Quality characteristics and hypoglycaemic effects of rice bread containing Helianthus tuberosus powder

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Abstract. This study aimed to investigate the quality characteristics of rice bread containing Helianthus tuberosus powder that shows excellent physiological functions, and the effect of its intake on blood glucose. Five samples were tested, H. tuberosus powder 5% (HRB1), 10% (HRB2), 15% (HRB3), 20% (HRB4) and control. HRB2 had the highest specific volume. The moisture content of rice bread tended to increase as the concentration of H. tuberosus powder increased. The L value and crumb colour value tended to decrease significantly with an increasing amount of H. tuberosus powder, whereas the b value was increased significantly. Hardness was the lowest in HRB2 and HRB3. In sensory evaluation, there was no significant difference in the appearance among the four groups. HRB1 had the highest values for flavour, texture, and overall evaluation. Taste showed no significant difference until HRB1. Rice bread samples with 15% HRB were selected to measure the hypoglycaemic effect of H. tuberosus compared to that of control rice bread (RB) and wheat bread (WB). The results showed significantly different blood glucose levels (p < 0.05) among treatments. Calculation of the glycaemic index (GI) showed HRB to have the lowest GI. As a result, rice bread containing H. tuberosus powder is expected to increase insulin sensitivity in diabetes.

1. Introduction

Rice, one of the world's three major crops, is consumed by more than half the world's population mainly in the form of rice, porridge, and rice cake [1]. However, the popularity of rice, which is the most loved grain among Korean people since ancient times, has been decreasing every year due to development of the national economy and westernization of lifestyle along with the popularization of various food cultures [2]. The general nutritional content of rice differs slightly among rice varieties and cultivation areas, but mostly rice is composed of starch, followed by protein, fat, fibre, ash, and minerals. It is known to be a good source of nutrients due to its abundance of vitamin B complexes, and it is also used for development of gluten-free foods [3, 4].

Due to economic growth and the development of medicine, increase in the average life span has also increased the number of patients over the past decades due to westernization of dietary habits.
Diabetes is a serious chronic disease that occurs when the pancreas cannot produce enough insulin (a hormone that regulates blood sugar or glucose) or when insulin cannot be effectively used by the body. The number of diabetic patients that reached 108 million in 1980 was estimated to reach 422 million adults globally by 2014; the worldwide prevalence of diabetes has almost doubled since 1980 from 4.7% to 8.5%. This reflects an increase in risk factors such as overweight or obesity and suggests an increase in health and economic impacts; thus, an interest in functional and preventative foods for diabetes continues to increase [5]. One of the promising ingredients that can be used in functional food development is inulin. Inulin, a polymer of fructose, is an indigestible dietary fibre that provides a variety of health benefits such as lowering the glycaemic index to manage the increased risk of chronic diseases (diabetes, cardiovascular disease, obesity, stroke, and cancer) and improve digestive health. It also reduces cholesterol and lipids and improves mineral absorption in the colon with a prebiotic role (prevention of osteoporosis) [6].

The main sources of inulin with these functional elements are Helianthus tuberosus and chicory roots. Among them, *H. tuberosus* L., originating from North America, is a plant belonging to the Asteraceae family, and its growth is suitable in the temperate zone with a high yield [7]. It accounts for about 75% of the dry weight of inulin and is known to be a good source of minerals (calcium, iron, selenium, potassium, phosphorus) and vitamins (vitamin B complex, vitamin C, and 3-carotene) [8]. In addition, in a search for physiologically active ingredients from dried *H. tuberosus*, a phytochemical with α-glucosidase inhibitory activity was reported to demonstrate the antidiabetic effect of a quinic acid-based 'phenolic compound' [9]. Recently, studies are actively being conducted on the physiological activity and the development of processed foods from rice. There is also a growing demand for such foods among health-conscious consumers. Therefore, we aimed to investigate the quality characteristics of rice bread with *H. tuberosus* powder, which has been previously determined as functional, and its effect on blood glucose.

2. Materials and Methods

2.1 Materials

The *H. tuberosus* powder used in this experiment was obtained by low-temperature aging, slicing, low-temperature drying, and then pulverizing of organic *H. tuberosus* (no chemical pesticide certification number: 11-10-3-135) cultivated in Yeongwol-eup, Gangwon-do, Republic of Korea. Rice flour dry-milled using an air-classification mill was supplied by Petitami Co., Ltd., Korea. Hydroxy propyl methyl cellulose (HPMC) was purchased from Lotte Fine Chemicals to be used for baking along with sugar (CJ CheilJedang Co., Korea), salt (CJ CheilJedang Co., Korea), canola oil (CJ CheilJedang Co., Korea), and dry yeast (Saf-instant, Lesaffre, Lille, France).

2.2 Methods

2.2.1 Preparation of rice bread containing *H. tuberosus* powder Table 1 shows the ratio of bread used for blood glucose measurement and rice bread prepared by varying the amount of *H. tuberosus* powder. The bread making process of the home bakery (SD-BH1000, Panasonic Co. Ltd., Osaka, Japan) was used for manufacture. The process required 20 minutes for initial dough formation, 30 minutes for incubation after yeast addition, 5 minutes for the first mixing, 60 minutes for the first fermentation, 5 minutes for the second mixing, 80 minutes for the secondary fermentation, and 40 minutes for baking at 200°C. The total time required was 4 hours. The temperature of water added during the baking process was adjusted by setting the target temperature of the final dough to 27°C.

2.2.2 Analyses of Physical Properties Moisture content was analysed using a drying method at 105°C [10]. Specific volume was determined by the seed displacement method [11]. The colour of rice bread with different amounts of *H. tuberosus* powder in the crust and crumb was determined using a
Chromameter CR-400/410 (Konica-Minolta, Tokyo, Japan) and Hunter's L (lightness), a (redness), b (yellowness) values were measured. Texture was analysed by hardness, adhesiveness, resilience, cohesiveness, springiness, and chewiness using a texture analyser (CT3 4500, Brookfield, Middleboro, MA, USA). Rice bread containing \textit{H. tuberosus} powder was cooled to room temperature for 1 hour and cut to a thickness of 15 mm. The diameter of the acrylic cylindrical probe was 38.1 mm, test speed was 2.0 mm/sec, and deformation was set at 50%.

2.2.3 \textit{Analyses of Physical Properties} Moisture content was analysed using a drying method at 105°C [10]. Specific volume was determined by the seed displacement method [11]. The colour of rice bread with different amounts of \textit{H. tuberosus} powder in the crust and crumb was determined using a Chromameter CR-400/410 (Konica-Minolta, Tokyo, Japan) and Hunter's L (lightness), a (redness), b (yellowness) values were measured. Texture was analysed by hardness, adhesiveness, resilience, cohesiveness, springiness, and chewiness using a texture analyser (CT3 4500, Brookfield, Middleboro, MA, USA). Rice bread containing \textit{H. tuberosus} powder was cooled to room temperature for 1 hour and cut to a thickness of 15 mm. The diameter of the acrylic cylindrical probe was 38.1 mm, test speed was 2.0 mm/sec, and deformation was set at 50%.

Table 1. Composition of rice bread containing \textit{H. tuberosus} powder

| Ingredients        | Control | HRB1 | HRB2 | HRB3 | HRB4 | Wheat bread |
|--------------------|---------|------|------|------|------|-------------|
| Wheat flour        | 0       | 0    | 0    | 0    | 0    | 0           |
| Rice flour         | 100     | 95   | 90   | 85   | 80   | 75          |
| \textit{Helianthus tuberosus} powder | 0      | 5    | 10   | 15   | 20   | 25          |
| Water              | 70      | 70   | 70   | 70   | 70   | 72          |
| Sugar              | 0       | 0    | 0    | 0    | 0    | 6.8         |
| Salt               | 1.5     | 1.5  | 1.5  | 1.5  | 1.5  | 2.0         |
| Yeast              | 1.4     | 1.4  | 1.4  | 1.4  | 1.4  | 1.12        |
| Oil                | 10      | 10   | 10   | 10   | 10   | 0           |
| HPMC               | 2.5     | 2.5  | 2.5  | 2.5  | 2.5  | 0           |

Control: rice bread containing no \textit{H. tuberosus} powder HRB1: rice bread containing 5% \textit{H. tuberosus} powder HRB2: rice bread containing 10% \textit{H. tuberosus} powder HRB3: rice bread containing 15% \textit{H. tuberosus} powder HRB4: rice bread containing 20% \textit{H. tuberosus} powder

2.2.4 \textit{Sensory evaluation} Sensory evaluation of rice bread containing \textit{H. tuberosus} powder was performed by 69 students from the Food and Food Service Industry Department of Kyungpook National University, who were trained in the purpose and evaluation method of this experiment. Appearance, colour, flavour, taste, texture, and overall acceptability of rice bread containing \textit{H. tuberosus} powder was evaluated on a 5-point scale (5 points: very good, 4 points: good, 3 points: normal, 2 points: bad, 1 point: very bad).
2.2.5 **Blood glucose measurement** This study was approved by Kyungpook National University Bioethics Review Committee (2018-0076) and proceeded from June 2018 to July 2018. The subjects of the blood glucose measurement test were 12 healthy persons without any clear disease who fully understood the purpose and contents of the study and submitted a document of voluntary participation intention. Fasting blood glucose was measured at 12 hours of fasting. Ten persons with normal fasting blood glucose levels were selected as the final blood glucose measurement subjects. Subjects who were fasting for 12 hours consumed 50 g of standard bread (WB) on the first day, 50 g of the control rice bread (RB) on the second day, and 50 g of rice bread with 15% *H. tuberosus* powder (HRB) on the third day. Blood was collected from fingertip capillary blood vessels at 0 minutes of fasting, and at 30, 60, 90, and 120 minutes of rice bread consumption, using a self-monitoring blood glucose meter (Nocodingone, i-SENS, Inc.). Subjects were given 200 mL of bottled water during the two hours of the experiment and had minimal daily activities in sedentary conditions.

2.2.6 **Glycaemic index calculation** The area under the curve of blood glucose increase was based on fasting blood glucose, the area below that was ignored and only the increased blood glucose area was calculated after intake of the control rice bread and rice bread containing 15% *H. tuberosus* powder [12]. The calculation formula is as follows.

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\text{Glycaemic index (GI)} = \frac{\text{Incremental area under the blood glucose response curve (IAUC) of experimental bread}}{\text{Incremental area under the blood glucose response curve (IAUC) of blood glucose measurement with standard bread}} \times 100
\]

2.2.7 **Statistical analyses** The means and standard deviations were calculated using SPSS version 23 package (SPSS Inc., Chicago, IL, USA). The difference between groups was analysed by analysis of variance (ANOVA). Statistical significance was considered at p < 0.05, by Duncan's multiple range test.

3. **Results and Discussion**

3.1 **Physical Properties of Bread**

3.1.1 **Water Content** Table 2 shows the moisture content of rice bread prepared with different amounts of *H. tuberosus* powder. The water content of the control, HRB1, HRB2, HRB3, and HRB4 was 40.93%, 42.92%, 42.45%, 42.59%, and 43.85%, respectively. The lowest value was observed in the control, and HRB1 showed a significant difference. The moisture content was the highest in HRB4 and tended to increase with increasing *H. tuberosus* powder. The reason for this result is thought to be an increase in water retention rate [13], which is influenced by the content of dietary fibre. Suh & Kim [14] reported that the water retention rate was significantly increased with the increasing amount of *H. tuberosus*. Therefore, the results of this experiment can be attributed to an increase in water holding capacity due to inulin, a soluble fibre contained in *H. tuberosus*.

3.1.2 **Specific Volume** The specific volume (mL/g) of the control was 4.93 mL/g, which was the highest value, and this was followed by 3.71, 3.81, 3.42, and 2.64 mL/g for HRB1, HRB2, HRB3, and HRB4, respectively (Table 2). As the amount of *H. tuberosus* powder was increased, the specific volume of rice bread tended to significantly decrease (p < 0.001). The control was found to have the highest specific volume due to the moisture retention by HPMC and the formation of a gel network
during the baking process, which resulted in an increase in dough strength and in the air entrapment capacity [15]. In the study of Rubel et al. [16], 2.5% of *H. tuberosus* inulin in the bread dough did not significantly affect the storage or elastic modulus (G’), but the dough with 5% *H. tuberosus* inulin showed destruction of the network causing deterioration of the air trapping ability, which reduced the specific volume of bread. In a study on the physicochemical and physical dough characteristics of wheat flour, a hydrocolloid mixture was the indigestible starch; as the amount of indigestible starch was increased, the setback viscosity of the dough was decreased along with the swelling power and solubility. Dough formation time and stability of dough were also reduced and affected the specific volume of bread. Thus, the specific volume of rice bread tends to decrease as the amount of *H. tuberosus* powder added increases. As the added amount of *H. tuberosus* powder with high water holding capacity increases, the bonding force between the dough increases, whereas the gas capturing power of HPMC decreases during the baking process.

Table 2. Moisture content, colour, specific volume, and texture of gluten free rice bread containing *H. tuberosus* powder.

| Parameter                        | Addition rate of Helianthus tuberosus (%) |
|----------------------------------|------------------------------------------|
|                                  | Control        | 5          | 10         | 15         | 20         |
| Moisture (%)*                   | 40.93±0.47     | 42.92±0.10  | 42.45±0.53  | 42.59±0.79  | 43.85±0.33  |
| Crust L                         | 75.72±0.60     | 62.25±1.19  | 56.28±2.52  | 53.32±1.29  | 48.67±1.58  |
| Crust a                         | 34.65±0.61     | 31.97±0.49  | 28.36±0.87  | 27.43±0.45  | 29.65±0.34  |
| Crust b                         | 2.81±0.35      | 12.51±0.67  | 11.71±0.31  | 14.09±0.13  | 16.05±0.55  |
| Hunter’s color value*           |              |            |            |            |            |
| Crust L                         | 84.72±1.99     | 69.31±0.66  | 64.13±0.68  | 57.99±0.33  | 57.23±0.71  |
| Crust a                         | 33.70±0.76     | 27.06±0.24  | 26.28±0.24  | 24.08±0.36  | 24.69±0.44  |
| Crust b                         | -15.42±0.48    | -0.46±0.24  | 6.07±0.28   | 7.88±0.52   | 10.17±0.48  |
| Specific volume (mL/g)**        |              |            |            |            |            |
| Textural properties (g)         |              |            |            |            |            |
| Hardness***                     | 389.84±68.07   | 439.78±63.23 | 350.68±28.89 | 333.26±28.47 | 431.50±47.90 |
| Springiness***                  | 5.08±1.31      | 7.94±0.93   | 5.99±0.10   | 4.99±0.91   | 5.99±0.63   |
| Chewiness***                    | 13.88±5.31     | 27.37±12.14 | 13.85±2.69  | 10.26±6.44  | 17.18±6.88  |

*Values with different superscripts within the same column are significantly different (p < 0.05). ** Significant at p < 0.001, respectively.

3.1.3 Colour Table 2 shows the results of colour measurement for rice bread prepared by adding *H. tuberosus* powder. The L value representing the lightness of the crust was 75.72, 68.25, 56.28, 53.32, and 48.67 for the control, HRB1, HRB2, HRB3, and HRB4, respectively. As the amount of *H. tuberosus* powder added was increased, the L value tended to become lower and the colour tended to become darker. The value indicating the redness of the crust was 34.65, 31.97, 28.36, 27.43, and 29.65 for the control, HRB1, HRB2, HRB3, and HRB4, respectively, indicating a tendency to decrease significantly with increasing HRB concentration. The b value representing the yellowness of the crust was 2.81, 12.51, 11.71, 14.09, and 16.05 in the control, HRB1, HRB2, HRB3, and HRB4, respectively, indicating a tendency to increase with the increasing amount of *H. tuberosus* powder. However, there was no significant difference between HRB1 and HRB3. In the study by Wahyono et al. [17], the brightness and yellowness of bread crust containing *H. tuberosus* was decreased, and was confirmed to show significantly increased redness. In a study on the quality characteristics of cookies containing added *H. tuberosus* powder [18], the lightness and yellowness decreased and the redness
increased with the increase in the added amount of *H. tuberosus* powder. The Maillard reaction of HPMC and inulin added to rice bread were the factors affecting chromaticity. In this experiment, HPMC was used as a gluten substitute and influenced the dispersion of water in dough and the distribution and movement of material; the Maillard reaction and the caramelization pattern were found to differ [19]. It has also been shown that the Maillard response is promoted with an increase in inulin addition [20]. A difference in redness and yellowness except for lightness could be observed in this study. These results suggest that the Maillard reaction, which is a nonenzymatic browning reaction, occurs because the protein content of wheat is higher than that of rice. The *L* value of the crumb was 84.72, 69.31, 64.13, 57.99, and 57.23 for the control, HRB1, HRB2, HRB3, and HRB4, respectively, showing a tendency to decrease with increasing HRB concentration. The *a* value of the crumb was 33.70, 27.06, 26.28, 24.08, and 24.69 for the control, HRB1, HRB2, HRB3, and HRB4, respectively, demonstrating a tendency to decrease. The *b* value of the crumb was -15.42, -0.46, 6.07, 7.88, and 10.17 for the control, HRB1, HRB2, HRB3, and HRB4, respectively, showing a significant increase. There was no significant difference between HRB1 and HRB3 in crust yellowness, but there was a significant difference in crumb yellowness. This was not affected by the Maillard reaction, suggesting that the effect of the *H. tuberosus* powder was more prominent.

### 3.1.4 Texture

Table 2 shows the results of texture measurement for rice bread prepared by adding *H. tuberosus* powder. The hardness was 448.09, 500.63, 379.89, 361.14, and 485.22 in the control, HRB1, HRB2, HRB3, and HRB4, respectively, indicating the lowest hardness in HRB2 and HRB3. The springiness was 5.08, 7.94, 5.99, 4.99, and 5.99 for the control, HRB1, HRB2, HRB3, and HRB4, respectively. The chewiness was 13.88, 27.37, 13.85, 10.26, and 17.18 in the control, HRB1, HRB2, HRB3, and HRB4, respectively.

### Table 3. Sensory properties of rice bread containing *H. tuberosus* powder.

| Parameter | Proportion of *H. tuberosus* (%) |
|-----------|----------------------------------|
|           | Control | 5  | 10 | 15 | 20  |
| Appearance**| 3.93 ± 0.71<sup>a</sup> | 3.62 ± 0.73<sup>b</sup> | 3.68 ± 0.85<sup>b</sup> | 3.35 ± 0.98<sup>a</sup> | 3.78 ± 1.06<sup>a</sup> |
| Color     |        |     |    |    |     |
| Crust     | 3.84 ± 0.80<sup>a</sup> | 3.58 ± 0.98<sup>b</sup> | 3.49 ± 0.90<sup>a</sup> | 3.41 ± 0.86<sup>a</sup> | 3.67 ± 1.08<sup>a</sup> |
| Crumb     | 3.89 ± 0.79<sup>a</sup> | 3.62 ± 0.79<sup>b</sup> | 3.67 ± 0.76<sup>a</sup> | 3.39 ± 0.94<sup>a</sup> | 3.29 ± 1.13<sup>a</sup> |
| Flavour   | 3.52 ± 1.02<sup>b</sup> | 3.54 ± 0.99<sup>b</sup> | 3.26 ± 1.18<sup>b</sup> | 3.10 ± 1.26<sup>b</sup> | 2.93 ± 1.42<sup>b</sup> |
| Taste***  | 3.46 ± 0.93<sup>a</sup> | 3.38 ± 1.15<sup>b</sup> | 2.93 ± 0.96<sup>a</sup> | 2.32 ± 0.90<sup>a</sup> | 2.51 ± 1.07<sup>a</sup> |
| Texture***| 3.42 ± 1.02<sup>b</sup> | 3.84 ± 0.96<sup>a</sup> | 3.07 ± 0.93<sup>a</sup> | 3.25 ± 1.02<sup>b</sup> | 2.90 ± 1.36<sup>a</sup> |
| Overall   | 3.59 ± 1.05<sup>b</sup> | 3.67 ± 0.95<sup>b</sup> | 3.22 ± 0.95<sup>a</sup> | 3.03 ± 1.01<sup>a</sup> | 3.03 ± 1.12<sup>a</sup> |

Mean ± S.D. (n = 69)

Values with different superscripts within the same column are significantly different (p < 0.05). ** and *** Significant at p < 0.01 and p < 0.001, respectively.

Data are significantly different by one-way ANOVA followed Duncan’s multiple range test at the p < 0.05 level of significance.

### 3.2 Sensory Evaluation

The results of sensory evaluation of rice bread prepared with *H. tuberosus* powder are shown in Table 3. The appearance of rice bread prepared with different amounts of *H. tuberosus* powder was not significantly different between the control, HRB1, HRB2 and HRB4 and was significantly lower (p < 0.01) for HRB3. Crust colour was the highest in HRB4 after the control. Crumb colour showed the highest values in the control. Flavour showed the highest value in HRB1 and decreased significantly from HRB2 (p < 0.01). There was no significant difference in taste between the control and HRB1, but the taste value decreased significantly (p < 0.01) in HRB2. These results suggest that as the amount of *H. tuberosus* powder added increases, the peculiar taste and flavour of *H. tuberosus* is rejected [21].
The value for texture was the highest for HRB1, and seemed to be related to the highest cohesiveness, springiness, and chewiness in texture measurements. In overall acceptability, HRB1 received the highest score. Thus, the optimum amount of *H. tuberosus* addition that can simultaneously satisfy the quality and sensory characteristics is considered to be 5%.

3.3 Blood glucose measurement

The results of blood glucose changes according to the intake of WB, RB, and HRB are shown in Table 4. The mean fasting blood glucose levels at 3 days in the 3 groups were 96.8, 93, and 95.2 mg/dL, respectively, and there was no significant difference. However, after the intake of bread for 0 to 30 minutes, which is the time for postprandial blood glucose rise, blood glucose levels after the intake of WB, RB, and HRB were 132.9, 127.7, and 126.9 mg/dL, respectively. The blood glucose increase rate of RB and HRB was significantly (p < 0.01) lower than that of WB. This finding is similar to the results of Park (18), who showed a significantly lower blood glucose increase rate after 30 minutes of ingesting a cookie containing 30% *H. tuberosus* powder. After 60 minutes of ingestion, the blood glucose level with WB, RB, and HRB was 126.9, 111.3, and 115.1 mg/dL, respectively, indicating a significant difference (p < 0.001). After 90 minutes of ingestion, WB and RB were not significantly different, but blood glucose was significantly lower (p < 0.01) in HRB. There was a significant difference (p < 0.01) between samples after 120 minutes of ingestion. Except for the RB, the blood glucose levels of WB and HRB were lower than those of fasting blood glucose. Consumption of foods with a low glycaemic index (GI), an indicator of the degree of blood glucose increase according to the absorption rate of saccharides in foods, is reported to reduce the risk of diabetes and coronary artery disease by minimizing blood glucose fluctuations and reducing blood insulin secretion. Calculation of the blood glucose index (Fig. 2) showed that the blood glucose level of HRB was the lowest, confirming the antidiabetic effect of phytochemicals in *H. tuberosus* [22] through suppressed postprandial hyperglycaemia. Therefore, gluten-free rice bread containing *H. tuberosus* powder is expected to increase insulin sensitivity to help manage diabetes. Future studies on rice bakery products with improved functionality need to be conducted actively to facilitate industrialization, which will allow meeting the demand of consumers interested in foods prepared using rice.

4. Conclusions

In general, Helianthus tuberosus powder significantly affected physical, sensorial and Glycaemic Index of enriched bread. The moisture content of rice bread tended to increase as the concentration of *H. tuberosus* powder increased. Darker crust and crumb of HRB were produced as the HT powder increased. Increased HT powder more than 5% produced a softer HRB. It was on the contrary with specific volume of HRB that decreased as the HT powder increased. In sensory evaluation, the HRB appearance, color, flavor, texture and overall acceptability were acceptable. Generally, the addition of HT powder up to 10% were insignificantly different (P<0.05) compared to that of control bread. In addition, taste of HRB was scored not acceptable with 15% of HT powder. Calculation of the glycaemic index (GI) showed HRB to have the lowest GI. As a result, rice bread containing *H. tuberosus* powder is expected to increase insulin sensitivity in diabetes.

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