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Original Article

Qualitative properties and retrogradation of buckwheat (*Fagopyrum esculentum* Moench) vegetable Jeolpyeon during storage

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Summary. Jeolpyeon is a type of Korean rice cake with health benefits, and buckwheat is a vegetable with multiple functional properties. The purpose of this study was to investigate the quality characteristics and retrogradation of Jeolpyeon made with buckwheat vegetable powder (BVP). The Jeolpyeon containing 2% BVP showed the best sensory properties such as taste, flavor, and overall preference. Treatments with added BVP had higher moisture content than that of the control group. Hardness, fracturability, and chewiness of all samples increased during the storage period. Generally, the greater the addition of BVP, the lower the increased rate of hardness. The 2% sample showed the slowest retrogradation as obtained by measurements using the Avrami equation. Thus, adding 2% buckwheat vegetable powder is recommended for desirable characteristics when preparing buckwheat vegetable Jeolpyeon.

Key words: Buckwheat (*Fagopyrum esculentum* Moench), rice cake, Jeolpyeon, Retrogradation, Sensory evaluation

«Proprietà qualitative e retrogradazione di Jeolpyeon di grano saraceno (Fagopyrum esculentum Moench) nel corso della sua conservazione.»

Riassunto. Il Jeolpyeon è un tipo di torta di riso coreana con benefici per la salute e il grano saraceno è un vegetale con varie proprietà funzionali. Lo scopo di questo studio è stato quello di indagare le caratteristiche di qualità e retrogradazione di Jeolpyeon prodotta con grano saraceno in polvere (BVP). Il Jeolpyeon contenente il 2% di BVP ha mostrato le migliori proprietà sensoriali come gusto, sapore e preferenza generale. Trattamenti con aggiunta di BVP avevano un contenuto di umidità superiore a quella del gruppo di controllo. Durezza, friabilità e masticabilità di tutti i campioni sono aumentate durante il periodo di conservazione. In generale, maggiore è l'aggiunta di BVP, minore è il tasso di aumento della durezza. Il campione al 2% ha mostrato la retrogradazione più lenta come ottenuta da misure che utilizzano l'equazione di Avrami. Perciò, preparando Jeolpyeon di grano saraceno, è raccomandata per le caratteristiche desiderabili l'aggiunta di un 2% di polvere di grano saraceno.

Parole chiave: Grano saraceno (*Fagopyrum esculentum* Moench), torta di riso, Jeolpyeon, retrogradazione, valutazione sensoriale

Introduction

Rice cakes are a unique Korean grain food consumed at holidays, rituals, and other traditional events. Jeolpyeon, as a type of rice cake, is made by the following process. The cereal hulls are removed and then the rice is ground to particles or powder. After steaming in a steamer, the rice is hit on a pounding board or mortar. Some earlier studies have examined the characteristics of the quality and function of Jeolpyeon according to supplements with *Lycil fructus* powder (1), green tea powder (2), and mulberry fruit powder (3).

Buckwheat (*Fagopyrum esculentum* Moench) refers to a variety of annual plants in the dicotyledon family Polygonacea (4). Buckwheat generally contains 12–14% protein, which is considerably higher than other cereals, 2–3% fat, and 60–70% carbohydrate. It also has high amounts of essential amino acids and minerals such as Zn, Mg, Mn, Cu, and Fe.

Buckwheat has been gaining people's attention as a new functional health food, because it contains certain physiologically active substances such as quercetin, quercitrin, myricetin, and rutin (5), Rutin, as a glucoside of flavonoids, is known as vitamin P, and has positive effects on blood vascular diseases. In general, buckwheat flowers contain the greatest amount of total rutin, followed by the leaves, stalks, stems, and roots (6,7).

Currently, there has been more emphasis on health foods than at any other time. Rice cakes, which have mainly been used for traditional ceremonies, are gradually expanding as a snack in daily life or a substitute for breakfast. Nonglutinous rice, the main ingredient of Jeolpyeon, contains amylose, the linear fraction of starch characterized by 1,4-α-glucosidic linkages, which tend to retrograde easily. The large polymer of D-glucose is slightly soluble, a characteristic of importance in starch cookery (8). Obviously, retrogradation is undesirable and reduces the quality of the food in which it occurs. Therefore, the purpose of this study was to develop an optimal mixing proportion to improve the storage and retorgradation conditions of Jeolpyeon.

Materials and Methods

Materials

Gyunggi-Gangwha white rice was used as the main ingredient to make the Jeolpyeon, which was cultivated in 2010. To prepare the buckwheat vegetable powder(BVP), buckwheat was purchased in Gapyung, Gyunggi, and its leaves and stems were cut to 10 cm in size, freeze-dried, ground, and passed through a 60 mesh sieve. Refined salt from Han-Ju Corp. and refined sugar from CJ Cheil-Jedang Corp. (Incheon, Korea) were also used.

Preparation of Jeolpyeon

The rice was washed three times with water at 20°C. After soaking in water for 24 h, it was dried for 30 min in a sieve. The rice was then ground twice and strained through a 20 mesh sieve. The mixture ratios are presented in Table 1. BVP was added to the rice flour at ratios of 0, 1, 2, 3, and 4%. Each sample was mixed with water and then poured into a steamer (25 × 25 × 10 cm). The rice was steamed for 3 min with a whisk (Zojirushi, Seoul, Korea) and cooled for 20 min. Afterwards, the sample weighing approximately 8g, was put into a Jeolpyeon frame (3 × 2 × 1 cm). To determine the retrogradation process and the material characteristics of the Jeolpyeon according to different storage times, each of the pieces was sealed and kept at 20°C and was examined for changes in characteristics at 24, 48, and 72 h.

Table 1. Formulas for buckwheat vegetable Jeolpyeon samples.

	Ingredients		
BVP (g/100g)	Rice flour (g)	BVP (g)	Water (g)
0 g/100 g	500	0	155
1 g/100 g	495	5	155
2 g/100 g	490	10	155
3 g/100 g	485	15	155
4 g/100 g	480	20	155

BVP: Buckwheat Vegetable Powder

Proximate analysis

The moisture, crude lipid, and crude ash contents of the Jeolpyoen were analyzed by AOAC methods (9), including the 105°C dry-oven method, the Kjeldahl method, Soxhlet extraction, and dry ashing, respectively. The carbohydrate content(%) was obtained from the difference in the weights of the raw materials and was calculated by subtracting the total amount of sample.

Sensory evaluation

Twenty-two specially trained panelists were selected. The panelists were told to taste five different samples and then rinse their mouths between samples. This process was repeated with 1–2 min intervals. The panelists evaluated the sensory properties of flavor, moistness, softness, and overall quality based on a seven-point scale.

Jeolpyeon color measurements during storage

Surface color was determined using a chroma meter (Minolta, Osaka, Japan). The chroma meter was calibrated on the Hunter L, a, and b color space system using a white tile (L:97.43, a:-0.01, b:+0.02) three times repeatedly.

Determination of moisture content

The moisture content of the Jeolpyeon samples was measured using a halogen moisture analyzer (Ohaus, Zurich, Switzerland). One gram of Jeolpyeon cut into thin slices was placed in an aluminum dish at 105°C and weighed continuously until a constant weight was obtained.

pH determination

The Jeolpyeon was sealed and stored in an incubator at a temperature of 20 ± 2°C with 60% humidity. A sample was collected on a regular basis from 0–72 h. Ten grams of each sample were combined with 100 ml of distilled water and stirred for 30 min at room temperature. For another 30 min, the samples were centrifuged at 3,000 rpm (Hettich, Tuttlingen, Germany). The pH was measured with a pH meter (Suntex, Taipei, Taiwan) three times.

Texture analysis of Jeolpyeon during storage

The texture values of the buckwheat vegetable Jeolpyeon were measured six times using a rheometer (Sun Scientific Co., Tokyo, Japan). Two-bite compression followed afterwards. The texture analyzer settings were as follows: probe diameter, 20 mm; table speed, 20 mm/min; compression, 30%; load cell force, 10 kg. The specimens were cut into a fixed size (3 × 3 × 2 cm). Peak height was determined as the hardness, adhesiveness, cohesiveness, chewiness, fracturability, and springiness.

Characteristics of retrogradation by the Avrami equation

The retrogradation rate was analyzed by the following Avrami equation.

$$\theta = \exp(-kt^n)$$

θ: Amorphism part at time (t)

k: Rate constant

n: Avrami exponent

If the change in hardness of a Jeolpyeon product is a criterion to measure the level of crystallization, it can be measured as follows.

$$\theta = (EL - ET) / (EL - EO) = \exp(-kt^n)$$

EO: Hardness at time 0

ET: Hardness at time (t)

EL: Maximum hardness

Where ET and EO are the elastic modulus at times t and zero, respectively, and EL is the limiting modulus after a theoretically infinite time.

Thus: $\log [-\ln(EL - ET) / (EL - EO)] = \log k + n \log t$ì

The Avrami exponent n is calculated from a graph of log[-ln {(EL- ET)/(EL - EO)}] regarding *log* t. The rate constant *K* is calculated from a graph of ln(EL- ET) regarding time, and its inverse number *1/K* is displayed as the time constant. In this test, E_L is the hardness value of a sample preserved for 192 h at 20°C, and it was measured with a rheometer.

Statistical analysis

The results were analyzed using SPSS version 12.0 (SPSS, Chicago, IL, USA), and the data are expressed as means ± SDs. Treatment differences were analyzed by a one-way analysis of variance with Duncan's multiple comparison test ($p < 0.05$).

Results and discussion

Proximate composition of the buckwheat vegetable powder

Chemical analysis of BVP showed 93% moisture, 2.2% crude protein, 1% crude fat, 2% crude ash, and 0.9% crude fibre. Carbohydrate content was 0.9% without crude fibre. On an average, buckwheat is composed of 13% protein, 2% lipids, and 65~70% carbohydrates; is high in calories; and contains numerous water-soluble proteins and thiamine, and therefore is of high biochemical and nutritional value. Specifically, buckwheat contains a high percentage of lysine among the amino acids (10, 11), and buckwheat can supplement the amino acids not present in rice flour during the manufacture of buckwheat vegetable powder Jeolpyeon. In addition, in a study on factors that influence the breakdown of rice cake, Park (12) reported that with higher protein content, the hydrogen bonds between the powder particles increase, and therefore, retrogradation of rice cake can be delayed. On the basis of these assumptions, when BVP with high protein content is added to rice cakes, degradation can be delayed. In addition, as the flower, leaf, stem, and grain have the highest dietary fibre content at 74.1%, adding BVP can increase the current quality of Jeolpyeon.

Sensory evaluation

The sensory test results of the Jeolpyeon samples with added BVP are shown in Figure 1. The control group recorded the highest color score. As increasing amounts of BVP were added, the color of the Jeolpyeon darkened. This is similar to the results found in study by Chae and Hong (13). No significant differences were observed for flavor between the samples, but the samples with added BVP tended to receive higher scores than those in the control group. Taste scores were highest for the sample with 2% added BVP, whereas they were lowest for the sample with 4% added BVP ($p < 0.05$). The sample with 4% added BVP also had the lowest chewiness score, and scores increased in the order of 3, 0, 2, and 1% added BVP. The Jeolpyeon samples with the least amount of added BVP were the most palatable in terms of taste, which is similar to the results of a study conducted by Paik et al. (14). Taken together, the sample with 2% added BVP had the highest overall sensory scores.

Color measurements of buckwheat vegetable Jeolpyeon during storage

The colour measurements during storage of the Jeolpyeon samples with BVP are shown in Table 2. The L-values gradually decreased during the storage period, but no significant differences were observed among the treatments. No significant differences were observed in the a-values among the treatments during the storage period, whereas b-values decreased significantly as the storage time increased. These results are similar to the results of a study by Yoon and Lee (15). In this study, increasing the amount of BVP in Jeolpyeon led to a decrease in brightness and an increase in redness. This increase in redness can be attributed to browning reactions between sugars and amino acids, which occur because of the heat applied during the process of Jeolpyeon production. With increasing storage time, the brightness generally decreased and the a-value tended to change; the changes were larger in the BVP-added group than in the control group. This is thought to be because of the phenolic compounds contained in the BVP and oxidizing in air with time, leading to a brown colour change. In addition, buckwheat contains many enzymes such as amylases, proteases, and lipoxygenases (16), and lipoxygenases in particular have been reported to be the main factors involved in the brown colour change and content changes during the storage of buckwheat. In baking and making pastries, if flour other than wheat flour is added, the type and colour of the flours added, the aminocarbonyl reaction during baking, and the degree of brown colour change from heat degradation are thought to be the main factors that influence the finished cake, and

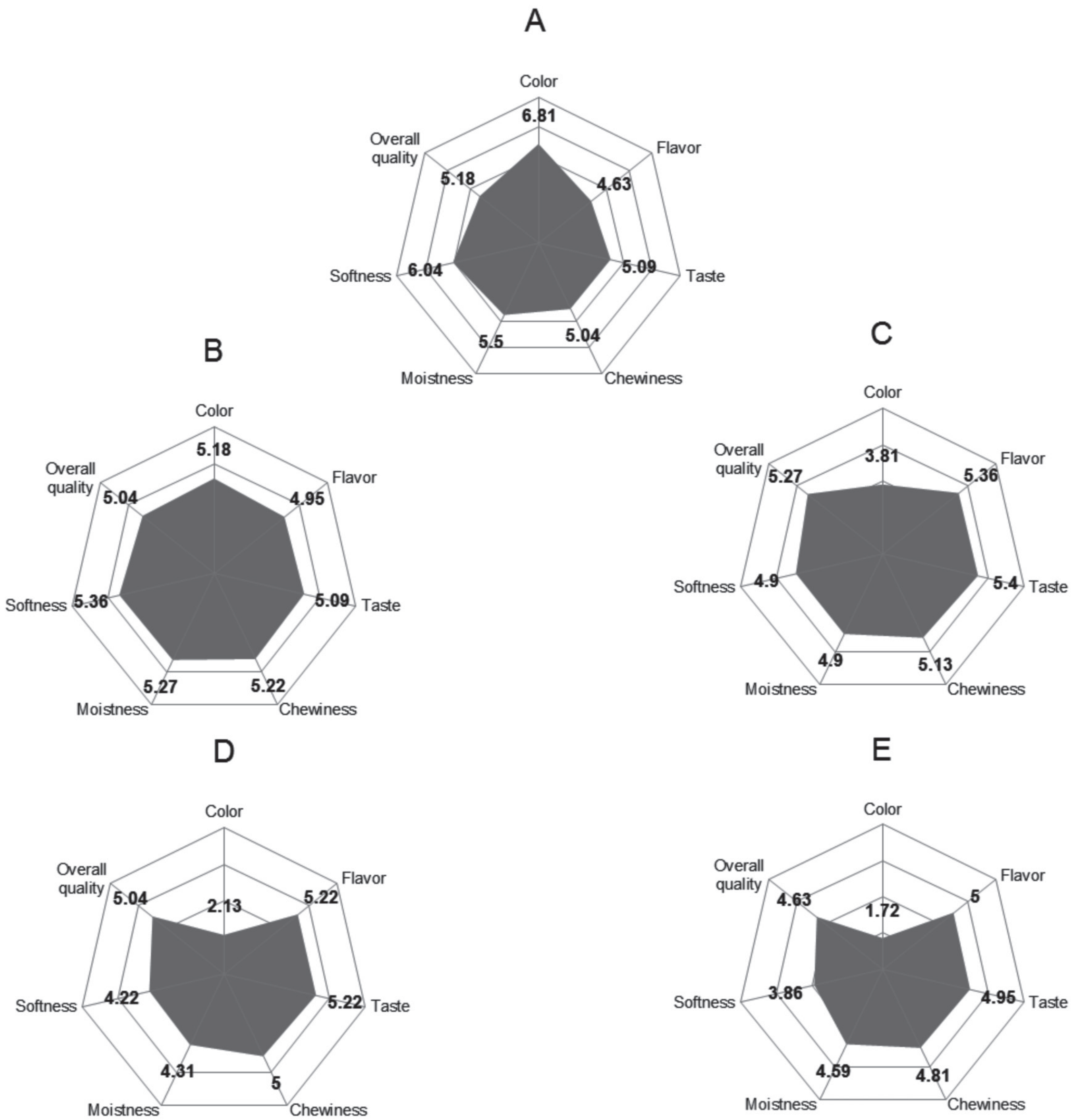

Figure 1. Sensory preference scores for Jeolpyeon with added buckwheat vegetable powder (BVP).
A: Control (without added BVP); B: 1 g/100 g added BVP; C: 2 g/100 g added BVP; D: 3 g/100 g added BVP; E: 4 g/100 g added BVP

this can be extended to cakes baked with rice flour with other powder additives (17).

Moisture content of buckwheat vegetable Jeolpyeon

The moisture content results of the Jeolpyeon samples are shown in Figure 2. During the storage period, the treatments with added BVP had higher moisture content than the control group. The moisture content of all the samples decreased sharply at 24 h of storage. At 48 and 72 h of storage, the 4% buckwheat Jeolpyeon group had the highest moisture content than the other treatments. This is similar to the results found in study by Chae and Hong (13), in which Jeolpyeon with additions of other elements had higher moisture content than the control group. As moisture content increases, retrogradation is delayed, and increasing the initial moisture content of Jeolpyeon because of the addition of BVP would delay

Table 2. Changes in Hunter's color values and pH in buckwheat vegetable Jeolpyeon during storage at 20°C.

Hunter's color value	Storage time (h)	Ratio of addition (%)				
		0	1	2	3	4
L	0	73.10±4.24NS	58.01±1.26a	48.72±0.67a	43.95±0.83a	40.49±0.89a
	24	73.81±2.07	55.10±1.19b	46.99±1.00b	39.89±0.76c	39.22±1.13ab
	48	72.44±1.5	55.45±0.86b	47.72±0.39ab	41.60±0.22b	38.23±0.57b
	72	72.50±0.41	55.79±0.94b	46.57±0.98b	41.07±0.41b	37.56±0.81b
a	0	-2.01±0.80a	-3.82±0.06b	-2.94±0.09b	-0.67±0.22NS	-0.53±0.08a
	24	-2.26±0.09b	-3.68±0.02a	-2.74±0.02a	-0.81±0.02	-0.57±0.03ab
	48	-2.27±0.06b	-3.63±0.03a	-2.73±0.05a	-0.27±0.05	-0.69±0.07b
	72	2.15±0.08ab	-3.57±0.10a	-2.74±0.10a	-0.92±0.13	-0.85±0.07c
b	0	3.13±1.10NS	18.90±0.58a	19.35±0.59 NS	18.51±0.38a	16.68±1.06a
	24	2.09±0.16	17.89±0.41b	18.95±0.34	16.09±0.23b	16.27±0.85a
	48	2.31±0.11	17.78±0.51b	18.44±0.04	16.93±0.76b	15.89±0.44ab
	72	2.73±0.13	17.37±0.33b	18.84±0.65	16.34±1.29b	14.69±0.33b
pH	0	6.56±0.02d	6.61±0.01c	6.65±0.02b	6.70±0.02a	6.71±0.02a
	24	6.38±0.04c	6.50±0.08b	6.67±0.06a	6.72±0.04a	6.72±0.07a
	48	5.89±0.04b	5.96±0.02b	6.28±0.11a	6.32±0.11a	6.38±0.14a
	72	5.23±0.04d	5.35±0.05c	5.74±0.00b	6.03±0.07a	6.08±0.06a

L-value is degree of whiteness (white + 100 ↔ 0 blank),
a-value is degree of redness (red + 100 ↔ 80 green),
b-value is degree of yellowness (yellow + 70 ↔ 80 blue),
Different lower case letters correspond to significant differences at p < 0.05.
Data are expressed as means ± standard deviations of three experiments.
NS: not significant; Means with different superscripts along horizontal line are significantly different by Duncan's multiple range test at P < 0.05.

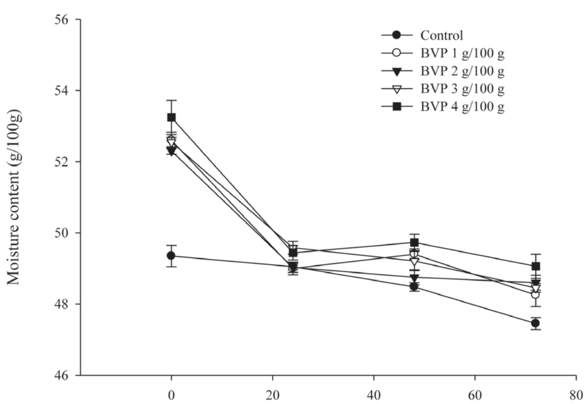

Figure 2. Moisture content of Jeolpyeon with different percentages of buckwheat vegetable powder during storage at 20°C.
*Different lower case letter correspond to significant differences at p<0.05

its degradation. It is commonly known that when fibre is added, water absorption increases, and therefore water retention increases, leading to delayed retrogradation of bread or cakes (18, 19). It is widely known that adding fibre increases moisture absorption and water retention in foods, and thus, assists in the delay of a food's retrogradation. Consistent with the results of a previous study showing that adding bamboo leaf flour delays the degradation of yellow layer cake, we believe that the increase in moisture absorption can be attributed to the dietary fibre present in BVP, and this can have an effect in delaying retrogradation (20).

Determination of pH

pH was measured at the time of Jeolpyeon production and then at 24, 48, and 72 h (Table 2). The pH of all the samples decreased as the storage period increased. In addition, the pH increased with higher BVP content, and this is consistent with the results of study by Kim and Kwak, in which the pH values of rice cakes with added yam flour (21) increased as the level of added flour increased. Rice flour normally degrades faster at lower pH. Roh et al. (22) reported in a study of the storage of rice cooked with green tea extracts that pH decreased with longer storage time. After 3 days of storage, the non-added group had a pH of 5.3 and the green tea extracted group had a pH of 5.8, indicating that the pH of decomposing cooked rice is 5.3~5.8. In this study, after 3 days of storage, the pH of the non-added group was 5.23 and that of the 4% added group was 6.08, indicating a result similar to the decomposition of rice cake. The pH change during storage was smaller with higher BVP addition, and this is believed to be attributable to the quercetin in BVP that decreases pH changes and moisture loss, leading to a stable pH. Quercetin, a polyphenolic compound, has various functions, including scavenging free radicals and preventing lipid oxidation (23, 24). Kremer et al. (25) reported that when quercetin was added 4 h before the shipment of pork, the decrease in pH after slaughtering was delayed significantly and moisture loss was prevented. Jang et al. (26) reported that quercetin delays the deterioration of proteins, indicating that the stabilizing effect of BVP on the pH of Jeolpyeon can lead to a delay in retrogradation and extension of storage time.

Texture analysis of buckwheat vegetable Jeolpyeon during storage

The texture analysis results during storage of the Jeolpyeon with added BVP are shown in Figure 3. Hardness, fracturability, and chewiness of all the samples increased as storage time increased, particularly at 72 h of storage. Generally, greater the added BVP, lower the increased rate of hardness. This is because dietary fibre content and moisture content increased as more BVP was added, which is supported by the result of the study by Ktari et al. (27) and Handa el al. (28). In a study by Lee and Koo (29), the hardness of Jeolpyeon with added pectin and cellulose was lower than the control group, and Choi and Kim (30) reported that rice cake with added dietary fibres had a significantly higher degree of gelatinsation and had a retrogradation-delaying effect. In addition, similar to the case with addition to rice flour, when rice bran fibre was added to wheat flour and DSC was measured, retrogradation was reported to have been delayed, indicating that dietary fibre is an important factor in delaying retrogradation (19). Therefore, the decrease in the hardness of BVP in this study is believed to be attributable to the moisture and fibre of BVP intercalating with starch particles of Jeolpyeon to make the arrangement of starch irregular and, in combination with amylose, preventing the re-formation of hydrogen bonds between gelatinized starch molecules. The quality of rice cake depends on the compatibility of the main and additional ingredients, balance of the mixture ratio, method of mixing and proper baking techniques, and additional ingredients. The density of the rice cake dough is the main quality assessment factor for the degree of expansion in the rice cake, and with higher density, the rice cake is more likely to crumble, influencing fracturability (31). According to Choi et al. (32), if perilla seeds are added to the rice cookie dough, density increases, and in this experiment, we observed that with increasing amount of BVP added, fracturability increased. We believe that this is attributable to the interaction between the dietary fibres and the protein. Adhesiveness was represented by the adherence of the Jeolpyeon to the probe and the stage after the first compression. Adhesiveness is the negative force area between the first and second bite, and in terms of the Jeolpyeon, adhesiveness was expressed as a negative with increasing levels of BVP. If other ingredients are added to rice flour that has high adhesiveness, the dietary fibre of the additional ingredients is thought to lead to lower adhesiveness. This data is similar to the results of the study by Lu et al. (33).

Characteristics of retrogradation by the Avrami equation

The retrogradation results are shown in Table 3. According to the theory by Avrami (34), unstable molecules form clusters, and subsequently, the sizes grow at a constant rate. In other words, the rice flour crystallization is believed to be due to instantaneous formation of a nucleus to change the structural phase

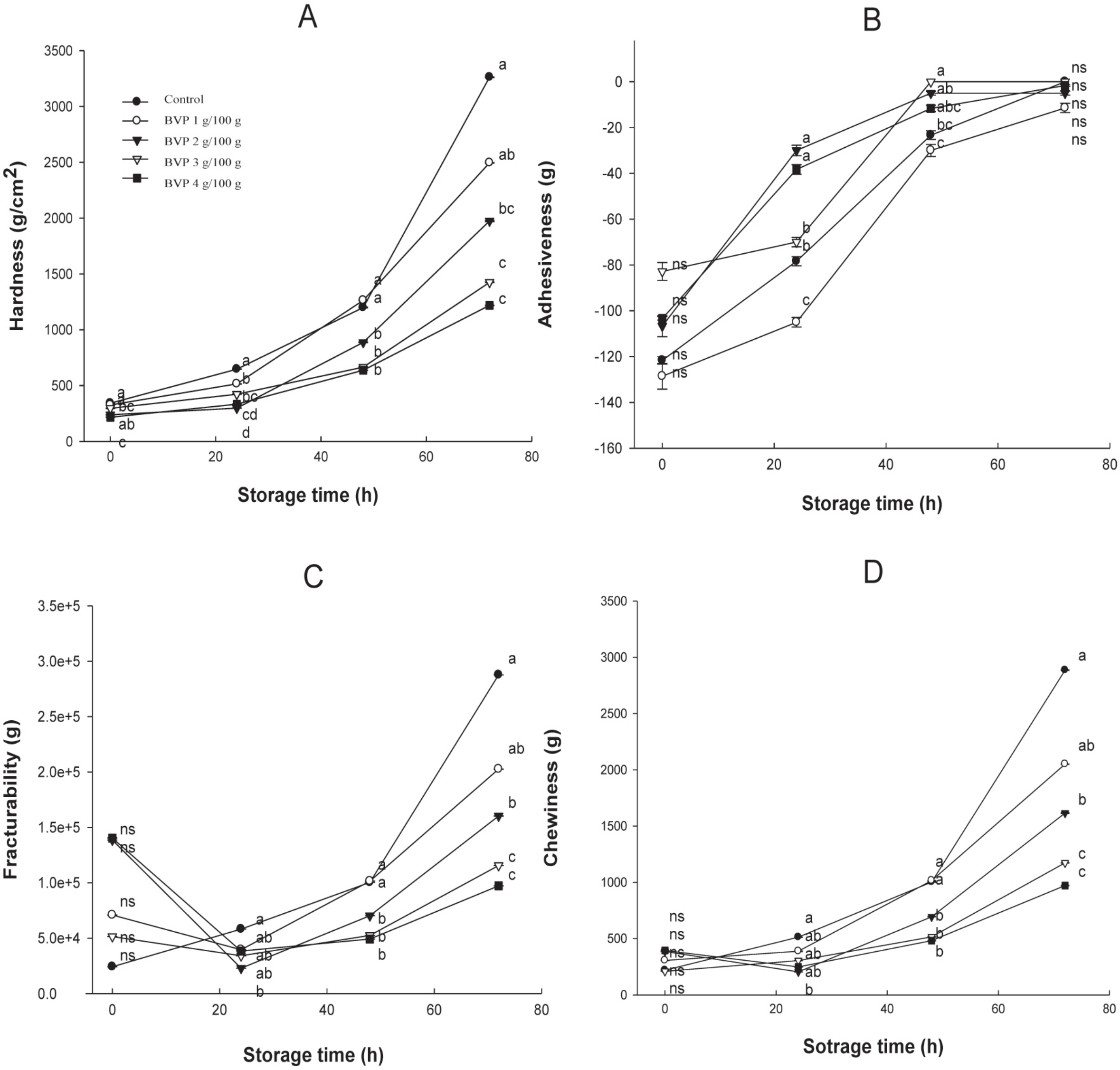

Figure 3. Changes in texture characteristics of buckwheat vegetable Jeolpyeon during storage at 20°C.
A : Hardness of buckwheat vegetable Jeolpyeon; B: Adhesiveness of buckwheat vegetable Jeolpyeon; C: Fracturability of buckwheat vegetable Jeolpyeon; D: Cheweness of buckwheat vegetable Jeolpyeon

and crystal formation, and a method that concretely describes this process is used to study the retrogradation of starch. However, in this experiment, we used the Avrami equation to compare the retrogradation rate of each sample. The Avrami exponent ranges from 0 to 4, according to the time and shape of crystallization, and if an exponent is closer to 1, the crystallization shape looks similar to that of a bar (19). The control group and groups with added BVP had values >1. The rate constant k represents the speed of retrogradation. In terms of k, the control group showed a rate of 10.68 ± 0.10, whereas the Jeolpyeon groups with added BVP showed values in the range of 19.43 ± 0.51–74.19 ± 0.88. In particular, the group with 2% BVP had the greatest delay of retrogradation, with a time constant of 74.19 ± 0.88; this was followed by the 3%, 4%, and 1% BVP groups, and finally the control group. The 4% treatment group showed an average rate of 20.21 ± 0.31. This is similar to the results of a study by Lee and Koo (29) in which sample groups

Table 3. Avrami exponents, rate constants, and time constants in buckwheat vegetable Jeolpyeon with different levels of buckwheat vegetable powder.

BVP(%)	Avrami exponents (n)	Rate constant (k)	Time constants (1/k)
0 g/100 g	1.61±0.02d	0.09±0.00a	10.68±0.10d
1 g/100 g	2.43±0.04b	0.05±0.01b	19.43±0.51c
2 g/100 g	3.47±0.08a	0.01±0.00c	74.19±0.88a
3 g/100 g	1.64±0.05d	0.02±0.00c	28.77±0.04b
4 g/100 g	1.91±0.03c	0.04±0.11b	20.21±0.31c

BVP: Buckwheat Vegetable Powder
Different lower case letters correspond to significant differences at $p < 0.05$.
Data are expressed as means ± standard deviations of three experiments.

without added dietary fiber had faster retrogradation rates than a group with added fiber. The time constant *1/k* indicates preservation, and the larger the constant, the greater the preservation and the slower the speed of retrogradation. The control group with no BVP had a lower time constant (1/*K*) than that of the Jeolpyeon groups with added BVP, and, thus, showed relatively rapid retrogradation. In conclusion, it is suggested that adding BVP delays the retrogradation of Jeolpyeon by effectively restricting its hardness.

Conclusion

From the results shown, adding BVP improved the quality of Jeolpyeon. From a mechanical and chemical (pH and moisture content) perspective, the Jeolpyeon group with 4% BVP showed the best results but when considering the sensory characteristics, the delayed rate of retrogradation, and the preservation benefits according to the Avrami constant, it is suggested that adding 2% BVP is the most suitable ratio to improve the quality and decrease retrogradation of Jeolpyeon rice cakes.

Acknowledgments

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