempered buckwheat grits were loaded into the storage hopper of the machine. While puffing, the buckwheat grits were automatically introduced into the preheated mold and pressed between the movable upper and lower platens. The heat-softened buckwheat grits were then puffed, due to the flash vaporization of the moisture caused by the sudden reduction of pressure inside the mold, and fused together to form the cake. After production, the cakes were cooled at room temperature and then sealed in polyethylene bags for further analysis.

Experimental Design. A 3 × 4 × 4 × 2 full factorial design consisting of three tempering moistures (15, 17, and 19% wb), four heating temperatures (240, 246, 252, and 258 °C), and four heating times (5, 6, 7, and 8 s) was used to study the effects of tempering and puffing conditions on the final product. All treatments were duplicated.

Analytical Methods. *Specific Volume.* Measurement of specific cake volume has been described previously (*10*). A buckwheat grit cake was weighed and placed in a plastic container of known weight and volume. The remaining space in the container was filled with rapeseed of a predetermined density. The weight and density of rapeseed were used to calculate the volume of rapeseed in the container. The volume of cake, then, was the difference between the container volume and the rapeseed volume. Specific volume was obtained by dividing the cake volume (cm^3) by the cake weight (g). Specific volumes of three cakes from each treatment were determined and averages reported.

Texture. A breaking test was used to determine the hardness of the buckwheat grit cakes. A whole buckwheat grit cake was placed on two parallel vertical metal supports 5 cm apart. A flat-edged blade was attached parallel with the support to the crosshead of a texture analyzer (model TA-HDi, Texture Technologies Corp., Scarsdale, NY). The test speed was set at 1 mm/s with the load cell set at 50 kg. The hardness was then determined from the height of the peak force. Eight cakes were randomly selected from each treatment and the averages reported.

Percent Weight Loss. The integrity of the buckwheat grit cakes, defined by percent weight loss after tumbling, is a measure of the fragility of the cakes. It can be used to predict breakage that could occur during shipping and handling of the product. Integrity was determined using the tumbling device described by Huff et al. (*11*). The device consisted of six cylinders mounted on the same axis, which was attached to a metal stand with two bearings. The cylinders were cut from a piece of PVC pipe (15.24 cm diameter) and were 30.48 cm long. One end of each cylinder was sealed with 1.91 cm plywood, and the other end had screw-on caps, which were removable for loading and unloading the cakes. At one end of the stand, the axis had a bracket that was chain-linked to a 186 W ($^1/_4$ hp) 30 rpm gear reduction AC motor. Thus, all six cylinders tumbled from end-to-end simultaneously. The integrity of the buckwheat grit cakes was determined by recording the initial weight of the cake and the weight after tumbling. Percent weight loss was then calculated using following equation

$$\% \text{ wt loss} = [(\text{initial wt} - \text{wt after tumbling})/(\text{initial wt})] \times 100$$

Percent weight loss was determined for three cakes from each treatment at a tumbling time of 4 min, which gave the most significant difference in the percent weight loss. The average of the values was reported.

Color. The color of the buckwheat grit cakes was determined using a Hunter D25L colorimeter (Hunter Associates Laboratory, Inc., Reston, VA). The colorimeter was standardized with a white tile ($L = 91.2$; $a = -1.0$; $b = -0.7$), and the values of L, a, and b were recorded. For each treatment, four cakes were randomly selected and two readings were taken on each, with the second reading taken after the buckwheat grit cake had been rotated ∼90°. The average value of the eight readings was reported.

Scanning Electron Microscopy (SEM). The microstructure of the cakes was examined using SEM. The samples for SEM were dried in a vacuum chamber at ambient temperature for 3 days. The transverse structures were observed by cutting a cross section of the samples with a razor blade. There were three specimens for each sample. The specimens were randomly selected from each sample. The outer ring of the puffed cake was avoided due to its compact structure. Each specimen was affixed to an aluminum stub by double-stick carbon tape. The specimens were then coated with platinum by a sputter coating machine (model K575X, Emitech, Ltd., Ashford, U.K.). A current of 20 mA was applied for 2 min to deposit a conductive layer of 20 μm thickness over the specimen. The cross sections of the specimens were viewed by a Hitachi SEM (model S-4700, Hitachi) at an accelerating voltage of 5 kV using secondary electron imaging. The micrographs (2560 × 1920 pixels) were digitally acquired using the image software built into the Hitachi microscope.

Rutin Content. Rutin content was determined by high-performance liquid chromatography (HPLC). Identification of rutin was based on the HPLC retention time using rutin standard (Sigma Chemical Co., St. Louis, MO). Buckwheat grits and cakes were dried in an oven at 70 °C for 24 h. Dry matter samples of 5 g were ground adequately. Rutin was extracted (*9*) by shaking (80 rpm) 1 g of powder in screw-capped test tubes containing 20 mL of methyl alcohol for 48 h at 35 °C. The extract was centrifuged at 5000 rpm for 20 min to obtain supernatant fluid. The supernatant fluid was adjusted to a volume of 50 mL with methanol. One milliliter of the adjusted supernatant fluid was evaporated at 70 °C under nitrogen purging. The evaporated sample was dissolved in 1 mL of mobile phase [2.5% acetic acid, methanol, and acetonitrile (35:5:10, v/v)] and filtered through a 0.45 μm Millipore filter prior to quantitative rutin analysis using a Perkin-Elmer series-410 LC equipped with a Perkin-Elmer LC-95 UV−visible spectrometer detector and a Supelcosil LC-18 (5-8298) column (250 mm × 4.6 mm, 5 μm) at 35 °C. Absorbance was monitored at 350 nm.

Data Analysis. All statistics were performed using the Statistical Analysis System (*12*). The analyses of variance were accomplished using the General Linear Model (GLM) procedure. The independent variables include the main effect of replication and the main effects and interactions of moisture content, heating temperature, and heating time. The REG procedure was used to obtain second-order polynomial regression equations to describe cakes' specific volume, texture, percent weight loss after tumbling, color, and rutin content. Only significant terms were retained in the second-order equation. The effects of tempering moisture, heating temperature, and heating time on each quality attribute of buckwheat grit cakes were plotted in three-dimensional graphs using regression equations.

RESULTS AND DISCUSSION

Specific Volume. The specific volume of buckwheat grit cake is an indication of the degree of expansion when buckwheat grits are puffed in the rice cake machine. Tempering moisture, heating temperature, heating time, and their interactions had significant effects on specific volume ($p < 0.05$). The tempering moisture had the greatest effect on specific volume, followed by the heating time ($p < 0.001$). **Figure 1a** ($r^2 = 0.918$) shows the effects of moisture content and heating time on the specific volume of buckwheat grit cakes at a heating temperature of 252 °C. As moisture contents and heating times increased, the specific volume increased. Tempering moisture had significant effects on the specific volume of buckwheat grit cakes as shown in **Table 1**. The average specific volume increased from 9.00 to 11.0 cm^3/g as the tempering moisture increased from 15 to 17% and then increased to 11.4 cm^3/g at a moisture content of 19%. The typical specific volume of commercial rice cake varies between 8.23 and 9.53 mg/L (*10*). Moisture content plays a critical role in the expansion of the buckwheat grit cake. The moisture present in the buckwheat grits is converted to superheated vapor as the grits are heated between a tightly pressed hot plate, providing the driving force for expansion. Therefore, higher moisture contents in the grits should result in more vapors after heating, yielding a greater force for

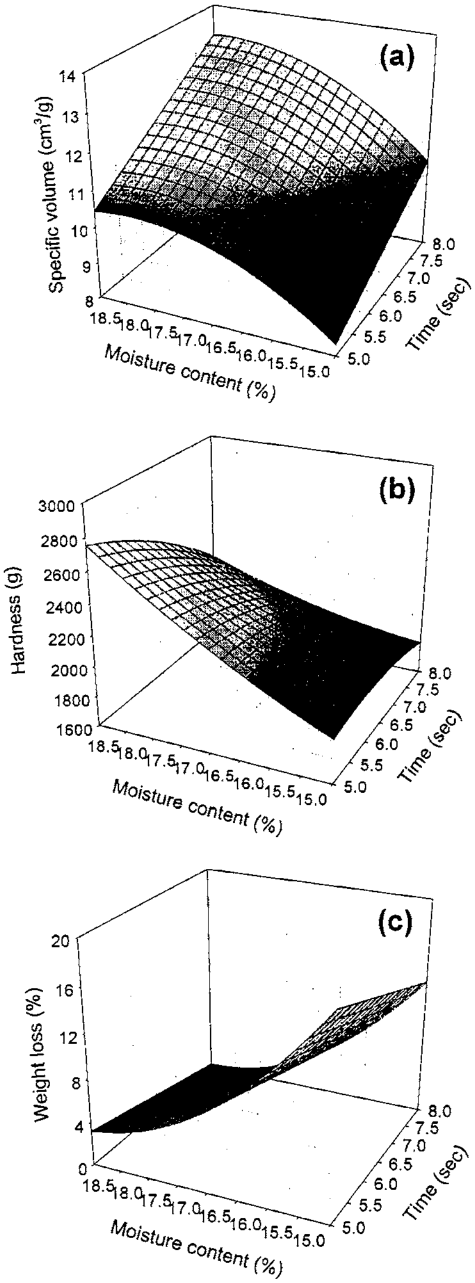

Figure 1. Effects of tempering moisture and heating time on the (a) specific volume, (b) hardness, and (c) weight loss after tumbling of buckwheat grit cakes at a heating temperature of 252 °C.

Table 1. Effects of Tempering Moisture on the Average Specific Volume, Hardness, Weight Loss after Tumbling, Color Values, and Rutin Content of Buckwheat Grit Cakes for All Heating Temperatures and Heating Times[a]

tempering moisture (%)	specific vol (cm^3/g)	hard-ness (g)	wt loss (%)	color values[b] *L*	*a*	*b*	rutin content (mg/100 g)
15	9.00c	1890c	16.1a	66.6a	1.66b	12.9c	1.72b
17	11.0b	2104b	6.18b	65.3b	2.76a	13.9a	1.70b
19	11.4a	2498a	2.61c	65.2b	2.83a	13.7b	1.91a

[a] Different letters in the same column indicate significant difference at 5% level. [b] *L* = lightness, *a* = redness, *b* = yellowness.

expansion. The elasticity of the molten grit determines the degree to which each grit can be stretched or expanded. Fan et al. (*13*) and Huff et al. (*11*) also reported that the specific

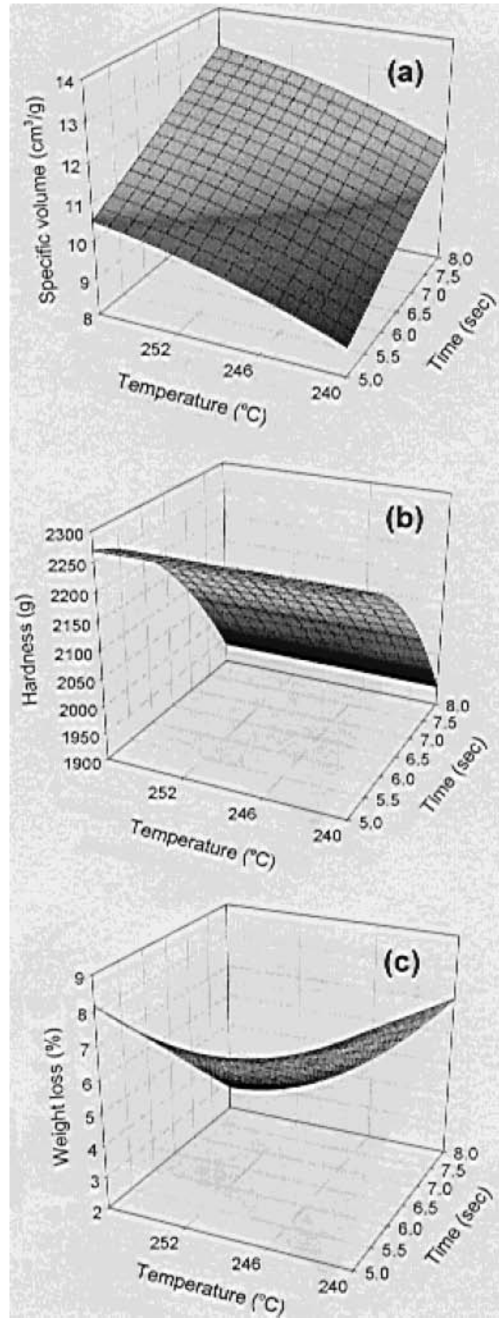

Figure 2. Effects of heating temperature and heating time on the (a) specific volume, (b) hardness, and (c) weight loss after tumbling of buckwheat grit cakes at 17% moisture content.

volumes of wheat cakes and medium-grain rice cakes increased continually as the tempering moisture increased. For long-grain rice cake, however, higher tempering moisture favored a slightly lower specific volume due to shrinkage caused by the presence of excessive tempering moisture after the cake was formed and cooled by the surrounding air (*11*).

The effects of heating temperature and time on the specific volume of buckwheat grit cake are shown in **Figure 2a** (r^2 = 0.918). As heating temperatures and heating times increased, the specific volume increased significantly. It is also evident that the increases in specific volume with temperature and time are nearly linear. **Table 2** summarizes the effects of heating temperature in buckwheat grit cakes. Raising the heating temperature significantly increased the specific volume of buckwheat grit cakes ($p < 0.05$). As the heating temperature

Table 2. Effects of Heating Temperature on the Average Specific Volume, Hardness, Weight Loss after Tumbling, Color Values, and Rutin Content of Buckwheat Grit Cakes for All Tempering Moistures and Heating Times[a]

heating temp (°C)	specific vol (cm^3/g)	hard-ness (g)	wt loss (%)	color values[b] *L*	*a*	*b*	rutin content (mg/100 g)
240	9.47d	2215a	10.1a	66.5a	1.90d	12.8d	1.96a
246	10.3c	2204a	8.02b	66.3a	2.18c	13.3c	1.78b
252	10.8b	2154ab	7.66b	65.9b	2.53b	13.6b	1.71bc
258	11.3a	2083b	7.49b	64.1c	3.07a	14.3a	1.64c

[a] Different letters in the same column indicate significant difference at 5% level. [b] *L* = lightness, *a* = redness, *b* = yellowness.

Table 3. Effects of Heating Time on the Average Specific Volume, Hardness, Weight Loss after Tumbling, Color Values, and Rutin Content of Buckwheat Grit Cakes for All Tempering Moistures and Heating Temperatures[a]

heating time (s)	specific vol (cm^3/g)	hard-ness (g)	wt loss (%)	color values[b] *L*	*a*	*b*	rutin content (mg/100 g)
5	9.17d	2303a	10.3a	68.4a	1.02d	12.2d	2.12a
6	10.1c	2247a	8.57b	67.1b	1.92c	13.4c	1.95b
7	11.0b	2138b	7.61c	64.8c	2.98b	14.0b	1.66c
8	11.7a	1968c	6.74d	62.4d	3.77a	14.4a	1.36d

[a] Different letters in the same column indicate significant difference at 5% level. [b] *L* = lightness, *a* = redness, *b* = yellowness.

increased from 240 to 258 °C, the average specific volume increased from 9.47 to 11.3 cm^3/g. Heating time also significantly influenced the specific volume of buckwheat grit cakes (**Table 3**). The specific volume increased from 9.17 to 11.7 cm^3/g when the heating time increased from 5 to 8 s. The greatest expansion was observed at 258 °C and 8 s for each moisture level studied. Increased heating temperatures accelerate the melting of the buckwheat grits, yielding more elastic and expandable grits. Longer heating times allow for more melting of the buckwheat grits and increase the evaporation of water in the grits, also yielding a more expanded puffed cake. This same increasing trend was revealed in research on wheat cakes (*13*) and yellow corn cakes (*14*).

Hardness. The texture of puffed buckwheat grit cakes was described by hardness, the maximum peak force generated during the breaking test. The hardness of buckwheat grit cakes was significantly affected by all of the variables and their interactions ($p < 0.001$). **Figure 1b** ($r^2 = 0.432$) illustrates the effects of moisture content and heating time on the hardness of buckwheat grit cakes at a heating temperature of 252 °C. As shown in this figure and in **Table 1**, moisture content had significant effects on the hardness of buckwheat grit cakes. Between moisture contents of 15 and 19%, the average hardness increased from 1890 to 2498 g. The increased hardness observed at the higher moisture contents was in agreement with the findings reported by Kloeppel (*14*) on the hardness of yellow corn cakes produced at moistures ranging from 13 to 17%. Increasing moisture content increased hardness more at shorter heating times than at longer heating times; however, raising the heating time decreased hardness more at a higher moisture content than at a lower moisture content (**Figure 1b**). At a moisture content of 15%, no significant differences were observed in the hardness values between heating times of 5 and 8 s, whereas the hardness significantly decreased at 19% moisture content as the heating time increased from 5 to 8 s ($p < 0.05$).

Two factors could affect the hardness of a buckwheat grit cake: the mechanical strength of adhesion between the surface of the grits and the mechanical strength of the individual grit (*13*). Both of these factors are related to the specific volume of the puffed cake. For example, the higher the specific volume, the greater the surface for adhesion among the puffed grits and thus the higher the adhesion strength. However, a higher specific volume means a larger volume of air cells inside the individual buckwheat grit and thus a lower mechanical strength. For buckwheat grit cakes produced at combinations of a low heating time (5 s) and a low moisture content (15%), puffing was very minimal, resulting in cakes with a low specific volume (**Figure 1a**) and low adhesion strengths that were easily broken (**Figure 1b**). On the other hand, buckwheat grit cakes produced at combinations of 19% moisture content and 8 s heating times, conditions that resulted in the highest specific volume, also tended to require slightly less force to break due to the larger volume of air cells within the individual grit (**Figure 1b**). It should be noted that both corn grits and buckwheat grits were similar in that both had no branny layer on the grit surface and a higher expansion would result in greater mechanical strength of adhesion. On the other hand, Fan et al. (*13*) reported a decrease in the hardness of puffed wheat cakes from 2496 to 2161 g as the moisture content increased from 14 to 16%. This might be due to the presence of a branny layer of whole-wheat kernels that weakens the adhesion strength among kernels after expansion.

The hardness significantly decreased with the increased heating times at each heating temperature tested at 17% moisture content ($p < 0.05$) (**Figure 2b**, $r^2 = 0.432$). When the heating time was raised from 5 to 8 s, the average hardness decreased from 2303 to 1968 g (**Table 3**). Also, the average hardness slightly decreased from 2215 to 2083 g when the heating temperature was increased from 240 to 258 °C (**Table 2**). Kloeppel (*14*) also reported that when the heating temperature was increased from 248 to 284 °C, the average hardness of yellow corn cakes decreased from 2285 to 2000 g. This is partially related to the specific volume of the puffed cake. Both longer heating times and higher heating temperatures resulted in higher specific volumes (**Figure 2a**; **Tables 2** and **3**), causing a larger volume of air cells inside the cake and, thus, a lower mechanical strength.

Integrity. Analysis of variance using the GLM model indicated that all three variables had significant effects on the percent weight loss after tumbling ($p < 0.001$). The effects of tempering moisture and heating time on the percent weight loss of buckwheat grit cakes are illustrated in **Figure 1c** ($r^2 = 0.841$). The moisture content had a greater effect than heating time followed by heating temperature. At each moisture level the percent weight loss decreased as the heating time was increased. At each heating time the percent weight loss also decreased as the moisture content increased. The percent weight loss decreased more significantly when the moisture content was increased from 15 to 17% than from 17 to 19%. As the moisture content was increased from 15 to 19%, the average percent weight loss decreased from 16.1 to 2.61% (**Table 1**). Huff et al. (*11*) have reported similar results for medium-grain rice cakes. They found that the percent weight loss for medium-grain rice cakes fell from 56 to 34% as the tempering moisture was increased from 12 to 14% but did not significantly change as the moisture was further increased to 16%. As heating temperatures and heating times increased, the percent weight loss decreased (**Figure 2c**, $r^2 = 0.841$). Between heating temperatures of 240 and 258 °C, the average percent weight loss decreased from 10.1 to 7.49% (**Table 2**). An even larger decrease from 10.3 to 6.74% occurred between heating times of 5 and 8 s (**Table 3**). These results are in agreement with those of Fan et al. (*13*) for wheat cakes. They reported that as the heating temperature was increased from 270 to 300 °C, the percent weight loss of wheat cakes decreased from 21.9 to 3.7%. A dramatic decrease in the percent weight loss of wheat cakes from 30.3 to 2.2% was also observed between heating times of 5 and 8 s. The percent weight loss is inversely related to the specific volume of the buckwheat grit cakes. The buckwheat grit cakes with higher specific volumes experienced less weight loss during tumbling. As previously mentioned, higher moisture contents, higher heating temperatures, and longer heating times resulted in buckwheat grit cakes with greater specific volumes which provide more surface for adhesion among the buckwheat grits and, thus, a higher adhesion force. Due to the stronger adhesion between grits on buckwheat grit cakes with greater specific volumes, these cakes experienced less weight loss during tumbling.

Color. The heating time had the most significant effects on the lightness of buckwheat grit cakes, followed by heating temperature and moisture content. The effects of heating time and tempering moisture on the lightness of buckwheat grit cakes at 252 °C heating temperature is shown in **Figure 3a** ($r^2 = 0.793$). The buckwheat grit cakes were lightest in color at 5 s heating time, with the average lightness decreasing from 68.4 to 62.4 as the heating time increased from 5 to 8 s (**Table 3**). **Figure 4a** ($r^2 = 0.793$) illustrates the effect of heating temperature and heating time on lightness at 17% moisture content. Generally, no significant changes in lightness were observed at any individual heating time as the heating temperature increased from 240 to 246 °C. However, the lightness significantly decreased with the increased heating temperature from 252 to 258 °C at heating times of 6, 7, and 8 s ($p<0.05$). The average lightness decreased from 66.5 to 64.1 as the heating temperature increased from 240 to 258 °C (**Table 2**). Higher heating temperatures and longer heating times accelerate the browning reactions that occur during puffing, generally resulting in a more scorched cake. As shown in **Figure 4a**, at lower heating temperatures the decrease in lightness with increased heating time was not nearly as severe as the decrease in lightness with heating time at higher temperatures. A correlation between specific volume and lightness of buckwheat grit cakes was evident (**Tables 2** and **3**). In general, buckwheat grit cakes with a lower specific volume had a lighter color. Huff et al. (*11*) explained that expansion of rice kernels creates numerous tiny air cells within each rice kernel, rendering the rice kernels more transparent and, hence, reducing the whiteness of the rice kernel and, thus, the lightness value. The average lightness decreased very little as the moisture content was increased from 15 to 19% (**Table 1**).

Parts b ($r^2 = 0.733$) and c ($r^2 = 0.825$) of **Figure 3** illustrate the effects of tempering moisture on the redness and yellowness of buckwheat grit cakes at each heating time studied. The average redness and yellowness significantly increased ($p < 0.05$) from 1.66 to 2.83 and from 12.9 to 13.7, respectively, as the moisture content increased from 15 to 19% (**Table 1**). The heating time also had a significant effect on redness and yellowness ($p < 0.001$). The average value of the redness increased from 1.02 to 3.77 when the heating time was increased from 5 to 8 s (**Table 3**). Similarly, as the heating time was raised from 5 to 8 s, the average yellowness value increased from 12.2 to 14.4. As shown in parts b ($r^2 = 0.733$) and c ($r^2 = 0.825$) of **Figure 4**, increasing the heating temperature significantly increased the redness and yellowness of buckwheat grit cakes ($p < 0.05$). When the heating temperature was raised from 240 to 258 °C, the average values of the redness and yellowness increased from 1.90 to 3.07 and from 12.8 to 14.3, respectively (**Table 2**). Fan et al. (*13*) also reported that the redness of wheat cakes increased from 2.2 to 3.6 over the temperature range of 270−300 °C and from 2.1 to 3.9 when heating time was increased from 5 to 8 s. Because higher heating temperatures and longer heating times significantly increased the browning reactions, this browning effect appeared to contribute to the redness and yellowness of buckwheat grit cakes.

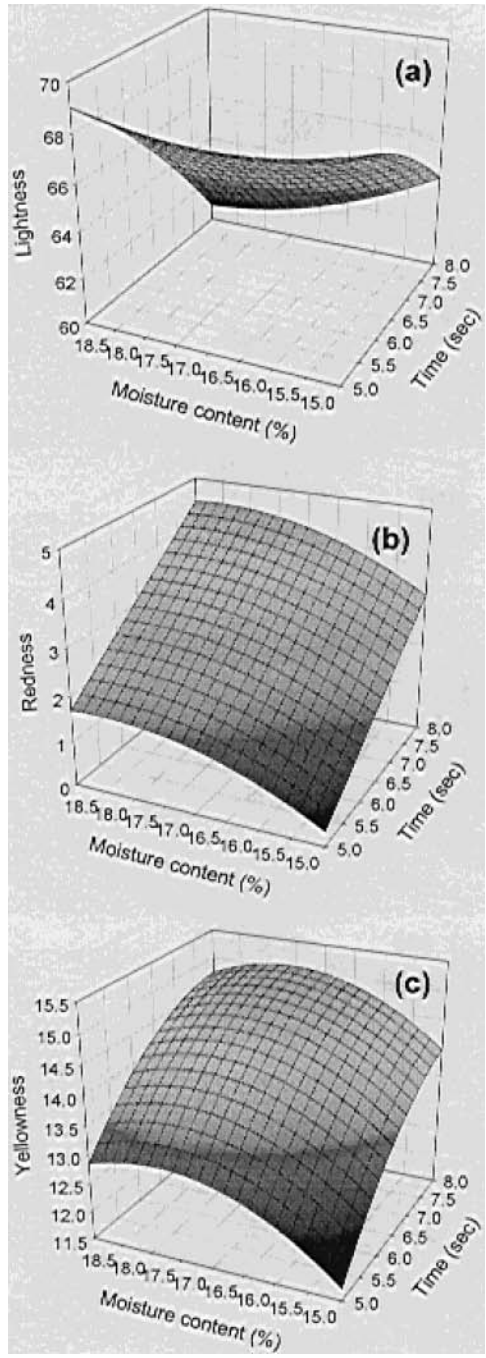

Figure 3. Effects of tempering moisture and heating time on the (a) lightness, (b) redness, and (c) yellowness of buckwheat grit cakes at a heating temperature of 252 °C.

Microstructure. Scanning electron micrographs at 100 times magnification were taken with cakes manufactured at different

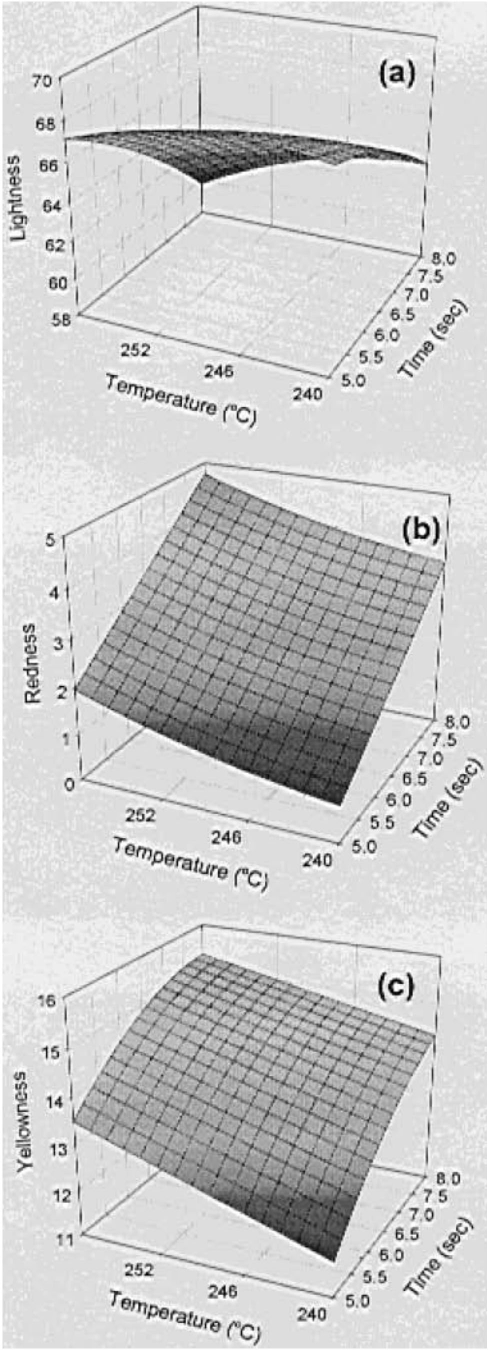

Figure 4. Effects of heating temperature and heating time on the (a) lightness, (b) redness, and (c) yellowness of buckwheat grit cakes at 17% moisture content.

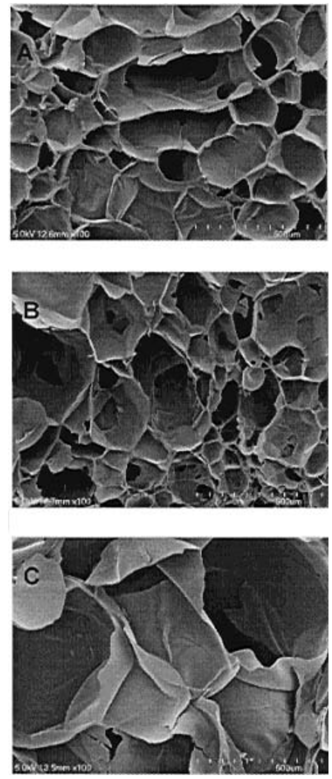

Figure 5. Scanning electron micrographs of buckwheat grit cakes (7 s heating time, 252 °C heating temperature) at (A) 15%, (B) 17%, and (C) 19% moisture content.

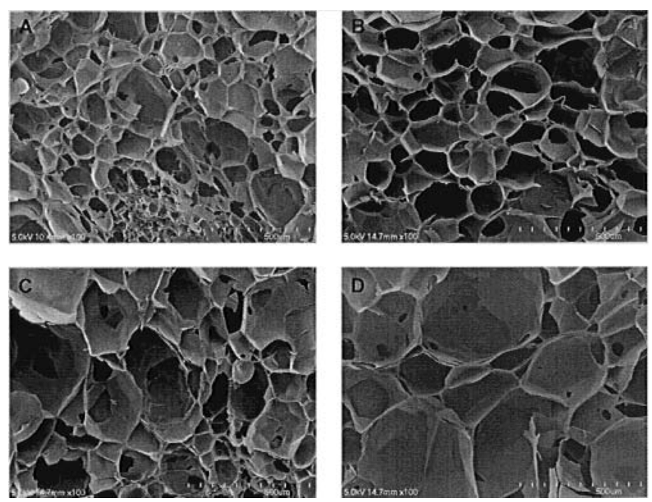

Figure 6. Scanning electron micrographs of buckwheat grit cakes (17% tempering moisture, 252 °C heating temperature) at (A) 5 s, (B) 6 s, (C) 7 s, and (D) 8 s heating times.

moisture contents and heating times. **Figure 5** shows micrographs of buckwheat grit cakes at 15, 17, and 19% moisture contents. The size of the air cells in the cakes seemed to be closely correlated with the tempering moisture. The air cells were smaller in the product that was processed at lower tempering moisture. The size of the holes on the surface was highest at 19% moisture content. Park (*15*) proposed that puffing phenomena of extrudates result from the vaporization of superheated water as the extrudate exits the die. The simultaneous flash-off of vapor expands the material, resulting in the porous, spongelike structure within the extrudate. Therefore, moisture content plays a critical role in the structural properties of the buckwheat grit cake. **Figure 6** illustrates micrographs of buckwheat grit cakes at 5, 6, 7, and 8 s heating times. The degree of expansion of buckwheat grit cakes is related to the size, number, and distribution of the air cells surrounded by the puffed matrix. Increased heating time resulted in more expansion in products, indicated by a less dense structure and large average cell size (**Figure 6**). At an 8 s heating time, the cells were largest and more organized. However, at a heating time of 5 s, the product was puffed only slightly, resulting in a dense structure. As a result, the cake puffed at a heating time of 5 s had the smallest specific volume and greatest hardness. **Table 3** shows that the specific volume of buckwheat grit cakes increased significantly as the heating time increased. The hardness of the puffed cakes decreased significantly as the heating time increased. In contrast, Guraya and Toledo (*16*) reported that

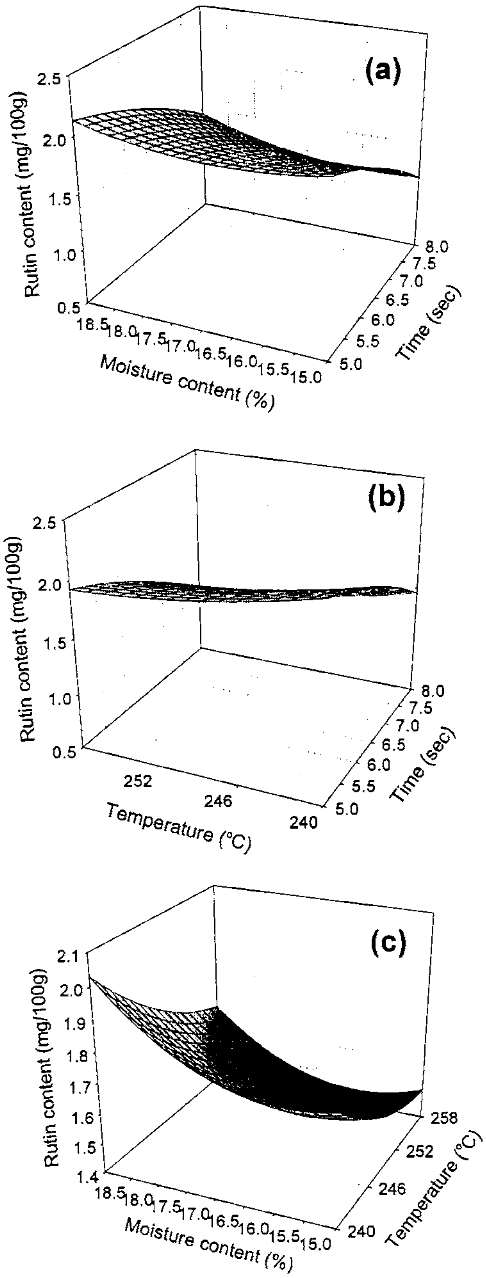

Figure 7. Effects of (a) tempering moisture and heating time at 252 °C heating temperature, (b) heating temperature and heating time at 17% tempering moisture, and (c) tempering moisture and heating temperature at 7 s heating time on the rutin contents of buckwheat grit cakes.

the increase in specific volume of puffed snack products highly correlated with cell diameter and cell wall thickness. A larger increase in specific volume results in thicker cell walls and bigger cell diameters, which results in a more resistant structure. However, according to Jin et al. (*17*), the more expanded extrudate would have larger cells with thinner cell walls and less expanded extrudate would have small cells with thicker cell walls.

Rutin Content. Buckwheat is a good source of rutin, which is a flavonoid. Rutin was eluted 4.7 min after injection. A linear relationship was obtained between the rutin standard content and the peak area ($r^2 = 0.999$). Analysis of variance using the GLM procedure revealed that the rutin content of buckwheat grit cakes was significantly affected by tempering moisture, heating temperature, heating time, and the interaction of tempering moisture and heating time ($p < 0.001$). The heating time had the greatest effect on rutin content, followed by the heating temperature and tempering moisture. The effects of heating time and tempering moisture on the rutin content of buckwheat grit cakes at 252 °C heating temperature are illustrated in **Figure 7a** ($r^2 = 0.890$). At each moisture level the rutin content decreased as heating time was increased. The average rutin content decreased from 2.12 to 1.36 mg/100 g when the heating time was increased from 5 to 8 s (**Table 3**). Minami et al. (*18*) reported that the rutin content decreased from 1.6 to 2.0% in buckwheat seeds with drying at 70 °C for 24 h in forced air oven.

Figure 7b ($r^2 = 0.890$) illustrates the relationship between heating temperature and heating time at 17% moisture content. As heating temperatures and heating times increased the rutin content decreased. With an increase in the heating temperature from 240 and 258 °C, the average rutin content significantly decreased from 1.96 to 1.64 mg/100 g (**Table 2**). **Figure 7c** shows the effects of moisture content and heating temperature on the rutin content of buckwheat grit cakes at a heating time of 7 s. The rutin content of buckwheat grit cakes tended to increase with increasing moisture content [**Figure 7c** ($r^2 = 0.890$) and **Table 1**]. The average rutin content increased from 1.70 to 1.91 mg/100 g when moisture was increased from 17 to 19%, although no significant changes in the average rutin content were found from 15 to 17% moisture.

Conclusions. The rice cake machine was competent to run and could be used to puff buckwheat grits. Puffed buckwheat cakes with specific volumes, hardness, and integrity similar to existing commercial rice cakes could be prepared from buckwheat grits, which had been tempered to 15−17% moisture and puffed for 5−7 s at 240−258 °C. Although longer heating times and higher heating temperatures favored the formation of cakes with higher specific volumes, they also led to darker cakes with lower rutin content. Thus, a tradeoff in heating time and heating temperature might be needed to prepare buckwheat grit cakes that are most acceptable to consumers. Further studies are needed regarding the consumer preference of puffed buckwheat grit cakes under various puffing conditions.

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