Canrea Journal: Food Technology, Nutritions, and Culinary, 2022; 5 (2): 183–207 OPEN ACCESS

e-ISSN : 2621-9468

Type of paper (Article)

Effects of water addition and baking time on the production process optimization of pumpkin muffins: Pilot plant study

Rina Rismaya[1,2*], Elvira Syamsir[2], and Budi Nurtama[2], Nawawee Tohyeng[3]

[1] Department of Food Technology, Faculty of Science and Technology, Universitas Terbuka, South Tangerang, 15437, Indonesia
[2] Department of Food Science and Technology, Faculty of Agricultural Technology, IPB University, Bogor, 16680, Indonesia
[3] Department of Agriculture and Product Processing, Pattani Community College, Pattani, 94000, Thailand

Abstract

Pumpkin muffins are rich in fiber but have low expansion volume and high hardness. To date, research on pumpkin muffins has only been conducted on a laboratory scale. Therefore, a pilot plant study is needed to optimize its production on an industrial scale. This work aimed to determine the processing conditions that could produce the optimum quality of pumpkin muffins on a pilot plant scale. Water addition and baking time were chosen as optimization variables, color, moisture content, expansion volume and hardness were selected as response variables. Optimization was conducted using Response Surface Methodology in Design Expert 7.0® program. The mathematical models for brightness and hue were cubic models, and those for moisture content, expansion volume, and hardness were quadratic models. Optimization results with a desirability value of 0.884 were obtained from the addition of 48% water and baking time of 22 minutes. The resulting pumpkin muffins had lightness of 41.21, hue of 70.74, moisture content of 27.96%, expansion volume of 185.39%, and hardness of 2.91 N and contained 27.96% moisture, 2.23% ash, 18.59% fat, 5.85% protein, 45.37% carbohydrates, and 8.76% dietary fiber. These findings provide new insights for researchers and bakery industries to improve the quality of muffins from local food sources.

Article History
Received August 5, 2022
Accepted November 27, 2022
Published December 5, 2022

Keywords
Dietary Fiber, Muffins, Pilot Plant, Process Optimization, Pumpkin.

1. Introduction

High-fiber food products have been developed because of new trends in society seeking for healthy food products with certain functional values. The high demand for high-fiber foods is inseparable from the research on the potential and benefits of dietary fiber in maintaining health, especially in the digestive tract. Dietary fiber has been widely studied and found to promote intestinal health (1), prevent colonic mucus deterioration (2), and reduce the risk of degenerative diseases, such as diabetes, cancer, obesity, and cardiovascular diseases (3,4). High dietary fiber intake can help regulate insulin levels in the blood, thereby reducing glucose levels and increasing glucose tolerance (5,6).

Muffins are quite popular and consumed by many people because they are considered practical and have a good taste; however, the muffins made from 100% wheat flour have a low crude fiber content of 0.72%. According to Kaur (7), the fiber content of wheat flour is only 0.50%. High-fiber muffins made from nonwheat flour ingredients have been developed

* Correspondence : **Rina Rismaya** rinarismaya@ecampus.ut.ac.id

ISSN 2621-9468 online, DOI 10.20956/canrea.v5i2.711

as a dietary supplement. Recent studies focused on the production of nonwheat-based high-fiber muffins, including muffins added with upcycled orange fiber (8), long-grain indica rice bran (9), spent espresso coffee (10), acorn (*Quercus suber* L.) (11), type 4 resistant starch (RS 4) (12), and orange peel substitution (13). We also developed the production process of high-fiber muffins with pumpkin flour substitution on a laboratory scale. Muffin made from 100% pumpkin flour has a dietary fiber content of 19.56%–20.69% and therefore is classified as high-fiber food (14). The high value of fiber in pumpkin muffins is due to the high-fiber content of pumpkin flour at 23.72% (15).

The use of no wheat flour affects the fiber content and physical, chemical, and sensory qualities of the muffins. In our previous research, we found that adding pumpkin flour to the muffin formula decreased the expansion volume and sensory acceptance of muffin but increased the hardness value of the muffin crumb; the maximum substitution of pumpkin flour in the muffin formula that preserved sensory acceptability was 50% of the total weight of the flour mixture (14). Thus, 50% pumpkin flour substitution was adopted in the current study for the production of pumpkin muffins on a pilot plant scale to achieve the maximum addition of dietary fiber while maintaining sensory acceptability.

The expansion volume and hardness of muffins are influenced by the quality of batter muffins. Adding a dietary fiber component with high water absorption ability could affect the batter muffin characteristics. The addition of fiber sources, such as apple, pea, or wheat, can increase the batter muffin's viscosity (16). In our previous work, we found that pumpkin muffin batter had a thicker and stiffer consistency than wheat flour muffins (14). Stiff, thick dough is difficult to hydrate, so a different kind of water must be added to the pumpkin muffin batter. A certain amount of water is also needed for the formation of gluten and the gelatinization of starch, which play an important role in forming the muffin framework. The matrix network structure is crucial in trapping air or gas during baking, which in turn determines the expansion volume (17). The negative effect of dietary fiber on dough formation is minimized by adding an optimal amount of water to the dough formula (16,18). Wheat flour and mixtures of different flour substitutions have varying water absorption capacities (19), so different volumes of water must be added at varying levels of flour substitution (20). Our hypothesis states that the baking time of muffins will vary with water addition level. This study aims to determine the process conditions that could produce optimum quality of pumpkin muffins on a pilot plant scale using the surface response method (RSM) with water addition and baking time as factors.

Our previous studies focused on the processing of high-fiber pumpkin muffins on a laboratory scale. The develop process would be difficult to apply in industrial scale production. The fundamental problem in implementing laboratory scale optimum process conditions on an industrial scale is the large difference in production capacity, process conditions, and equipment. Upscaling to a pilot plant is the key link in the processing of pumpkin muffins from a laboratory scale to an industrial scale.

2. Materials and Methods

2.1. Ingredients of Pumpkin Muffins

The main ingredient of pumpkin muffins was pumpkin flour (80 mesh), which was obtained from small and medium enterprises in Kusuka Ubiku, Kepuh Kulon, Wirokerten, Banguntapan, Bantul Yogyakarta. Other ingredients included "Segitiga Biru" wheat flour (100 mesh), margarine, water, salt, eggs, fine granulated sugar, and baking powder.

2.2. Processing of Pumpkin Muffins

The formula and procedure for making pumpkin muffins were adopted from our previous research (14). The production processes included weighing ingredients, making dough, and baking dough. The flour ingredients were sifted, weighed, and placed in a mixer bowl (Planetary dough mixer B60A, China). Other ingredients (margarine, water, and salt) were heated, poured into the mixer bowl, and stirred at medium speed. Eggs were added gradually and stirred into the mixture until evenly mixed, and fine granulated sugar and baking powder were then added and stirred into the mixture until evenly mixed. The dough was poured into muffin cups to ±3/4 height. The cup had a diameter of 3.8 cm and a height of 4 cm. The muffin dough was baked in the oven (gas oven PCH 10303) at different levels of water addition and baking time according to the treatment. The basic muffin formula is presented in Table 1.

Table 1. Basic muffin formula (14).

Ingredient	Percentage (%)	Amount (g)
Flour mixture	100	525
Margarine	66	345
Water	31	163
Salt	0.6	3
Egg	57	300 (± 6)
Fine granulated sugar	72	380
Baking powder	2	10

The percentage (%) of each ingredient used was based on the weight of the components of the flour mixture (ratio of flour to pumpkin flour 1:1) weighing 525 g.

2.3. Baking Temperature Determination

On the basis of our previous research, a baking experiment was carried out at two different temperatures of 200 °C on the laboratory scale (14) and 158 °C on the pilot plant scale (21).

2.4. Optimization Process Design

D-Optimal RSM design was used for randomization. The design begins with determining the independent variables of the process conditions, namely, water addition and baking time. The range of independent variables determined from literature review, and trial and error were carried out to determine the upper and lower limits of each factor based on the parameters of color (L* and Hue*), expansion volume, and hardness. The obtained upper and lower limits were entered into the DX 7.0® program with the D-Optimal RSM design for randomization. A total of 16 treatments were generated Table 4.

2.5. Response Analysis and Process Optimization

Each response was analyzed by ANOVA. Design Expert 7.0® software provided a polynomial model that represents the response of each factor. Polynomial models can be mean, linear, 2FI (two factors interaction), quadratic, or cubic. The model was represented in the form of a 3D surface graph. The ANOVA model was chosen according to the program's recommendation, namely, a model that can represent the response well by meeting the following four criteria. First, the selected model should have: 1). a “prob>f” value less than or equal to 0.05 (significant); 2). a lack of fit greater than 0.05 (not significant). The lack of fit value which was not significant indicated the suitability of the response data with the model; 3) the difference between the predicted R-squared and adjusted R-squared values which is less than 0.2; and 4). The last criterion is based on the adequation precision value which must be greater than 4.

Responses are optimized by determining the criteria first. Thus, to get the optimum process conditions, we needed to determine goals and importance. The goal value consists of the target (the point to be achieved), in range (within a certain range), maximize (maximum or upper limit), or minimize (minimum or lower limit). In addition, there is importance which has a value of 1–5 (+) to (+++++) to determine the level of importance of each response. The greater the importance indicated a high desire to achieve the ideal optimal product. The output of the optimization phase was the recommendation of several optimal process conditions created by program. The most optimal process conditions are recognized by the high desirability value. The desirability values ranged from 0 to 1.0. The high desirability value (close to 1.0) indicated the process condition suggested by program will produce a more perfect product.

2.6. Verification

After obtaining the optimum process conditions based on the desirability value, thus we proceed with the verification stage through response testing in the laboratory. The response analysis results of verification were compared with the predicted responses given by the Design Expert 7.0® software. To determine the conditions of the verified process, the confidence interval (CI) and prediction interval (PI) values were given for each response prediction value at a significance level of 5%. The CI range showed the average expectation of the next measurement results at a significance level of 5%, while the PI range showed the expected response measurement results with the same conditions at the 5% significance level. Verification was carried out by testing in the laboratory with two experimental repetitions and three measurement repetitions. Then, the results obtained were compared with the value of the response variable predicted by the Design Expert 7.0®program, so that it was seen the suitability at the verification stage.

2.7. Pumpkin Muffin Analysis

2.7.1. Crumb color analysis

Color analysis of pumpkin muffin crumbs referred to the method of Matos et.al., (22) with modifications to the tools used. Their study used A Konica Minolta CM-3500, while color measurements in this study used the Chromameter CR 300 Minolta. Pumpkin muffin samples were cut at the top at muffin height, then placed in a sample container in the form of a small petri dish. Measurement results in various notation systems were recorded or printed. Color measurement results in L*, a*, b* and hue values calculated as $\tan^{-1}$ (b*/a*). L indicates lightness with values 0 (black) and 100 (white). A* values indicate green (−a*) to red (+a*) and b* values indicate blue (−b*) to yellow (+b*). The color groupings based on hue values are as follows (23).

Hue 342-18 : *Red purple*
Hue 18–54 : *Red*
Hue 54–90 : *Yellow red*
Hue 90–126 : *Yellow*
Hue 126–162 : *Yellow green*
Hue 162–198 : *Green*
Hue 306–342 : *Purple*
Hue 270–306 : *Blue purple*
Hue 198–234 : *Blue green*
Hue 234–270 : *Blue*

2.7.2. Expansion volume analysis

The analysis of expansion volume referred to the method of Krisnawati et al. (24). Modifications were how to calculate expansion volume. Their research used length, width, and height for volume calculating, while this study used the seed displacement method with barley seeds. The barley seeds were put into the measuring container until they were completely flat. After the container was full of barley seeds, some of the seeds were temporarily transferred to another container, then the muffins were put into the container and filled again with the barley seeds that were previously temporarily transferred to another container until they were full. The remaining barley seeds were measured using a measuring cup as the muffin volume. Muffin dough volume was measured using a measuring cup. The measuring cup was first weighed with a Camry EHA 401 digital scale with an accuracy of two digits behind the comma, then calibrated. Then the dough was put into a measuring cup and the volume and weight were recorded. The weight of the dough was used as a reference to determine the volume of muffin dough.

2.7.3. Texture analysis of pumpkin muffin crumbs

Texture measurements were carried out objectively using the texture analyzer instrument TA-XT2i (TAHDI, Stable Microsystem, UK) following the method of Feili et al. (25). Modifications were made to the sample size of the pumpkin muffin test from a size of 2 cm x 2 cm x 2 cm to a size of 3 cm x 3 cm x 3 cm. All test samples were prepared and baked on the test day. The probes were calibrated according to the instructions before use. The sample was cut and shaped like a cube in the center of the muffin sample (crumb) and placed centrally under the probe [SMSP 75] using the following conditions: pretest speed: 1.0 mm/s, test speed: 1.0 mm/s, posttest speed: 10.0 m/s, compression distance: 25%, and trigger type: auto-5 g.

2.7.4. Water content analysis

Moisture content was analyzed using AOAC method (26). Empty aluminum crucibles were dried in an oven at 105 °C for 15 minutes and cooled in a desiccator for 5–10 minutes and then weighed (W_2). Then, 2–3 g (W) of the sample was placed in a cup and dried in an oven at 105 °C for 6 hours or until the sample weight was constant. The cup containing the dried sample was transferred to a desiccator, cooled for 15 minutes, and weighed again (W_1), as formulated in equation (1).

$$\text{Water content (\% wet base)} = \frac{W-(W_2-W_1)}{W} \times 100\ \% \tag{1}$$

2.7.5. Analysis of ash content

Analysis of ash content referred to the AOAC method (26). The porcelain dish for ashing was dried in an oven 105 °C for 15 minutes and then cooled in a desiccator and weighed (A). The sample with a certain weight (B) was placed in a porcelain dish, burned in a smoke chamber until it no longer emitted smoke, and burned again in a furnace at a temperature of 400 °C–600 °C for 4–6 hours until white ash formed and constant weight. The ash and the porcelain dish were cooled in a desiccator and then weighed (C). The ash content of the sample was calculated by equations (2) and (3), where wb and db are wet and dry bases, respectively.

$$\text{Ash content (\%wb)} = \frac{(\text{C-A})}{\text{B}} \times 100\ \% \tag{2}$$

$$\text{Ash content (\%db)} = \frac{\text{ash content (\%wb)}}{\text{100-water content (\%wb)}} \times 100\ \% \tag{3}$$

2.7.6. Soxhlet method of fat content analysis

The fat content analysis was referred to the AOAC method (26). A total of 1–2 g of sample was weighed (W) and put into filter paper. The filter paper containing the sample was dried in an oven at 105 °C to dry. The dried filter paper was inserted into the sleeve with a cotton plug. Thus, the sleeve was inserted into the Soxhlet extraction apparatus and connected to the condenser and the fat flask. Then the fat was previously dried in an oven at 105 °C to dry and weighed (W_1). The condenser was placed on the top and the fat flask was placed under it. The hexane solvent was added to the fat flask to taste. Subsequently, extraction was carried out for 6 hours. The solvent in the fat flask was distilled and collected again. Then the fat flask containing the extracted fat was dried in an oven at 105 °C, cooled in a desiccator, and weighed (W_2). Drying was repeated until a constant weight was reached. Fat content was calculated by equations (4) and (5).

$$\text{Fat content (\%wb)} = \frac{(\text{W}_2\text{-W}_1)}{\text{W}} \times 100\ \% \tag{4}$$

$$\text{Fat content (\%db)} = \frac{\text{Fat content (\%wb)}}{\text{100-Water content (\%wb)}} \times 100\ \% \tag{5}$$

2.7.7. Protein content analysis

Analysis of protein content referred to the AOAC method (26). A total of 0.1 g of sample was weighed in a Kjeldahl flask, then 1.0±0.1 g Merck K_2SO_4 (Germany), 40±10 mL Merck HgO (Germany), and 2.0±0.1 mL Merck H_2SO_4 (Germany) were added. Then boil until the liquid sample is clear and then cooled. This clear sample solution was transferred to a distillation apparatus quantitatively. The Kjeldahl flask was rinsed with 1–2 mL of distilled water, then the washing water was put into the distillation apparatus, and rinsing was carried out 5–6 times. A total of 10 mL of a 60% NaOH–5% $Na_2S_2O_3.5H_2O$ Merck (Germany) solution was added to the distillation apparatus. Under the condenser is placed an Erlenmeyer containing a mixture of 5 mL of Merck (Germany) saturated H3BO3 solution and 2–4 drops of indicator (2 parts 0.2% methylene red and 1 part 0.2% methylene blue in 95% ethanol) Merck (Germany). The end of the condenser tube must be submerged in Merck's (Germany) H_3BO_3 solution, then distillation is carried out to obtain about 15 mL of distillate. The distillate obtained was titrated with 0.02 N Merck (Germany) HCl which had been standardized until the color changed from green to gray. Nitrogen content and crude protein content by wb and db are determined by equations (6) to (8).

$$\text{N content (\%wet base)} = \frac{(\text{Vs - Vb}) \times \text{N} \times 14.007}{\text{W}} \times 100\ \% \qquad (6)$$

$$\text{Crude protein content (\%wb)} = \text{\%N} \times \text{Fk} \qquad (7)$$

$$\text{Crude protein content (\%db)} = \frac{\text{Crude protein content (\%wb)}}{\text{100-water content (\%wb)}} \times 100\ \% \qquad (8)$$

Where, Vs = Volume of HCl spent titrating the sample (mL), Vb = Volume of HCl spent on blank titration (mL), N = Normality of HCl which has been standardized (N), W = Sample weight (mg), and Fk = Correction factor (6.25 for muffin products).

2.7.8. Analysis of Carbohydrate Content Method by Difference

Carbohydrate content was calculated as the remainder of the moisture content, ash content, fat content, and protein content. In this analysis, it is assumed that carbohydrates were the weight of the sample in addition to moisture, ash, fat, and protein as formulated by equation (9).

$$\text{Carbohydrate content (\% wb} = 100 - (\text{\% moisture} + \text{\% ash} + \text{\% fat} + \text{\% protein}) \qquad (9)$$

2.7.9. Total Dietary Fiber Analysis

Analysis of dietary fiber referred to the method of Asp et al. (27). The sample was weighed as 1 g (W) with an accuracy of up to 0.1 mg into a 400 mL beaker. Furthermore, 25 mL of 0.1 M Merck phosphate buffer (Germany) pH 6.0 and 0.1 mL of Merck's Termamyl solution (Germany) were added, covered with aluminum foil, and placed in a water bath shaker at 99 °C for 15 minutes, shaking slowly every 5 minutes. Then, 20 mL of distilled water was added, cooled to room temperature, then the pH value was adjusted to pH 1.5 by adding Merck (Germany) 4 M HCl. After the pH was acidified, 100 mg of pepsin was added and placed in a water bath shaker at 40 °C for 60 minutes with continuous agitation. After that, 20 mL of distilled water was added, then the pH value was adjusted again until it reached pH 6.8 by adding 4 M Merck NaOH (Germany). After the pH was reached 6.8, 100 mg of pancreatin was added and placed in a water bath shaker (D-30938 Burg wedel, Germany) at 40°C for 60 minutes with continuous agitation. After the process was completed, the pH value was adjusted again until it reached pH 4.5 by adding 4 M HCl. Then 280 mL of 95% ethanol which had been preheated (60°C) was added (volume measured after heating). Incubate at room temperature for 60 minutes to form a precipitate. The precipitate was filtered using a crucible of known dry weight. Furthermore, the residue from the sample was washed with 2 × 10 mL of distilled water, 2 ×10 mL of 95% ethanol, and 2 x 10 mL of Merck acetone (Germany), then the residue was dried at 105 °C to a constant weight (about 12 hours), cooled in desiccator and weighed ($Wres$). One replicate sample was placed in a furnace at 525°C for at least 5 hours, cooled in a desiccator, and weighed ($Wash$). One replicate sample was calculated for protein content using the Kjeldahl ($Wpro$)

method. Blank samples were used to determine the weight of contaminants from reagents and enzymes (Wb). Total dietary fiber is calculated by equation (10).

$$\text{Total dietary fiber (\%)} = \frac{(\text{Wres-Wpro-Wash-Wb})\times 100}{\text{W}} \qquad (10)$$

3. Results and Discussion

3.1. Baking Temperature Determination

Muffin baking temperature is important for physical characteristics, such as good appearance, texture, and color. Upscaling from the laboratory to the pilot plant caused differences in the quantity of materials, process conditions, and equipment. The use of different baking ovens in the laboratory and pilot plant led to different heat distribution and heat flow patterns. Baking at 200 °C using an electric oven (Oxone OX-898BR) in a laboratory could not be applied directly to a pilot plant. Figure 1 shows the pumpkin muffins baked at 200 °C using a gas oven in a pilot plant (PCH 10303). Poor quality characteristics were observed, including the dark brown spot on the surface (see red square in Figure 1a), low expansion volume, and hard texture.

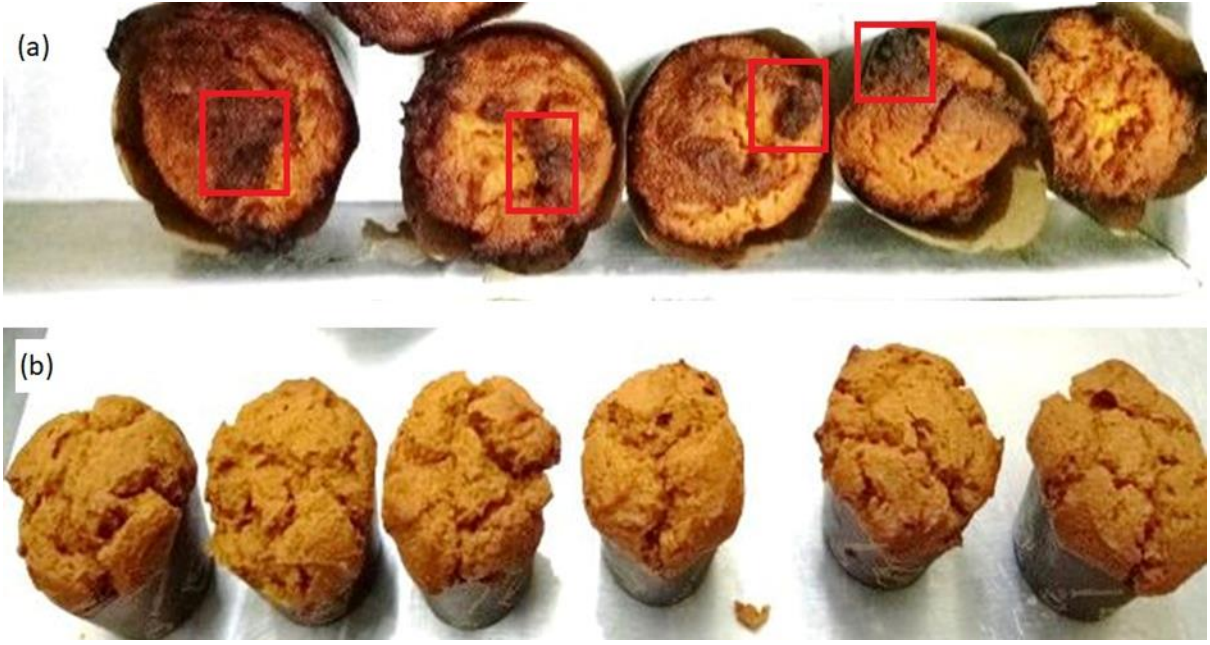

Figure 1. Visual appearance of muffins baked (a) at 200 °C and (b) 158 °C (b).

The pumpkin muffins baked at 158 °C h exhibited a perfect level of baking. They had good appearance, high expansion volume, and low texture. Therefore, 158 °C was suitable as the baking temperature of pumpkin muffins in a pilot plant. This temperature was also adopted for the optimum process condition for baking muffins substituted with sweet potato and corn flour composites using a pilot plant scale oven (21). Visual differences in the muffins baked at the two temperatures are presented in Figure 1. This observation was expected because of the differences in circulation or heat distribution, heat flow patterns, drying air rates, and partial vapor pressures in electric ovens used in laboratories and gas ovens used in pilot plants. Laboratory ovens utilize an electric heat source that maintains temperature and humidity, so the drying process is relatively stable. Meanwhile, pilot plant ovens employ gas fuel, which causes high air temperature and fast drying (28).

3.2. Process Optimization Design Plan

The range of factors for the processing of pumpkin muffins was determined from literature review (29,30) as follows: 30%–50% water addition and 20–30 minutes of baking time at ±200 °C. A trial and error approach was adopted for the two process conditions (X and Y) of pumpkin muffins as presented in Table 2. Process condition X was the addition of 30% water with a baking time of 20 minutes, and process condition Y was the addition of 60% water with a baking time of 40 minutes. Independent samples t-test was performed using SPSS V.22 to determine the significant difference between the measured response values for the pumpkin muffins prepared using the two process conditions.

Table 2. Measurements and response analysis of pumpkin muffins prepared using two different process conditions.

Parameter	Process conditions	
	X	Y
Lightness (L*)	38.50^b	40.96^a
Hue (°h)	67.92^b	69.80^a
Expansion volume (%)	169.77^b	174.90^a
Hardness (N)	4.20^a	3.70^b

The numbers in the same row followed by the same letter are not significantly different at the 5% test level, X= 30% water addition and 20 minutes of baking time, Y= 60% water addition and 40 minutes of baking time, N= newtons.

Table 2 shows that the pumpkin muffins produced using process condition X had lower L values, hue, and volume expansion and higher hardness than the muffins produced from process condition Y. Statistical analysis with independent samples t-test revealed a significant difference in response values between the pumpkin muffins under process conditions X and Y. In process condition X, the added water is not enough for the hydration of the ingredients in the dough. Water plays an important role in the viscoelastic properties of the dough through the formation of disulfide and ionic bonds between protein components, which determines the expansion volume (18,31,32). A certain amount of water is required for gelatinization so that starch swells and a gel is formed, which play an important role in the formation of the muffin skeleton network. In addition, water is required for the formation of gluten, which gives elastic properties to the dough together with the gelatinized starch in the muffin skeleton network. The matrix network structure traps air or gas during baking, which determines the expansion volume. Disproportionate water addition in baking causes problems in the expansion volume of pumpkin muffins. Analysis results showed that the interval for water addition was between 30% and 60%, and that for baking time was around 20–40 minutes (Table 3). The upper and lower limits were then entered into the DX 7.0® program, and 16 treatments were generated as presented in Table 4

Table 3. Upper and lower limits of factors.

Factor	Lower limit	Upper limit
Water addition (%)	30	60
Baking time (minutes)	20	40

Table 4. Design of the processing conditions for pumpkin muffins from the program.

Treatment	Factor A: Water addition (%)	Factor B: Baking time (minutes)
1	30	20
2	60	34
3	51	40
4	30	40
5	60	20
6	43	29
7	54	28
8	45	20
9	30	30
10	38	23
11	41	39
12	60	20
13	30	20
14	30	40
15	60	34
16	51	40

3.3. Response Analysis

The responses of pumpkin muffins measured in this study were lightness, hue, moisture content, expansion volume, and hardness. The resulting values of the five responses in Table 5 were then entered into the DX 7.0® program with the RSM D-optimal design for response analysis. The results are presented in Table 6. Mathematical equations were also generated for each response as listed in Table 7.

Table 5. Resulting values of the five responses of pumpkin muffins.

Treatment	A	B	Lightness (L*)	Hue (°h)	Water content (%wb)	Expansion volume (%)	Hardness (N)
1	30	20	39.19	67.95	22.99	168.93	4.60
2	60	34	41.25	69.63	24.78	177.92	3.88
3	51	40	38.06	66.94	24.23	182.27	3.49
4	30	40	36.62	65.52	21.33	169.35	5.19
5	60	20	42.82	70.83	29.50	184.38	3.25
6	43	29	39.03	68.03	26.28	189.04	2.73
7	54	28	40.99	70.14	27.67	180.66	3.78
8	45	20	41.56	69.79	28.20	185.36	2.93
9	30	30	37.04	65.79	21.76	169.91	4.28
10	38	23	40.44	69.10	25.50	182.80	3.81
11	41	39	36.72	65.93	22.87	186.30	3.25
12	60	20	41.61	70.24	28.92	173.14	4.13
13	30	20	39.05	68.60	22.15	169.38	4.29
14	30	40	36.20	65.20	19.89	169.56	5.03
15	60	34	41.12	69.90	23.60	173.58	3.78
16	51	40	37.82	66.90	23.24	182.41	3.58

Description: A= water addition (%), B=baking time (minutes), % wb =wet basis, N=Newton

Table 6. Recapitulation of the results of the optimization of the five measured responses

Parameter	Mathematical models	Model significance ($p<0.05$)	*Lack of fit* ($p>0.05$)	*Adjusted-R^2 model*	*Predicted-R^2 model*	*Adequation precision*
Lightness (L*)	*Cubic*	< 0.0001	0.5363	0.9644	0.8015	18.449
Hue (°h)	*Cubic*	< 0.0001	0.4522	0.9752	0.8176	21.946
Water content (%*wb*)	*Quadratic*	< 0.0001	0.8960	0.9569	0.9239	23.817
Expansion volume (%)	*Quadratic*	0.0005	0.8087	0.7951	0.6171	9.215
Hardness(N)	*Quadratic*	0.0018	0.2538	0.7294	0.5611	8.866

Description: % wb =wet basis, N=Newton

Table 7. Mathematical equations of the five measured responses

Parameter	Mathematical equations
Lightness (L*)	$-32.5529+3.0625A+3.3964B-0.0336AB-0.0581A^2-0.1059B^2+5.9918\times10^{-4}A^2B-2.9137\times10^{-4}AB^2+3.1355\times10^{-4}A^3+1.3633\times10^{-3}B^3$
Hue (°h)	$+28.4379+1.2580A+2.5571B+0.0205AB-0.0339A^2-0.1137B^2+2.6303\times10^{-4}A^2B-7.0044\times10^{-4}AB^2+2.0111\times10^{-4}A^3+1.6179\times10^{-3}B^3$
Water content (%wb)	$-8.2265+1.3654A+0.2768B-8.7902\times10^{-3}AB-0.0107A^2-1.9208\times10^{-3}B^2$
Expansion volume (%)	$+32.443+6.008A+1.138B-0.011AB-0.061A^2-0.012B^2$
Hardness (N)	$+15.0121-0.4668A-0.0844B-1.8918\times10^{-4}AB+4.9816\times10^{-3}A^2+1.9221\times10^{-3}B^2$

Description: A= water addition (%), B=baking time (minutes), % wb =wet basis, N=Newton

3.3.1. Color of Pumpkin Muffins

Color is an important factor in product development because consumers generally judge a product from its visual appearance. Here, the measured color parameters were the lightness level (L*) and hue degree. L* represents the lightness with a value of L*=0 meaning black and L*=100 meaning white. Chromatic color or hue describes the actual dominant color, such as red, blue, and yellow, based on the light reflected by the object (33). The hue value was obtained from the conversion of the a* and b* chromaticity values from the color measurement using a chromameter (22).

Response analysis in Table 6 shows that the predictive model for the lightness of the pumpkin muffins was a cubic model because its “prob>f” (<0.0001) was smaller than 0.05 (significant). Meanwhile, the lack of fit F-value was 0.5363, which was greater than 0.05 and indicated that the lack of fit was not significant relative to pure error. Insignificant lack of fit is a requirement of a good model because it shows the suitability of the lightness response data with the model. In addition, the difference between the predicted R-squared and adjusted R-squared values was <0.2, and the adequation precision value was <4, namely, 18.449. On the basis of these four criteria, the cubic model is a good model and is expected to provide good predictions for the lightness value.

ANOVA results showed a significant effect on lightness for factors B (baking time) and A^2B (quadratic interaction of adding water and baking time) but not for factors A (water addition), AB (interaction of water addition with baking time), A^2 (quadratic interaction between water addition), B^2 (quadratic interaction between baking time), AB^2 (interaction of water addition with quadratic interaction of baking time), A^3 (cubic interaction between water addition), and B^3 (cubic interaction between water addition). As listed in Table 7, the mathematical equation for the lightness response revealed the increasing lightness level with factors A, B, A^2B, A^3, and B^3 as indicated by positive coefficients. However, the lightness level decreased with the increase in factors AB, A^2, B^2, and AB^2 as indicated by negative coefficient values.

The 3D surface graph (Figure 2) illustrates the relationship between the combination of adding water, baking time, and the lightness value of the muffin. The red part of the graph shows the highest lightness value of 42.82, and the blue part shows the lowest lightness value of 36.20. The higher the lightness value, the brighter the pumpkin muffin color. The highest lightness value was found in the muffins with 60% water addition and 20 minutes of baking time, and the lowest was found in the muffins with 30% water addition and 40 minutes of baking time. These results were in accordance with Martunis' research (34), which stated that drying time reduced the lightness of potato starch. Other researchers also stated that the length of the oven decreased the lightness value of paper squid products (35) and instant spice "*Rujak Cingur*" (36). According to Ahrne et al. (37), the low moisture content of the dough causes the bread color to darken and the sensory reception to decrease.

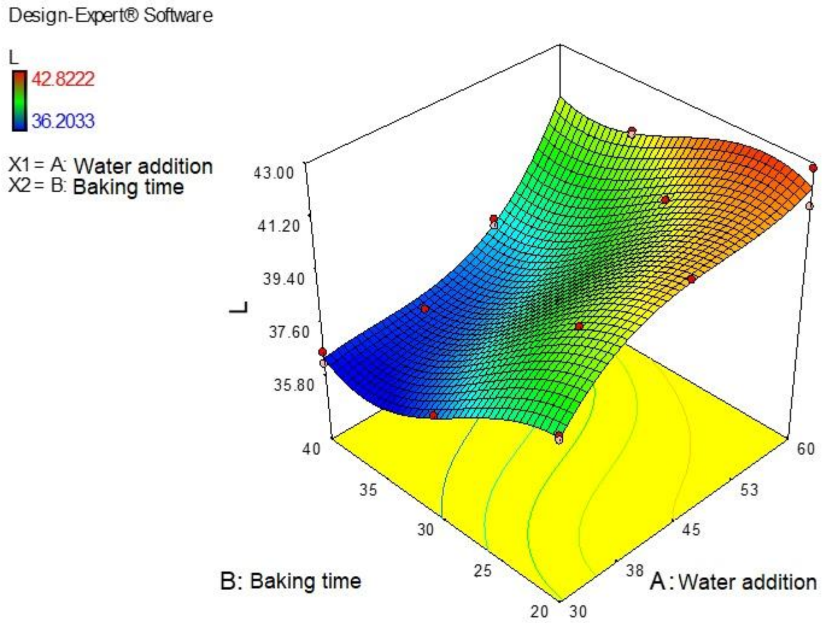

Figure 2. 3D surface graph of the relationship between the combination of factors (water addition and baking time) with lightness.

Hue response analysis (Table 6) showed that the model used to predict the hue response was a cubic model because its "prob>f" value (< 0.0001) was smaller than 0.05 (significant) and its lack of fit value (cubic) was 0.4522 (not significant). The difference between the predicted R-squared and adjusted R-squared values was <0.2, and the adequation precision value met the requirement of >4, namely, 21.946. On the basis of these four criteria, the cubic model is a good model and is expected to provide good predictions for the hue response.

ANOVA results showed a significant effect on the hue response for factors A (water addition), B (baking time), and AB^2 (interaction of water addition with quadratic baking time) but not for factors AB (interaction of adding water and baking time), A^2 (quadratic interaction between water addition), B^2 (quadratic interaction between water addition), A^2B (quadratic interaction between adding water and baking time), A^3 (cubic interaction between water additions), and B3 (cubic interaction between baking times). According to the mathematical equation for the hue response (Table 7), the hue value increased with the factors A, B, AB, A^2B, A^3, and B^3 as indicated by positive coefficients. However, the hue value decreased with the increase in factors A^2, B^2, and AB^2 as indicated by negative coefficient values.

The 3D surface graph (Figure 3) illustrates the relationship of the combination of water addition factors and baking time with the hue response. The red part of the graph shows the highest hue value of 70.82, and the blue part shows the lowest hue value of 65.20. The highest hue value was found in the muffins with 60% water addition and 20 minutes of baking time, and the lowest was found in the muffins with 30% water addition and 40 minutes of baking time.

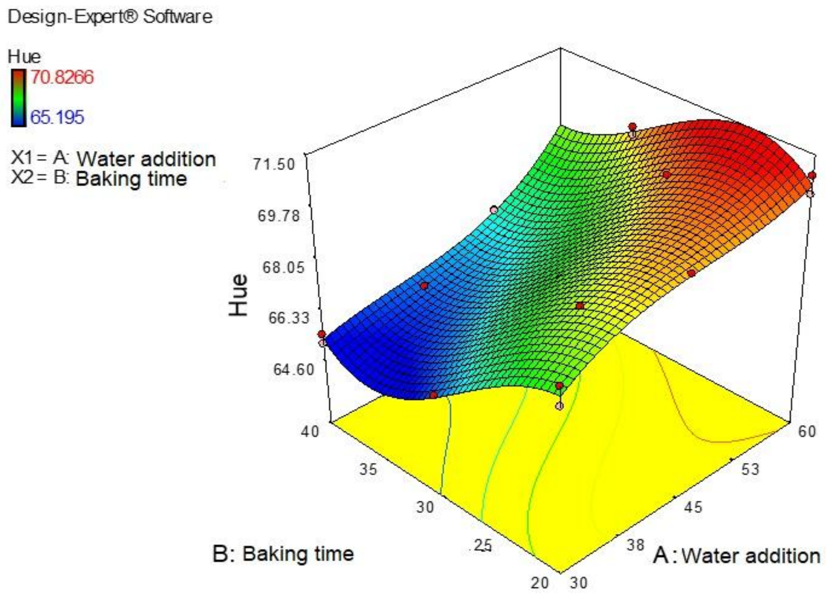

Figure 3. 3D surface graph of the relationship of the combination of water addition factors and baking time with the degree of hue.

The changes in lightness and hue of muffins were caused by a browning reaction (Maillard reaction) that occurred during baking. The Maillard reaction is a reaction between free amino groups and carbonyl groups that occurs under heating or storage for a long time (38). Melanoidin, a brown pigment, is a product of the reaction and is formed with prolonged baking time. Owing to this pigment, the muffins baked for a long time will have low lightness and hue values. In addition to baking time, the water added to the muffin batter also affects the lightness value because the Maillard reaction can either be inhibited when water levels are high or triggered when water levels are low (39). At high levels, water tends to shift the reaction to the left, indicating that the formation of N-substituted glycosylamine is inhibited (40). N-substituted glycosylamine has an important role in the formation of melanoidin compounds and is the final product of the Maillard reaction.

3.3.2. Moisture Content of Pumpkin Muffins

Moisture content is an important component that can affect the stability and durability of foodstuffs. The presence of water can be used as an indicator to determine the level of food safety (40). The moisture content of the product is influenced by the amount of water added to the pumpkin muffin formula, so measuring the moisture content is important. After the measurement of the moisture content, a response analysis was carried out for moisture content based on ANOVA (Table 6). The model used to predict the moisture content was a quadratic model because its "prob>f" value (<0.0001) was smaller than 0.05 (significant) and its lack of fit value was 0.8960 (not significant). The difference between the predicted R-squared and adjusted R-squared values was <0.2, and the adequation precision value met the requirement of >4, namely, 23.817. On the basis of these four criteria, the quadratic model is a good model and is expected to provide good predictions for the moisture content response.

ANOVA results showed a significant effect on the moisture content for factors A (water addition), B (baking time), AB (interaction of adding water and baking time), and A^2 (quadratic interaction between water addition) but not for factor B^2 (quadratic interaction between baking time). According to the moisture content response equation (Table 7), the moisture content increased with A and B as indicated by the positive coefficient. However, the moisture content decreased with the increase in AB, A^2, and B^2 as indicated by a negative coefficient.

The 3D surface graph (Figure 4) illustrates the relationship of the combination of water addition and baking time with the moisture content. The red part shows the highest moisture content (29.50%), and the blue part shows the lowest moisture content (19.89%). The highest moisture content was found in the muffins with 60% water addition and 20 minutes of baking time, and the lowest was found in the muffins with 30% water addition and 40 minutes of baking time.

A long baking time increases the evaporation of water from the material (41). The decrease in moisture content is possibly due to the evaporation of water from foodstuffs to the outside environment due to the heat difference between the material and the temperature in the oven. When heat is applied, the temperature of the food increases and the water in the food evaporates. The decrease in moisture content of baked goods such as muffins because the heat from the oven evaporates the water in the baked dough.

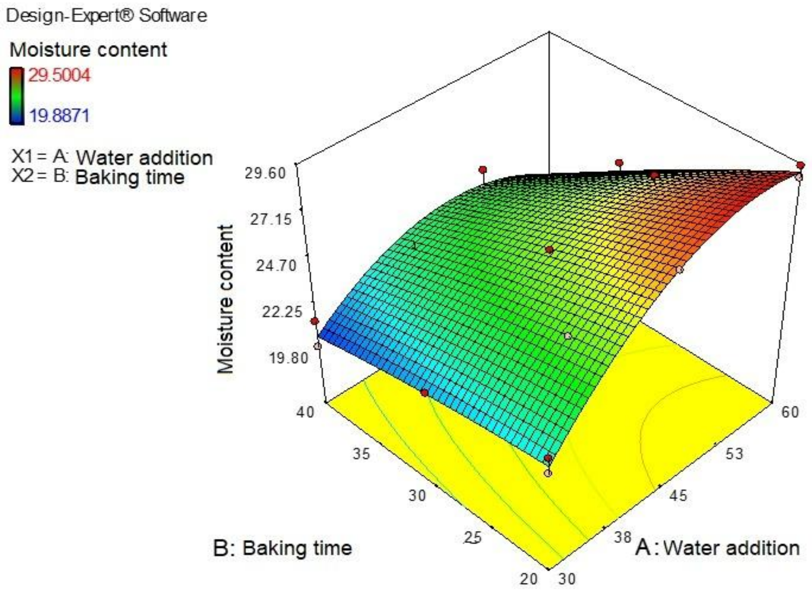

Figure 4. 3D surface graph of the relationship between the combination of factors water addition and baking time with moisture content.

A long baking time increases the heat received by the ingredients. Hence, the amount of water evaporating from the food increases, and the measured moisture content is low. The results of this study were in accordance with the research of Kawai et al. (42) and Ureta et al. (41), who stated that the moisture content of cookies and bread decreased with the increasing temperature and baking time. Ibrahim et al. (43) also reported that increasing baking time reduced the moisture content of bread with green coffee beans. This result was expected to be influenced by water diffusion, which drives water out of the product (44) and simulates water transfer during baking. High water diffusion rate indicates an easy transfer of water molecules and the formation of water vapor during baking. In addition to baking time, the moisture content in the dough also affects the moisture content of the baked product. If the amount of water in the food is high, then a large amount of energy is needed to evaporate some of the water from the food. When baked at the same temperature and time, a dough with high moisture content will produce a product with a higher moisture content compared with a dough with low moisture content.

3.3.3. Expansion Volume of Pumpkin Muffins

Expansion volume is an important parameter that affects the consumer acceptance of muffin products. Muffins with large expansion are preferred by consumers because they give the impression of a product that expands well because it has a hollow or porous structure. The measurement results of expansion volume were obtained by response analysis, which resulted in a quadratic model because its "prob>f" value (0.0005) was smaller than 0.05 (significant) and its lack of fit value (quadratic) was 0.8087 (not significant). The predicted R-squared and adjusted R-squared values for the response volume development were close to 1.0, namely, 0.6171 and 0.7951, respectively. The difference between the predicted R-squared and adjusted R-squared values was <0.2, and the adequation precision value met the requirement of >4, namely, 9.215. On the basis of these four criteria, the quadratic model qualifies as a good model and is expected to provide good predictions for the expansion volume response.

ANOVA results indicated a significant effect on the expansion volume for factors A (water addition) and A^2 (quadratic interaction between water addition) but not for factors B (baking time), AB (addition interaction water with baking time), and B^2 (quadratic interaction between baking time). According to the response equation (Table 7), the expansion volume increased with A and B as indicated by a positive coefficient value. However, the expansion volume decreased with the increase in AB, A^2, and B^2 as indicated by a negative coefficient.

The 3D surface graph (Figure 5) illustrates the relationship between the combination of adding water and baking time with the expansion volume. The red part of the graph shows the highest response volume expansion (189.04%), and the blue part shows the lowest response value (168.93%). The highest expansion volume was found in the muffins with 43% water addition and 29 minutes of baking time, and the lowest was found in the muffins with 30% water addition and 20 minutes of baking time. According to the 3D graph, the relationship of the combination of water addition and baking time with the expansion volume response was as follows: the addition of too low or too much water decreases the expansion volume. Hence, caution is needed in determining the amount of water added.

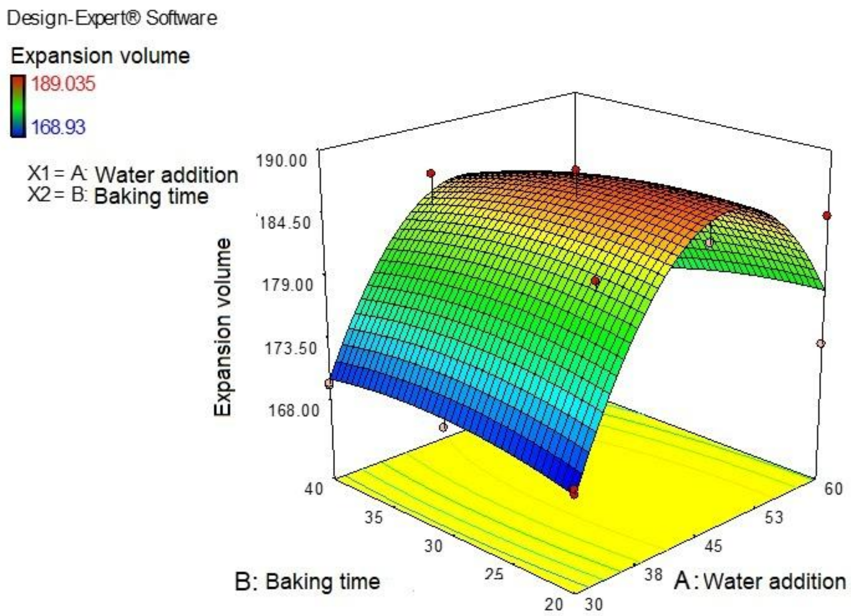

Figure 5. 3D surface graph of the relationship between the combination of water addition factors and baking time and expansion volume

The water in the dough affects the rheology of the dough and the quality of the final product (45). Under certain water levels, proteins glutenin and gliadin can form an elastic mass and expand to what is known as gluten. The elastic and expandable physical properties of gluten allow the dough to retain gas and the bread product to have a smooth and uniform hollow structure and a soft and elastic texture. In addition, water dissolves the ingredients and allows the starch to gelatinize during baking. When the dough is thick, starch hydration becomes difficult, and gelatinization is consequently hampered. The water in the dough diffuses into the starch granules and causes starch gelatinization by heating. The more water added to the dough, the more water will diffuse into the starch granules, causing the starch granules to irreversible swell and thereby increasing the starch gelatinization (46). Starch gelatinization causes starch swelling and gel formation, which, together with the coagulated gluten protein, form a matrix structure for the muffin network. The matrix network structure plays an important role in trapping air or gas during baking, which determines the expansion volume of muffins.

3.3.4. Crumb Hardness of Pumpkin Muffins

The model used to predict the response to force is a quadratic model because its “prob>f” (0.0018) was smaller than 0.05 (significant) and its lack of fit value (quadratic) was 0.2538 (not significant). The predicted R-squared and adjusted R-squared values for the response to violence were close to 1.0, namely, 0.5611 and 0.7294, respectively. The difference between the predicted R-squared and adjusted R-squared values was <0.2, indicating the absence of outlier data. The adequation precision value met the requirement of >4, namely, 8.866. On the basis of these four criteria, the quadratic model is a good model for the force response.

ANOVA results showed that factors A (water addition) and A^2 (quadratic interaction between water addition) have a significant effect on the hardness of pumpkin muffin crumbs. Meanwhile, factors B (baking time), AB (addition interaction water with baking time), and B^2 (quadratic interaction between baking time) had no significant effect on the hardness of pumpkin muffin crumbs. According to the hardness response equation (Table 7), an increase in the quadratic interaction between water addition and baking time also increased the hardness of pumpkin muffins as indicated by the positive coefficient. Meanwhile, an increase in water addition, baking time, and the interaction between these two decreased the hardness value as indicated by the negative coefficient.

The 3D surface graph (Figure 6) illustrates the relationship of the combination of adding water and baking time with the hardness response of pumpkin muffins. The red part of the graph shows the highest hardness response (5.19 N), and the blue part of the graph shows the lowest hardness response (2.73). The lowest hardness was found in the muffins produced with 43% water addition and 29 minutes of baking time, and the lowest was found in the muffins produced with 30% water addition and 40 minutes of baking time.

This finding was supported by several studies stating that the longer the baking time, the more water is evaporated. As a result, the moisture content of the product decreases. This observation was also in agreement with Dessev et al. (47), who reported that the longer the heating, the harder the texture of a product. Mudgil et al. (48) also stated that increasing the baking time decreased the moisture content and increased the hardness of cookies. When the baking time is long, the water in the dough greatly evaporates. The moisture content of the product decreases, causing its texture to harden. With a short baking time, a sufficient amount of moisture is left in the dough and causes the bread to remain soft (43).

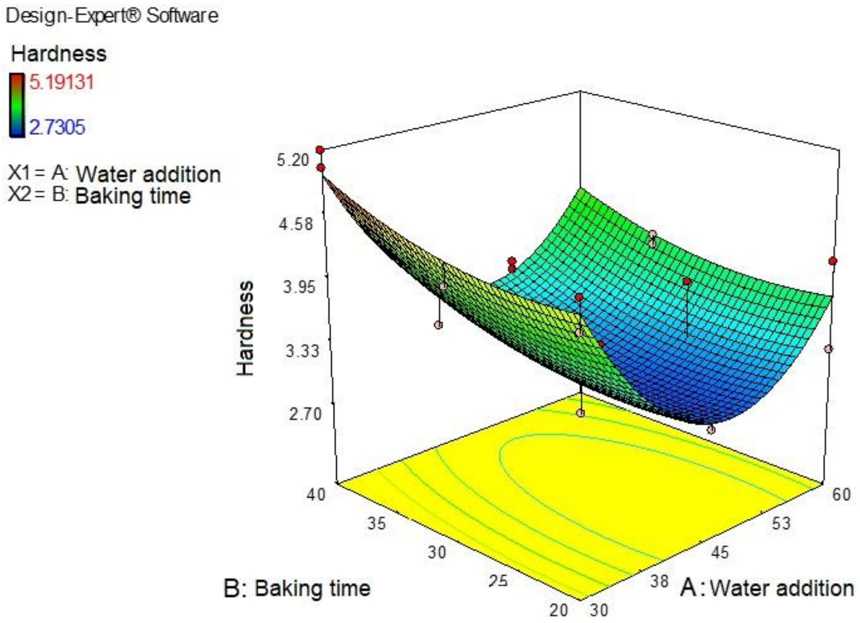

Figure 6. 3D surface graph of the relationship of the combination of water addition and baking time with hardness.

The hardness of pumpkin muffins can be related to the expansion volume. Muffins with a low expansion volume have a dense and hard crumb structure (11). Meanwhile, pumpkin muffins with a large volume expansion have a hollow and porous structure, so that the force required for the deformation decreases. Pumpkin muffins with the addition of too low or too much water have low volume expansion, so the resulting muffin structure is dense, compact, and rigid. As a result, the force required for the deformation increases. This finding indicated that pumpkin muffins with low expansion volume have a harder texture than those with large expansion volumes.

3.4. Process Optimization

After the response were analyzed, the next step was to optimize the process. This stage aimed to obtain the process conditions that could produce an optimal response of pumpkin muffins according to the desired optimization criteria. The resulting optimization target value is generally known as the desirability value, which is indicated by a value of 0–1. Optimal response was presented from the desirability value, which is close to 1. Each response in the optimization process was given importance with a value of 1 (+) to 5 (+++++) depending on the level of importance of the response. The greater the value of importance, the higher the level of importance of the response. The factors and response criteria used in determining the optimum process conditions for pumpkin muffins are presented in Table 8.

Table 8. Process criteria and responses to determine the optimum quality of pumpkin muffins.

Factor/response	Goal	Importance
Water addition (%)	In range	+++
Baking time (minutes)	In range	+++
Lightness (L*)	Maximum	+++
Hue (°h)	Maximum	+++
Moisture content (% wb)	In range	+++
Expansion volume (%)	Maximum	+++++
Hardness (N)	Minimum	+++++

Description: Wb=wet basis, N= Newton

Table 8 shows that for water addition and baking time, a range goal was given with importance of three (+++). For lightness and hue response criteria, a goal maximized with three importance (+++) was given because the pumpkin muffins are expected to have a high lightness level and an optimum level of sensory reception. Our previous research revealed that a decrease in lightness level reduced the panelists' sensory acceptance of color attributes (14). The moisture content response was given a goal range of 19.89%–29.50% with three importance (+++) because this range was within normal. Previous studies on muffins substituted with other high-fiber flours showed that the moisture content of the product was 20%–30%. The moisture content of muffins substituted with fiber-rich barnyard millet flour was 22.40% (49), that of muffins substituted with soy flour was 30.2% (50), and that of muffins substituted by spent espresso coffee as fiber source was 31.89%–32.25% (10).

The response to force was given a goal minimized with an importance of five (+++++) because it is expected that muffins prepared under optimum process conditions have a low level of hardness. The expansion volume response is given a goal maximized with five importance (+++++) because it is expected that muffins prepared under optimum process conditions exhibit a large expansion. Our previous research revealed that the main problems in upscaling the processing of pumpkin muffins in the laboratory were the low volume of expansion and high hardness values. Pumpkin muffins that are optimum have minimum hardness and maximum expansion volume, so these two parameters were considered important responses in muffins. On the basis of these criteria, the optimization results obtained were 48% water addition and 22 minutes of baking time with a desirability value of 0.884.

3.5. Result Verification

The verification stage aimed to compare the actual response value obtained from the experimental results with the response value predicted by the program. The data from the verification results of several tested responses (lightness, hue, moisture content, hardness, and expansion volume) were compared with the predicted values from the program as presented in Table 9.

Table 9. Comparison of actual response values with program prediction values.

Response	Prediction	Verification	95% CI *low*	95% CI *high*	95% PI *low*	95% PI *high*
Lightness (L*)	41.51	41.21	40.76	42.34	40.29	42.80
Hue (°h)	70.05	70.74	69.49	70.67	69.14	71.02
Moisture content (%wb)	28.5	27.96	27.91	29.36	27.12	30.15
Expansion volume (%)	187.62	185.39	183.58	191.44	179.31	195.71
Hardness (N)	2.96	2.91	2.53	3.41	2.06	3.89

Description: CI= Confidence Interval, PI= Prediction Interval, wb= wet basis, N=Newton.

Comparison showed that the experimental results in the laboratory were in accordance with the predicted values from the program. The verification results were still in CI or PI range. The prediction results from the program indicated that muffins prepared under optimum process conditions will have lightness value of 41.51, hue of 70.05, moisture content of 28.54%, expansion volume of 187.62%, and hardness of 2.96 N. Meanwhile, the verification results showed that the selected yellow pumpkin muffins had lightness value of 41.21, degree of hue (°h) of 70.74, moisture content of 27.96 %wb, expansion volume of 185.39%, and hardness of 2.91 N. The verification results were in accordance with the predictions made by the Design Expert 7.0® program. Therefore, the mathematical equation of each response is good enough to predict the value of the response in determining the optimum process.

3.6. Optimum Characteristics of Pumpkin Muffins

3.6.1. Optimum Chemical Characteristics and Dietary Fiber Content of Pumpkin Muffins

The optimum chemical characteristics of pumpkin muffins can be determined based on proximate analysis. Chemical analysis carried out on the optimum pumpkin muffins included the analysis of moisture content, ash content, fat, protein, and carbohydrates. Total dietary fiber analysis was carried out to determine the optimum total dietary fiber content of pumpkin muffins. The results of the proximate analysis and total dietary fiber content of pumpkin muffins are presented in

Table *10*.

Table 10. Results of proximate analysis and total dietary fiber content of optimum pumpkin muffins.

Parameter (%wb)	Measurement results
Moisture content	27.96±0.04
Ash content	2.23±0.02
Protein content	5.85±0.00
Fat content	18.59±0.02
Carbohydrate content	45.37+0.03
Total dietary fiber content	8.76±0.03

Description: %wb= percentage on wet basis.

Proximate analysis showed that pumpkin muffins prepared under optimum process conditions had a moisture content of 27.96 g/100g. The moisture content was classified as high because the amount of water added to the dough reached 48% of the total weight of flour (wheat and pumpkin flour). Analysis of the ash content of pumpkin muffins by the gravimetric method revealed a value of 2.23 g/100 g, which was still in range of 1.91%–2.41% for the pumpkin bread from Aljahani's study (51). Previous studies stated that pumpkin flour can increase the ash content of food products. Other researchers reported that the ash content of taro flakes increased with the proportion of pumpkin flour addition (52). Aljahani (51) showed that pumpkin flour can significantly increase the ash content of bread. The difference in value is influenced by differences in the components that make up the flour raw materials. According to Kaur et al. (7), the ash content of wheat flour is 0.38% and that of pumpkin flour is 6.78% (15).

The protein content of pumpkin muffins prepared under the optimal process conditions was 5.85 g/100 g. Aljahani (51) stated that the substitution of pumpkin flour reduced the protein content of donuts because the protein content of the former was lower than that of the latter. According to Kristiani et al. (15), the protein content of pumpkin flour is 9.36% and that of wheat flour is 11.47% (7). Proximate analysis showed that the fat content of pumpkin muffins was 18.59 g/100g. The high fat content is due to the addition of margarine, which comprises a large proportion in the formula at 66% of the total weight of flour. Carbohydrate content was measured by the by difference method, and the result was 45.37 g/100g. This value was due to the high carbohydrate content of pumpkin flour (79.18%). By contrast, the carbohydrate content of blue triangle flour listed on the packaging label is 71.82% (7).

Analysis of total dietary fiber showed that the pumpkin muffins prepared under the optimal process conditions had a high-fiber content of 8.76±0.03 g/100 g. BPOM (53) states that a food product is a source of dietary fiber when its fiber content is not less than 3 g/100 g and is high in fiber when its fiber content is not less than 6 g/100 g. Pumpkin muffins have a high dietary fiber content due to the high dietary fiber content of the pumpkin flour used as a raw material. According to Kristiani et al. (15), the total dietary fiber content of pumpkin flour ranged from 23.67% to 23.72%. Similar results were reported by Tamba et al. (54), who stated that the addition of pumpkin flour can increase the crude fiber content of donut products.

4. Conclusion

Process optimization was performed with a range of factors tested using the DX-7 program. The obtained optimum process conditions with the highest desirability value of 0.884 were as follows: 48% water addition and 22 minutes of baking time, which resulted in 41.21 lightness, 70.74 hue, 27.96% wb moisture content, 185.39% volume of expansion, and 2.91 N hardness. Verification carried out was in accordance with the predicted response issued by the program. Proximate analysis showed that the optimum ash, fat, protein, and carbohydrate contents of pumpkin muffins were 2.23% wb, 18.59% wb, 5.85% wb, and 45.37 % wb, respectively. The optimized pumpkin muffins were classified as high-fiber foods because they contained 8.76% dietary fiber. The results of this research provide new insights for researchers and bakery industries to improve the quality of muffins from local food sources.

Acknowledgements

The research team would like to thank to Prof. Dr. Muji Setiyo, S.T., M.T., Prof. Dr. Anuraga Jayanegara, S.Pt., M.Sc., and the Scientific Research Center, Institute for Research and Community Service (LPPM), Universitas Terbuka for the guidance and journal consignment facilities provided.

Author Contributions

R.R. conceptualized the idea, performed the experiments, and wrote this paper; E.S. revised the manuscript, B.N. designed the experiments and analyzed the data responses; N.T contributed to proofreading of this paper.

Funding

This research received no external fundings.

Institutional Review Board Statement

Not applicable.

Data Availability Statement

Available data are presented in the manuscript

Conflicts of Interest

Authors may declare no conflict of interest.

References

1. Wang H, Huang X, Tan H, Chen X, Chen C, Nie S. Interaction between dietary fiber and bifidobacteria in promoting intestinal health. Food Chem [Internet]. 2022;393:133407. Available from: https://www.sciencedirect.com/science/article/pii/S0308814622013693
2. Schroeder BO, Birchenough GMH, Ståhlman M, Arike L, Johansson MEV, Hansson GC, et al. Bifidobacteria or fiber protects against Diet-Induced Microbiota-Mediated Colonic Mucus Deterioration. Cell Host Microbe. 2018;23(1):27–40.e7.
3. McRae MP. Dietary Fiber Is Beneficial for the Prevention of Cardiovascular Disease: An Umbrella Review of Meta-analyses. J Chiropr Med. 2017 Dec;16(4):289–99.

4. He Y, Wang B, Wen L, Wang F, Yu H, Chen D, et al. Effects of dietary fiber on human health. Food Sci Hum Wellness [Internet]. 2022;11(1):1–10. Available from: https://www.sciencedirect.com/science/article/pii/S2213453021000677
5. Dahal C, Wawro N, Meisinger C, Brandl B, Skurk T, Volkert D, et al. Evaluation of the metabotype concept after intervention with oral glucose tolerance test and dietary fiber-enriched food: An enable study. Nutr Metab Cardiovasc Dis [Internet]. 2022; Available from: https://www.sciencedirect.com/science/article/pii/S0939475322002575
6. Hua M, Fan M, Li Z, Sha J, Li S, Sun Y. Ginseng soluble dietary fiber can regulate the intestinal flora structure, promote colon health, affect appetite and glucolipid metabolism in rats. J Funct Foods [Internet]. 2021;83:104534. Available from: https://www.sciencedirect.com/science/article/pii/S1756464621001833
7. Kaur A, Kaur R, Bhise S. Baking and sensory quality of germinated and ungerminated flaxseed muffins prepared from wheat flour and wheat atta. J Saudi Soc Agric Sci [Internet]. 2020;19(1):109–20. Available from: https://www.sciencedirect.com/science/article/pii/S1658077X18302017
8. Rodríguez R, Alvarez-Sabatel S, Ríos Y, Rioja P, Talens C. Effect of microwave technology and upcycled orange fibre on the quality of gluten-free muffins. LWT [Internet]. 2022;158:113148. Available from: https://www.sciencedirect.com/science/article/pii/S0023643822000834
9. Kaur A, Virdi AS, Singh N, Singh A, Kaler RSS. Effect of degree of milling and defatting on proximate composition, functional and texture characteristics of gluten-free muffin of bran of long-grain indica rice cultivars. Food Chem [Internet]. 2021;345:128861. Available from: https://www.sciencedirect.com/science/article/pii/S0308814620327230
10. Severini C, Caporizzi R, Fiore AG, Ricci I, Onur OM, Derossi A. Reuse of spent espresso coffee as sustainable source of fibre and antioxidants. A map on functional, microstructure and sensory effects of novel enriched muffins. LWT [Internet]. 2020;119:108877. Available from: https://www.sciencedirect.com/science/article/pii/S0023643819312198
11. Masmoudi M, Besbes S, Bouaziz MA, Khlifi M, Yahyaoui D, Attia H. Optimization of acorn (Quercus suber L.) muffin formulations: Effect of using hydrocolloids by a mixture design approach. Food Chem [Internet]. 2020;328:127082. Available from: https://www.sciencedirect.com/science/article/pii/S0308814620309444
12. Stewart M, Zimmer J. Post-prandial glucose and insulin response to high-fiber muffin top containing resistant starch type 4 in healthy adults: a double-blind, randomized, controlled trial. Nutrition. 2018 Feb 1;53.
13. Talens C, Álvarez-Sabatel S, Rios Y, Rodríguez R. Effect of a new microwave-dried orange fibre ingredient vs. a commercial citrus fibre on texture and sensory properties of gluten-free muffins. Innov Food Sci Emerg Technol [Internet]. 2017;44:83–8. Available from: https://www.sciencedirect.com/science/article/pii/S1466856416305562
14. Rismaya R, Syamsir E, Nurtama B. Pengaruh Penambahan Tepung Labu Kuning Terhadap Serat Pangan, Karakteristik Fisikokimia dan Sensori Muffin. J Teknol dan Ind Pertan. 2018 Jun 1;29:58–68.
15. Kristiani Y, Rismaya R, Syamsir E, Faridah DN. Pengaruh suhu perendaman dengan

larutan Natrium Metabisulfit terhadap karakteristik fisikokimia tepung labu kuning (Cucurbita moschata D.). J Food Sci Technol. 2022;2(1):1–19.

16. Struck S, Gundel L, Zahn S, Rohm H. Fiber enriched reduced sugar muffins made from iso-viscous batters. LWT - Food Sci Technol [Internet]. 2016;65:32–8. Available from: https://www.sciencedirect.com/science/article/pii/S0023643815300700
17. Rathnayake HA, Navaratne SB, Navaratne CM. Porous Crumb Structure of Leavened Baked Products. Ibrahim SA, editor. Int J Food Sci [Internet]. Hindawi; 2018;2018:8187318. Available from: https://doi.org/10.1155/2018/8187318
18. Zhou Y, Dhital S, Zhao C, Ye F, Chen J, Zhao G. Dietary fiber-gluten protein interaction in wheat flour dough: Analysis, consequences and proposed mechanisms. Food Hydrocoll [Internet]. 2021;111:106203. Available from: https://www.sciencedirect.com/science/article/pii/S0268005X20310754
19. Oyet GI, Chibor BS. Amino Acid Profile, Mineral Bioavailability, and Sensory Properties of Biscuits Produced from Composite Blends of Wheat, Coconut and Defatted Fluted Pumpkin Seed Flour. Eur J Agric Food Sci. 2020;2(6):1–7.
20. Rauf R, Sarbini D. Daya serap air sebagai acuan untuk menentukan volume air dalam pembuataan adonan roti dari campuran tepung terigu dan tepung singkong. J Agritech. 2015;35(3):324–30.
21. Purnomo EH, Azis BS, Denny SA, Purwiyatno H, Hartono S. Formulation and Process Optimization of Muffin Produced From Composite Flour of Corn, Wheat and Sweet Potato. J Teknol dan Ind Pangan. 2012;23(2):165–72.
22. Matos ME, Sanz T, Rosell CM. Establishing the function of proteins on the rheological and quality properties of rice based gluten free muffins. Food Hydrocoll [Internet]. 2014;35:150–8. Available from: https://www.sciencedirect.com/science/article/pii/S0268005X13001434
23. Loppies CRM, Apituley DAN, Sormin RBD, Setha B. Kandungan mioglobin ikan tuna (Thunnus albacares) dengan pemakaian karbon monoksida dan filter smoke selama penyimpanan beku. Ina J Teknol Has Perikan. 2021;1(1):12–20.
24. Krisnawati R, Indrawati V. Pengaruh subtitusi puree ubi jalar ungu (Ipomea batatas) terhadap mutu organoleptik roti tawar. J Boga. 2014;3(1):79–88.
25. R. Feili, W. Zzaman, W.N.W. Abdullah AYT. Physical and Sensory Analysis of High Fiber Bread Incorporated with Jackfruit Rind Flour. Food Sci Technol. 2013;1(2):30–6.
26. AOAC. Official methods of analysis. Washington, DC: Association of Official Analytical Chemists Washington, DC; 2005.
27. Asp N-G, Schweizer TF, Southgate DAT, Theander O. Dietary fibre analysis. Dietary Fibre—A Component of Food. Springer; 1992. p. 57–101.
28. Vachlepi A, Purbaya M. Perbandingan Cara Pengeringan Menggunakan Oven Laboratorium Dan Alat Pengering Skala Pabrik Terhadap Kadar Karet Kering (Kkk). J Stand. 2018;19(3):265.
29. Hussain SZ, Beigh MA, Qadri T, Naseer B, Zargar I. Development of low glycemic index muffins using water chestnut and barley flour. J Food Process Preserv. 2019;43(8):1–9.
30. Acosta K, Cavender G, Kerr WL. Sensory and physical properties of muffins made with waxy whole wheat flour. J Food Qual. 2011;34(5):343–51.
31. Schopf M, Scherf KA. Water absorption capacity determines the functionality of vital gluten related to specific bread volume. Foods. 2021;10(2):0–12.
32. Li M, Yue Q, Liu C, Zheng X, Hong J, Wang N, et al. Interaction between gliadin/glutenin

and starch granules in dough during mixing. Lwt [Internet]. Elsevier Ltd; 2021;148(March):111624. Available from: https://doi.org/10.1016/j.lwt.2021.111624

33. Hartanto R, Fitri SRF, Kawiji K, Prabawa S, Sigit B, Yudhistira B. Analisis Fisik, Kimia, dan Sensoris Teh Bunga Krisan Putih (Chrysanthemum morifolium Ramat.) dengan Pengeringan Kabinet. J Teknol Ind Pertan. 2021;15(4):1011–25.
34. Martunis. Pengaruh Suhu dan Lama Pengeringan terhadap Kuantitas dan Kualitas Pati Kentang Varietas. J Teknol dan Ind Pertan Indones. 2012;4(3):26–30.
35. Trilaksani W, Erungan AC, Mardi S. Pengaruh Suhu dan Lama Pengovenan terhadap Karakteristik Cumi-Cumi (Loligo sp) Kertas. J Pengolah Has Perikan Indones. 2004;7(2):19–29.
36. Sarastuti M, Yuwono SS. The Effect Of Oven And Heating Time On Rujak Cingur Instant Seasoning's Characteristics During Storage. J Pangan dan Agroindustri. 2015;3(2):464–75.
37. Ahrné L, Andersson C-G, Floberg P, Rosén J, Lingnert H. Effect of crust temperature and water content on acrylamide formation during baking of white bread: Steam and falling temperature baking. LWT - Food Sci Technol [Internet]. 2007;40(10):1708–15. Available from: https://www.sciencedirect.com/science/article/pii/S002364380700028X
38. Provost J. The Maillard Reaction. Food Aroma Evolution. CRC Press; 2019. p. 281–91.
39. Laguna L, Salvador A, Sanz T, Fiszman SM. Performance of a resistant starch rich ingredient in the baking and eating quality of short-dough biscuits. LWT - Food Sci Technol [Internet]. 2011;44(3):737–46. Available from: https://www.sciencedirect.com/science/article/pii/S0023643810002008
40. Kusnandar F. Kimia pangan komponen makro. Bumi aksara; 2019.
41. Ureta MM, Diascorn Y, Cambert M, Flick D, Salvadori VO, Lucas T. Water transport during bread baking: Impact of the baking temperature and the baking time. Food Sci Technol Int. 2019;25(3):187–97.
42. Kawai K, Hando K, Thuwapanichayanan R, Hagura Y. Effect of stepwise baking on the structure, browning, texture, and in vitro starch digestibility of cookie. LWT - Food Sci Technol [Internet]. 2016;66:384–9. Available from: https://www.sciencedirect.com/science/article/pii/S0023643815302863
43. Ibrahim UK, Rahman NAA, Suzihaque MUH, Hashib SA, Aziz RAA. Effect of baking conditions on the physical properties of bread incorporated with green coffee beans (GCB). IOP Conf Ser Mater Sci Eng. 2020;736(6).
44. Emerald FME, Pushpadass HA, Manjunatha M, Manimala K, Dejey D, Salish K, et al. Modelling approaches for predicting moisture transfer during baking of chhana podo (milk cake) incorporated with tikhur (Curcuma angustifolia) starch. J Food Meas Charact [Internet]. Springer US; 2020;14(6):2981–97. Available from: https://doi.org/10.1007/s11694-020-00543-9
45. Cappelli A, Bettaccini L, Cini E. The kneading process: A systematic review of the effects on dough rheology and resulting bread characteristics, including improvement strategies. Trends Food Sci Technol [Internet]. 2020;104:91–101. Available from: https://www.sciencedirect.com/science/article/pii/S0924224420305665
46. Muhandri T, Subarna. Pengaruh Kadar Air, NaCl dan Jumlah Passing terhadap Karakteristik Reologi Mi Jagung. J Teknol dan Ind Pangan. 2009;20(1):71–7.
47. Dessev T, Lalanne V, Keramat J, Jury V, Prost C, Le-Bail A. Influence of baking

conditions on bread characteristics and acrylamide concentration. J food Sci Nutr Res. Fortune Journals; 2020;3(4):291–310.

48. Mudgil D, Barak S, Khatkar BS. Cookie texture, spread ratio and sensory acceptability of cookies as a function of soluble dietary fiber, baking time and different water levels. LWT [Internet]. 2017;80:537–42. Available from: https://www.sciencedirect.com/science/article/pii/S0023643817301548
49. Goswami D, Gupta RK, Mridula D, Sharma M, Tyagi SK. Barnyard millet based muffins: Physical, textural and sensory properties. LWT - Food Sci Technol [Internet]. 2015;64(1):374–80. Available from: https://www.sciencedirect.com/science/article/pii/S0023643815004235
50. Padhi EMT, Dan Ramdath D, Carson SJ, Hawke A, Blewett HJ, Wolever TMS, et al. Liking of soy flour muffins over time and the impact of a health claim on willingness to consume. Food Res Int [Internet]. 2015;77:491–7. Available from: https://www.sciencedirect.com/science/article/pii/S0963996915301800
51. Aljahani AH. Wheat-yellow pumpkin composite flour: Physico-functional, rheological, antioxidant potential and quality properties of pan and flat bread. Saudi J Biol Sci [Internet]. The Author; 2022;29(5):3432–9. Available from: https://doi.org/10.1016/j.sjbs.2022.02.040
52. Purnamasari IW, Dwi W, Putri R. Effect of pumpkin flour and addition of Sodium Bicarbonate on taro flakes characteristics. J Pangan dan Agroindustri. 2015;3(4):1375–85.
53. BPOM. Peraturan Kepala Badan Pengawas Obat Dan Makanan Republik Indonesia Nomor 13 Tahun 2016 Tentang Pengawasan Klaim Pada Label Dan Iklan Pangan Olahan. Bpom. 2016;1–16.
54. Tamba M, Ginting S, Limbong LN. Pengaruh Substitusi Tepung Labu Kuning Pada Tepung Terigu Dan Konsentrasi Ragi Pada Pembuatan Donat. Rekayasa Pangan dan Pertan. 2014;2(2):117–23.