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Quality and antioxidant properties of wheat cookies supplemented with maqui berry powder

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Abstract

Wheat-based products have been supplemented with various health-promoting ingredients to improve their overall qualities. Maqui berries are one of the healthiest berries in nature; however, their use in cookie making has not been reported. Herein, we aimed to develop functionally and nutritionally improved wheat cookies by partially replacing white wheat flour with maqui berry powder (MBP). We prepared cookies supplemented with different MBP concentrations (2.5%, 5%, 7.5%, and 10%) and compared their quality characteristics and antioxidant activities with those of control cookies (100% wheat flour without MBP addition). The incorporation of MBP significantly affected the physicochemical parameters of cookie dough and cookies. Specifically, MBP supplementation significantly decreased the pH, while slightly decreasing the density of cookie dough ($p<0.05$). The cookie spread factor increased; however, the hardness decreased significantly as the MBP concentration increased ($p<0.05$). No significant changes in loss rates were observed upon MBP supplementation ($p>0.05$). Regarding the color of the cookie surface, L* and b* values significantly decreased, while the a* value increased with the addition of MBP ($p<0.05$). The 2,2-Diphenyl-1-picrylhydrazyl and 2,2'-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid radical scavenging activities were significantly increased ($p<0.05$) as the concentration of MBP increased, and both activities were well correlated. Hedonic sensory results indicated that cookies supplemented with 7.5% MBP generally received satisfactory acceptance scores. Overall, the analysis indicated that cookies with acceptable physical characteristics and improved antioxidant activities can be produced by partially replacing wheat flour with MBP. Thus, the addition of MBP to cookies may be a valuable strategy to increase the consumption of health-promoting ingredients in a diet that includes convenience foods.

Key words : maqui berry powder, wheat cookie, physicochemical properties, consumer acceptance, antioxidant properties

Introduction

Bioactive compounds with health-promoting properties are of utmost importance for the food and pharmaceutical industries. Antioxidant compounds delay the oxidation process, inhibiting chain-reaction polymerization and subsequent oxidizing reactions (Halliwell and Aruoma, 1991). Berry fruits have recently gained attention because of their attractive flavor and diverse health-promoting components, including dietary fiber, phenolic acids, flavonoids, vitamins, and minerals (Antoniewska et al., 2019; Ruiz et al., 2013).

Maqui (*Aristotelia chilensis* L.) is a common edible berry that belongs to the *Elaeocarpaceae* family, which is grown in central and southern Chile. Maqui berry contains high amounts of anthocyanins, which are a good source of natural colorants (Genskowsky et al., 2015; Girones-Vilaplana et al., 2014). The fruit has been reported as one of the healthiest berries in nature because of its bioactive components (Nakamura et al., 2014; Schreckinger et al., 2010). Several studies have linked the phenolics of maqui berries with their

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high antioxidant capacity (Girones-Vilaplana et al., 2012; Romero-Gonzalez et al., 2020), digestive enzyme inhibition potential (Bastias-Montes et al., 2020), antidepressant effects (Di Lorenzo et al., 2019), cardioprotection (Cespedes et al., 2008), and *in vitro* and *in vivo* anti-diabetic effects (Rojo et al., 2012). Maqui berries have recently gained more popularity than any other berry (Brauch et al., 2016); however, their application in food product development is scarce.

In the cookies industry, several functional ingredients have been incorporated into cookies to improve their overall quality, including sensory properties. Cookies generally contain wheat flour, sugar, and fat with a low final moisture content of <20% (wet basis) (Cappa et al., 2020). Cookies are one of the most popular and widely consumed bakery products worldwide owing to their affordable cost, taste, convenience, and relatively longer shelf life (Wang et al., 2014). They can easily provide a good source of energy and refreshment in the form of ready-to-eat convenience food (Park et al., 2017) and are a valuable supplementation vehicle for nutritional improvement (Zucco et al., 2011). Thus, adding berry powder to cookies could be a promising strategy to increase the consumption of healthy ingredients in a diet that includes convenience foods (Klopsch et al., 2019).

Rapidly growing concerns about healthy diets have led to the study of wheat-based products supplemented with various berry powders as new natural value-added food ingredients. Cookies with these characteristics have been produced from the blends of wheat and powders of strawberry (Lee and Kim, 2009), blueberry (Ji and Yoo, 2010; Kim et al., 2014), acai berry (Choi et al., 2014), and cranberry (Choi and Lee, 2015) powders; however, there is no information on the use of maqui berry powder (MBP) in cookie making. In this study, we aimed to assess the suitability of MBP for improving the quality and antioxidant properties of cookies.

Materials and methods

Materials

Freeze-dried organic MBP was obtained from Sandlehae (Ham Yang, Korea), while wheat flour (soft flour, CJ Cheiljedang, Yangsan, Korea), white sugar (CJ Cheiljedang, Seoul, Korea), salt-free butter (Lotte Food Co., Cheonan, Korea), and eggs were purchased from a local market.

Cookie formulation and preparation

The standard cookie (control) recipe comprised of 200 g (100%) of white wheat flour, 90 g salt-free butter, 100 g white granulated sugar, and 50 g eggs. Composite flour cookies were prepared by combining white wheat flour and MBP in ratios of 97.5:2.5, 95:5, 92.5:7.5, and 90:10. Butter, sugar, and eggs were creamed using a kitchen mixer (5K5SS, KitchenAid Inc., St. Joseph, MI, USA) at speed 2 for 2 min and scraped down every minute. Afterward, wheat flour and MBP were added and mixed at speed 2 for 3 min. The dough was placed in a refrigerator at 4℃ for 30 min before sheeting. To prepare the cookies, the dough was slightly flattened with the palm of the hand, sheeted with a roller to a uniform thickness of 4 mm, and cut into circular shapes with a diameter of 5 cm. Then, the dough pieces were placed on a baking tray with baking paper and baked at 170℃ for 7 min in a preheated oven (KXS-4G+H, Salvia industrial S.A., Lezo, Spain). Baked cookies were removed from the oven and cooled for 1 h at room temperature before the analyses were conducted. The test cookie samples containing 0%, 2.5%, 5%, 7.5%, and 10% MBP were designated as control, MBP2.5, MBP5, MBP7.5, and MBP10, respectively.

Physicochemical analyses of cookie dough and cookies

A dough sample (*ca*. 5 g) was mixed with 45 mL of distilled water and vortexed for 1 min. The mixture was held at room temperature for 1 h to separate the solid and liquid phases. The pH of the supernatant was measured using a pH meter (pH/Ion 510, Oakton Instruments, Vernon Hills, IL, USA). Dough density measurements were performed in a 30 mL mass cylinder by water displacement (Kim and Chung, 2017; Lee et al., 2017).

The cookie spread factor was determined according to AACC Method 10-50D (AACC, 2000). The diameter was measured using a Vernier caliper by laying down six cookies edge to edge. The diameters of the six cookies were measured again after rotating each cookie 90°, and then the average diameter was calculated. Six cookies were stacked on each other, and their thicknesses were measured. Afterward, cookies were restacked in random order, the thickness was measured again, and the average thickness was calculated. The spread factor of cookies was calculated by dividing the average diameter of cookies by the average thickness. The loss rate was expressed as a percentage of the weight ratio before and after baking. The moisture content of the cookie was obtained by drying a specific amount (*ca*. 5 g) of the sample to a constant weight at 105℃ in an oven (FOL-2, Jeio Tech Co., Daejeon, Korea), and the results were reported on a wet basis (w.b.).

The hardness of the baked cookies was measured using a texture analyzer (LRX*Plus*, Lloyd Instrument Limited, Fareham, Hampshire, UK) in a compression mode via the 3-point bending test using a 3-point bending rig, trigger force of 0.05 N, and load cell of 100 N. The textural studies were conducted at a test speed of 1.0 mm/s and a distance 10 mm, and the distance between the two bottom supports was adjusted to 40 mm. The peak value of the fracture force (maximum) was recorded as the hardness at a point when the cookies were broken into two major pieces (Chakraborty et al., 2009). The peak force to snap the cookies was reported as the fracture force in N. Surface color measurement was carried out based on the CIELAB L*, a*, and b* color system using a spectrophotometer (CM-600d, Minolta Co., Osaka, Japan).

Determination of free radical scavenging activities

The 2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activities of the samples were measured in terms of their hydrogen-donating or radical scavenging activities using stable DPPH radicals. The assay was performed as previously described by Blois (1958) with some modifications. Briefly, a 0.15 mM solution of DPPH radical in ethanol was prepared, after which 5 mL of this solution was added to 1 mL of the sample solution in ethanol at different concentrations, shaken, and left to stand for 10 min. The decolorization of DPPH-donated protons was determined by measuring the absorbance at 517 nm using a spectrophotometer (Optizen 2020 UV Plus, Mecasys Co., Ltd., Daejeon, Korea).

The spectrophotometric analysis of 2,2’-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid $(ABTS)^+$ radical scavenging activity was performed according to the method described by Re et al. (1999), with slight modifications. The $ABTS^+$ cation radical was produced via a reaction between 7.4 mM ABTS in H_2O and 2.6 mM potassium persulfate during storage in the dark at room temperature for 12 h. Before use, the $ABTS^+$ solution was diluted with methanol to obtain an absorbance of 1.1 at 734 nm. Subsequently, 3 mL of $ABTS^+$ solution was added to 0.1 mL of the sample. After 10 min, the percent inhibition at 734 nm was calculated for each concentration relative to the blank absorbance. The scavenging activities of DPPH and $ABTS^+$ radicals were calculated using the following equation:

$$\text{Radical scavenging activity (\%)} = [(\text{Abs.}_{\text{control}} - \text{Abs.}_{\text{sample}}) / \text{Abs.}_{\text{control}}] \times 100$$

Sensory evaluation

Cookies were subjected to sensory evaluation using 50 untrained volunteer panelists (14 males and 36 females, aged 20 to 30), drawn within the university community. Cookies were evaluated for color, flavor, softness, taste, and overall acceptance. The ratings were carried out on a 9-point hedonic scale ranging from 9 (like extremely) to 1 (dislike extremely). The order of serving was randomized. Overall acceptance was evaluated first, and another session was held to evaluate the remaining attributes. An inter-stimulus interval of 30 s was imposed between the samples to allow time for recovery from adaptation. Participants were advised to rinse their palates between the samples. Sufficient space was provided to handle the samples and questionnaires, and the evaluation time was not constrained. No specific compensation was provided to the participants. This study was approved by the Daegu University Institutional Review Board (IRB #1040621-201703-HR-011- 02).

Statistical analysis

Each measurement was conducted in triplicate, except for color (n=9), hardness (n=15), and sensory evaluation (n=50). The experimental data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure to identify significant differences among the samples. The mean values were compared using Duncan’s multiple range test. The significance level was set at 5%.

Results and discussion

Physicochemical characteristics of cookie dough

Table 1 lists the physicochemical characteristics of cookie dough supplemented with different levels of MBP. The pH

Table 1. Physicochemical characteristics of cookie dough containing different levels of MBP

Sample (%)	Property	
	pH	Density (g/mL)
0	6.83±0.12[a1)]	1.24±0.02[a]
2.5	6.07±0.06[b]	1.23±0.02[ab]
5	5.60±0.00[c]	1.22±0.00[ab]
7.5	5.17±0.06[d]	1.21±0.02[ab]
10	4.93±0.06[e]	1.20±0.02[b]

[1)]Means within the same row without a common letter ([a-e]) are significantly different ($p<0.05$).

ranged from 4.93 to 6.83 (range=1.9) and significantly decreased upon the addition of MBP ($p<0.05$). Rather drastic changes were observed, presumably due to the strongly acidic nature of MBP. Thus, it seems that MBP supplementation could result in the production of cookies with considerably lower pH depending on the level of supplementation. A similar reduction in pH was observed for cookies containing blueberry powder (Ji and Yoo, 2010), acai berry powder (Choi et al., 2014), and cranberry powder (Choi and Lee, 2015). Berries generally contain various organic acids and sugars, and possess strong acidic characteristics in general. The pH of MBP was reported to be 3.92 (Lee, 2020a).

The density of cookie dough appeared to decrease slightly upon the addition of MBP; nevertheless, minor changes were observed, and only significant differences were found between the control and MBP10 (range=0.04) ($p<0.05$). The changes in the dough density could be attributed to the interaction between wheat flour protein and the cellulose contained in MBP (Seong et al., 2017); however, the effect was minimal. A similar minimal effect was also reported for cookies supplemented with different levels of black sesame powder (up to 8%, w/w), whose density ranged from 1.24 to 1.26 kg/L (Lim and Lee, 2015).

Physicochemical characteristics of cookies

Table 2 presents the physicochemical characteristics of cookies supplemented with different levels of MBP. The spread of cookies is an indicator of how the dough is pushed outward during the baking process, resulting in reduced thickness and increased diameter (Lee, 2020b). The spread factor has been widely used as a cookie quality indicator, and spread of cookies is a relatively complex phenomenon influenced by various factors (Pareyt et al., 2009), including the type and absorption of flour, the type and addition of fat and sugar, the kneading time and method, and baking time and temperature (Koh and Noh, 1997).

As the substitution level of white wheat flour increased, the spread factor increased significantly from 8.64 to 11.13 ($p<0.05$). Compared to control samples, the spread factor of MBP10 samples was significantly different ($p<0.05$), whereas that of MBP2.5, MBP5, and MBP7.5 samples was not ($p>0.05$). Similarly, the differences between MBP7.5 and MBP10 were not significantly different ($p>0.05$). The increase in the spread factor from 8.64 to 11.13 supported previous studies on cookies containing cranberry and black sesame powder (Choi and Lee, 2015; Lim and Lee, 2015). This could be attributed to the impact of wheat gluten and maqui berry fiber on dough formulation (Oladunjoye et al., 2021). The reduction in gluten formation as the wheat flour is substituted by MBP may lead to the increase in the spread

Table 2. Physicochemical characteristics of cookies containing different levels of MBP

Sample (%)	Property			
	Spread factor	Loss rate (%)	Moisture content (%, w.b.)	Hardness (N)
0	8.64±0.33[c1)]	12.68±0.87[a]	5.69±0.31[a]	22.87±6.12[a]
2.5	10.17±0.32[b]	13.01±1.00[a]	5.14±0.58[ab]	14.34±3.11[b]
5	10.35±0.53[b]	13.02±0.48[a]	4.77±0.68[ab]	13.89±2.73[b]
7.5	10.53±0.33[ab]	13.20±0.92[a]	4.64±0.98[ab]	11.95±4.39[b]
10	11.13±0.41[a]	13.22±0.21[a]	3.62±1.09[b]	11.69±3.16[b]

[1)]Means within the same row without a common letter ([a-c]) are significantly different ($p<0.05$).

factor (Choi and Lee, 2015; Lim and Lee, 2015), consequently influencing the hardness of the cookies.

The loss rate likely increased slightly with increasing amounts of MBP; however, there was no significant difference among all samples ($p>0.05$). This slight increase is probably due to the increase in the spread factor resulting from the introduction of MBP as the increase in surface area allows for more feasible moisture evaporation during the baking process inside the oven (Lim et al., 2009). Lim and Lee (2015) replaced wheat flour with black sesame powder in cookies and reported similar trends for substitution between 2% and 8% (13.43-15.10).

The moisture content of cookies ranged from 3.62 to 5.69% (w.b.) and decreased significantly upon the addition of MBP ($p<0.05$), with no significant differences among MBP2.5, MBP5, and MBP7.5 samples ($p>0.05$). An affinity effect between MBP and moisture likely existed (Lim et al., 2003); however, the overall moisture content obtained in this study was within the acceptable moisture level (~5%) of freshly baked cookies to improve keeping quality (Cauvain and Young, 2008).

The hardness of wheat cookies (22.87 N) was significantly decreased with the addition of MBP ($p<0.05$). The hardness values for MBP cookies were in the ragne of those found by others (Choi and Lee, 2015; Lee, 2017). These textural changes indicated that the cookies became softer with increasing concentrations of MBP. The decreased hardness of composite cookies may be due to the limited formation of the gluten dough network during baking (Choi and Lee, 2015; Kang and Lee, 2007). A decrease in the hardness of wheat cookies containing blueberry and cranberry powders has also been reported (Choi and Lee, 2015; Ji and Yoo, 2010). Yang et al. (2020) reported lower hardness values (10.5-20.0 N) for cookies prepared from wheat malt than those recorded in this study. The variations in cookie hardness may be attributed to the differences in the preparation methods and the amounts of fiber, starch, and protein components included in the partially replaced ingredients (Ji and Yoo, 2010; Oladunjoye et al., 2021).

Regarding color characteristics, the data were expressed as CIELAB L*, a*, and b* values of the cookies obtained from different formulations and are presented in Table 3 and shown in Fig. 1. The L*, a*, and b* values correspond to lightness, redness, and yellowness, respectively. The effect

Table 3. Color characteristics of cookies containing different levels of MBP

Sample (%)	CIELAB color characteristics		
	L*	a*	b*
0	62.53±0.25[a1)]	5.62±0.18[a]	29.36±0.30[a]
2.5	35.87±1.46[b]	3.24±0.57[d]	5.18±0.91[a]
5	28.65±2.07[c]	4.56±0.21[c]	1.44±0.62[c]
7.5	24.72±1.55[d]	4.97±0.79[bc]	-0.32±0.28[d]
10	21.45±2.18[e]	5.32±0.68[ab]	-1.74±0.30[e]

[1)]Means within the same row without a common letter ([a-e]) are significantly different ($p<0.05$).

(A) (B) (C) (D) (E)

Fig. 1. Images of cookies with different MBP substitution levels.
A, control; B, 2.5%; C, 5%; D, 7.5%; E, 10%.

of the addition of different levels of MBP can easily be established by observing the values of control cookies and MBP-added cookies. As the concentration of MBP in the formulation increased, the cookies became darker and browner in color, as evidenced by the lower L* values of MBP-added cookies when compared with control cookies. Control samples exhibited the highest L* value (62.53), whereas MBP10 samples exhibited the lowest value (21.45). The a* and b* values of the MBP-added cookies were lower than those of the control cookies. The a* value increased, whereas the b* value decreased significantly as the MBP level increased ($p<0.05$). These color changes were due to the formation of Maillard browning reactions. The occurrence of a higher degree of Maillard reaction with a high redness surface was probably due to the higher protein and fiber contents in MBP than in wheat flour (Sozer et al., 2014). These results are in accordance with the findings reported for cookies supplemented with different types of berry powders, namely blueberry (Ji and Yoo, 2010), cranberry (Choi and Lee, 2015), and acai berry (Choi et al., 2014) as well as wheat malt (Yang et al., 2020).

Radical scavenging activities

Antioxidant compounds are well known to prevent, delay, or retard rancidity and other flavor deterioration in foods and are capable of protecting the human body from oxidative damage (Jan et al., 2016). The antioxidant activities of control and composite cookies are presented in Fig. 2, which shows that the activity of control samples was significantly lower than that of the composite cookies containing MBP ($p<0.05$). Antioxidant activity increased with increasing concentrations of MBP (control < MBP2.5 < MBP5 < MBP7.5 < MBP10). The highest DPPH and ABTS activities (86.85% and 94.49%, respectively) were exhibited by cookies containing 10% MBP. Thie increase could be related to the significant amounts of polyphenols present in MBP (Girones-Vilaplana et al., 2012; Romero-Gonzalez et al., 2020). Cookies supplemented with powders of cranberry (Choi and Lee, 2015), flaxseed (Kaur et al., 2017), pak choi (Lee, 2020b), and wheat-hog plum bagasse (Oladunjoye et al., 2021) have shown a similar increase in the antioxidant activity.

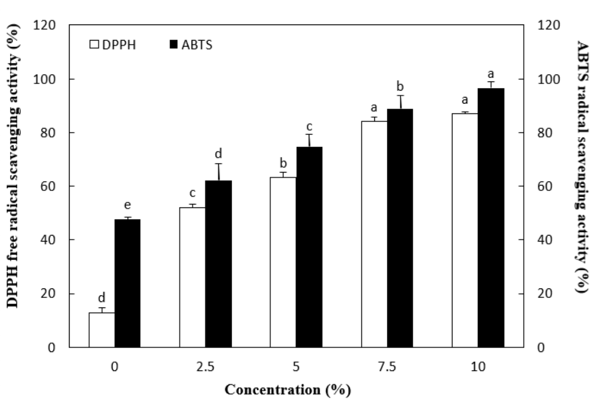

Fig. 2. DPPH and ABTS radical scavenging activities of cookies with different MBP substitution levels.

Means within the same activity without a common letter ($^{a-e}$) are significantly different ($p<0.05$).

The thermal stability of the antioxidant properties of MBP or any other ingredients during baking is not a concern for the development of these types of value-added cookies. Studies have shown that the antioxidant activities (DPPH and ABTS radical scavenging activities) of selected fruits and vegetables increase as the heating temperature during heat treatment (110, 120, 130, 140, and 150℃ for 2 h) increases (Kim et al., 2008). Volf et al. (2014) also reported that exposure of the standard solutions and vegetal extracts exposed to high temperatures (up to 100℃ for 4 h) exhibit relatively stable concentrations of phenolic compounds. Moreover, baking has reportedly increased the antioxidant activity of cookies due to the formation of dark brown color pigments during the baking process (Chauhan et al., 2015). Thus, MBP may be suitable for use as a healthy ingredient in baked cookies to bolster antioxidant content.

Sensory quality of cookies

The sensory qualities of control cookies were compared to those of composite cookies, and the results are shown in Table 4. The mean sensory scores of control cookies were 6.88 for color, 6.16 for flavor, 4.94 for softness, 5.38 for taste, and 5.80 for overall acceptability. The sensory panelists rated the control sample with the highest scores for color and flavor. These were closely followed by MBP7.5 samples. Cookies containing MBP at lower concentrations exhibited reduced sensory scores except for softness. However, MBP7.5 cookies obtained the highest or statistically comparable scores for all sensory attributes, including overall acceptability, except for color. Furthermore, MBP addition significantly lowered all sensory scores, except for

Table 4. Sensory scores of cookies prepared from blends of MBP and wheat flour

Sample (%)	Attribute				
	Color	Flavor	Softness	Taste	Overall acceptability
0	6.88±1.62[a1)]	6.16±1.52[a]	4.94±1.81[b]	5.38±2.01[bc]	5.80±2.10[b]
2.5	2.63±1.63[d]	5.08±1.64[b]	5.52±2.09[b]	5.12±2.02[c]	4.48±2.22[c]
5	4.35±1.55[c]	5.38±1.95[b]	4.80±1.83[b]	4.90±1.83[c]	4.96±1.54[c]
7.5	6.10±1.82[b]	5.56±1.89[ab]	6.34±1.94[a]	6.76±1.71[a]	6.70±1.79[a]
10	5.96±2.02[b]	4.92±2.20[b]	5.46±2.15[b]	6.06±1.88[ab]	5.78±1.84[b]

[1)]Means within the same row without a common letter ([a-c]) are significantly different ($p<0.05$).

taste ($p<0.05$). On a nine-point hedonic scale, MBP7.5 received mean scores over 6.10, except for flavor (5.56), which seems very acceptable. The best sensory quality for MBP cookies was achieved when the MBP concentration was 7.5%. Considering these results, partial replacement of white wheat flour with 7.5% MBP in the cookie formulation seems satisfactory. In a similar study reported by Choi et al. (2014), it was observed that acai berry powder can be incorporated into cookies as a partial replacement for wheat flour at a maximum of 6%, without negatively affecting the physical and sensory quality of the final product.

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Conflict of interests

The authors declare no potential conflict of interest.

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