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Inhibition of Browning and Preference Improvements of *Dioscorea batatas* through the Addition of Sugar Alcohols and Organic Acids

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Abstract

In this study, the color value, water solubility, swelling power and sensory evaluation of *Dioscorea batatas* was examined with the addition of functional additives such as sugar alcohols and organic acids to investigate the browning inhibition and preference of these additives. Treatment with erythritol and citric acid were found to result in the highest hunter L-value, solubility and swelling power relative to the other functional additives. Therefore, erythritol and citric acid were selected as additives for *Dioscorea batatas*. The *Dioscorea batatas* containing the mixed additives (erythritol and citric acid) showed higher brightness, water solubility and swelling power than those containing only a single additive. In addition, the color and taste preference determined in the sensory evaluation had higher values when the mixed additives were used.

Key words: *Dioscorea batatas*, functional additives, physicochemical properties, sensory preference

INTRODUCTION

Dioscorea batatas is often used as an herbal medicine and is consumed after being processed such as uncooked or steaming-and-drying its periderm after peeling. It contains mannan, a mucous polysaccharide (1,2), protein, mineral, steroidal saponin, and a phenanthrene derivative (3-5). *Dioscorea batatas* has been known to contain beneficial nutrients and has been used for energy boosting. In addition, it has been used to treat diabetes, pulmonary tuberculosis, disinfection, antidote, neuralgia and rheumatism (6). Pharmacological studies have revealed that it can act as an anti-oxidant, help regulate glucose levels (7-9) and act as an anti-cancer agent (10). In addition, it has been shown to have beneficial effects on obesity (11), immuno-regulation (12,13), intestinal function (14,15), and lipid metabolism (16). Due to the recent increased interest in consuming healthier foods, the demand for *Dioscorea batatas* has increased. However, it is usually consumed with *Saeng-sik* because process methods have not yet been developed and its quality may deteriorate when stored for extended periods of time since it is composed of about 80% water (17). *Saeng-Sik* is used with or without water after the being subjected to the drying process. To minimize the loss of nutrition and inactivation of enzymes, standard drying processes, such as freeze drying, natural drying or Pneumatic drying below 60°C are often used (18). Freeze drying prevents the loss of functional substances but has several disadvantages including slow speed, high cost, and low production efficiency. In contrast, hot-air drying is a simple process, has a lower cost, and less time is required to grind *Dioscorea batatas* into a powdered state; however, it causes physicochemical changes such as constriction, stiffening of the surface, loss of volatile substances, maillard reaction and it also affects the quality and taste.

Changes in the color in *Dioscorea batatas* is caused by the browning reaction, which decreases the overall nutritional value due to the loss of sugars and amino acids, especially lysines, and has adverse effects on the flavor and color (19).

Although some reductants, such as SO_2 gas (sulfuring) and sulfiting agents, have been shown to act as the anti-browning agents and decrease the maillard reaction, these agents also have adverse effects since they are sulfide compounds and can cause allergies if they remain in the food after treatment. Therefore, these should be substituted for other, less adverse, functional additives (17,19,20).

Sugar alcohols exist in the form of hydrogenated aldehydes or ketones, which can be reduced back to alcohols. It has been reported that sugar alcohols could reduce the maillard reaction when heated (21).

Organic acids can be used with anti-browning agents to prevent enzymatic browning after peeling when heat-

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ing is not used. Organic acids lower the pH of *Dioscorea batatas*, thus reducing enzymatic browning by polyphenol oxidase (22).

The aim of this study was to examine the effects of functional additives, such as sugar alcohols and organic acids, on the browning reaction. We carried out experiments under conditions for quick suspension and tested the water solubility, swelling power, the degree of intensity and sensory evaluation of *Dioscorea batatas* in the presence of different additives and determined the optimal mixing ratio of the most preferred additives in regards to inhibiting the browning reaction.

MATERIALS AND METHODS

Materials

Dioscorea batatas used in this study was grown in Bukhu-myeon, Andong-si, Gyeongsangbukdo, South Korea, and purchased in April 2008. Sugar alcohols such as erythritol, maltitol, sorbitol, xylitol (Mitsubishi, Japan), mannitol (Dae-Jung, Korea) and organic acids such as citric acid (Sigma, USA), fumaric acid, malic acid (Dae-Jung, Korea), tartaric acid (Kanto, Japan), and succinic acid (Hayashi, Japan) were used in this study as the functional additives. All other chemicals used in the experiments were of analytical grade.

Preparation of *Dioscorea batatas* powder

Sliced *Dioscorea batatas*, which were 2～3 mm thick, were dipped in solutions containing 10% of each sugar alcohol (erythritol, malititol, mannitol, sorbitol and xylitol) and 0.2% of each organic acid (citric acid, fumaric acid, malic acid, succinic acid and tartaric acid) for 1 hr. *Dioscorea batatas* treated with the additives were dried by a hot-air drier (HK-DO1000F, Korean Eng. Corp, Korea) at 60°C for 6 hr with a water content of 7.36±0.6%. Dried *Dioscorea batatas* without additives were used for the control. After the hot-air drying process, the slices of *Dioscorea batatas* were triturated using a mill (HMF-985, Hanil, Korea) for 1 min and ground into powders with a 200 mesh.

Measurement of color value

The color values were measured using a colorimeter (CR-300 series, Minolta, Japan) to determine the degree of browning in *Dioscorea batatas* powders. L (lightness), a (redness), and b (yellowness) values were measured using the Hunter system. The white board for the standard was L=97.57, a=0.00, b=1.79.

Measurements of water solubility and swelling power

Water solubility and swelling power were measured by observing the suspension speed of *Dioscorea batatas* powders using the modification method of Dubois et al. (23) and Leach et al. (24).

Sample dispersions of 1.25% were put in centrifuge tubes and heated in a water bath at a temperature of 30°C for 30 min while stirring at 120 rpm. The treated samples were then centrifuged (2,000×*g*, 30 min). Precipitated paste was separated from the supernatant and weighed (Wp). Both phases were dried at 105°C for 24 hr and the dried solids of the precipitated paste (Wps) and supernatant (Ws) were measured. The swelling power was calculated using the ratio of the weight of the swollen sample between the hydrated supernatant (Wp) and dry supernatant (Wps).

$$\text{Swelling power (g/g)} = \frac{\text{(Wp) hydrated supernatants}}{\text{(Wps) dried supernatants}} \times 100$$

The water solubility was calculated using the percentage of soluble solids (Ws) over the dried mass of the whole starch sample (Wo).

$$\text{Water solubility (\%)} = \frac{\text{(Ws) soluble solids}}{\text{(Wo) dried mass of whole sample}} \times 100$$

Sensory evaluation

The sensory evaluation was carried by 30 panelists. To determine the most appropriate ratio of powder over water before conducting the sensory evaluation, the ratio was chosen by the preference test of drinking at the ratios of 1:1, 3:1, 5:1, 7:1 and 10:1 (water : powder).

The processed powders were evaluated in terms of its intensity characteristics and preference characteristics by providing 20 mL of each sample to each panelist (25).

Both the intensity characteristics in terms of brightness, texture, sweetness and sour taste and the preference test, which was divided into color and flavor, were conducted using a 9-point scale from 1-point (extremely weak) to 9-points (extremely strong).

Statistical analysis

All results were displayed as mean±standard deviation determined from triplicate experiments. The sensory evaluation (single additive powders) were analyzed by the one-way analysis of variance (ANOVA) and statistical differences between samples were determined using the Duncan's multiple-range test. The difference between each mixing additive powder was determined by the t-test. A p value <0.05 was used as a statistically significant difference between the treatments.

RESULTS AND DISCUSSION

Measurement of color value of single additives powder

Table 1 shows the color values of the *Dioscorea bata-*

Table 1. Color value of *Dioscorea batatas* powder treated with each single additives

Group	Color value		
	L (lightness)	a (redness)	b (yellowness)
Control-T	79.41±1.63[g]	3.25±0.40[a]	19.28±1.92[a]
Erythritol-T	89.64±0.31[ab]	1.13±0.08[b]	10.46±0.22[ab]
Mannitol-T	91.66±0.29[a]	0.61±0.04[g]	7.06±0.22[g]
Maltitol-T	84.63±1.41[de]	1.66±0.06[c]	18.24±0.83[b]
Sorbitol-T	83.05±0.43[f]	1.34±0.15[cd]	16.02±0.43[c]
Xylitol-T	83.52±2.00[ef]	1.28±0.18[de]	12.99±0.55[def]
Citric acid-T	86.80±0.42[c]	0.92±0.10[ef]	12.45±0.28[de]
Fumaric acid-T	86.48±0.43[c]	0.67±0.05[g]	11.17±0.65[de]
Malic acid-T	85.70±0.46[cd]	0.78±0.06[fg]	11.33±0.37[f]
Succinic acid-T	85.88±0.22[cd]	1.01±0.06[de]	12.80±0.20[d]
Tartaric acid-T	87.88±1.12[b]	0.75±0.17[gf]	11.56±0.27[f]

[a-g]Superscript letters indicate significant difference at α =0.05 as determined by Duncan's multiple range test.

Table 2. Water solubility and swelling power of *Dioscorea batatas* powder treated with each single additives

Group	Water solubility (%)	Swelling power (g/g)
Control-T	5.94±0.07[b]	4.12±0.02[b]
Erythritol-T	10.37±0.12[a]	7.58±0.06[a]
Mannitol-T	6.61±0.03[b]	5.54±0.08[b]
Maltitol-T	5.61±0.02[b]	5.28±0.06[ab]
Sorbitol-T	6.32±0.10[b]	5.74±0.13[ab]
Xylitol-T	6.91±0.17[b]	5.34±0.12[ab]
Citric acid-T	6.34±0.16[b]	5.07±0.07[ab]
Fumaric acid-T	6.71±0.71[b]	4.88±0.49[b]
Malic acid-T	6.00±0.10[b]	4.83±0.06[b]
Succinic acid-T	6.53±0.05[b]	4.26±0.03[b]
Tartaric acid-T	6.75±0.36[b]	4.75±0.13[b]

[a,b]Superscript letters indicate significant difference at α =0.05 as determined by Duncan's multiple range test.

tas powder treated with each additive alone. The experimental group treated with additives had higher color values than the control. The Hunter L-value of the *Dioscorea batatas* powders treated with mannitol and erythritol were 91.66 and 89.64, respectively, and were significantly different compared with the other treatments, which appeared ivory white by the naked eye (data were not shown). The *Dioscorea batatas* powders treated with the organic acids had color values that were similar to the others where the *Dioscorea batatas* powders treated with tartaric acid had the highest Hunter L-value (87.88).

The control sample had the highest Hunter a-value (redness) and b-value (yellowness), which indicates that the control was the darkest. However, the Hunter a-value (redness) and b-value (yellowness) of the sample treated with mannitol, which had the highest Hunter L-value, was the lowest, 0.61 and 7.06, respectively.

The Hunter L-value of the samples treated with sugar alcohols was higher than the control and organic acids treatments. This trend was similar to previous results obtained for malititol treatment, which showed higher value than sorbitol and sucrose treatments (26). In addition this was also similar to a previous study on sugar alcohols, especially for erythritol and xylitol, which were heat stable and showed higher Hunter L-values with significant difference in processed products containing additives (27).

Measurements of solubility and swelling power of single additives powder

The solubility of the processed powder (Table 2) was highest after erythritol treatment (10.37%) and was significantly different compared to the other sugar alcohols. Samples treated with tartaric acid had the highest solubility (6.75%) among the organic acids but there was no significant difference.

Erythritol showed the highest water solubility among the sugar alcohols and tartaric acid when added to the *Dioscorea batatas*. Although the solubility among the sugar alcohols were different from each other, the solubility of samples treated with the different organic acids were similar. For the sugar alcohols, the heavier the molecular weight, the lower its water solubility. Thus, the *Dioscorea batatas* powders treated with erythritol showed the highest water solubility.

The swelling power of samples (Table 2) treated with erythritol was the highest, which was also in observed for the solubility. In addition, citric acid treatment had the highest swelling power relative to the other organic acids, which showed a significant difference. Overall, the powders treated with sugar alcohols had a higher swelling power than the powders treated with organic acids.

Sensory evaluation to select appropriated water ratio

An initial sensory evaluation test was carried to determine the most appropriate ratios of powder and water (1:1, 3:1, 5:1, 7:1 and 10:1 (powder : water)) prior to conducting the sensory tests with the addition of functional additives. The color of the suspended solution was the best at the 7:1 and 10:1 ratios; however, there were no significant differences between these two samples. The viscosity increased as the amount of water was decreased and the taste of the solution was the best at a ratio of 10:1. In the overall preference test, a ratio of 10:1 was the most preferred. Therefore, the samples treated with functional additives were subjected to the sensory evaluation tests based on the results of the above experiments (Table 3).

Sensory evaluation of single additives powder

In the intensity evaluation (Table 4), the brightness

Table 3. Sensory evaluation of *Dioscorea batatas* solutions under the different mixing ratios

Ratio (water : powder)	Color	Viscosity	Taste	Overall acceptability
1 : 1	4.00 ± 0.82^{b}	8.00 ± 0.82^{a}	2.75 ± 2.06^{bc}	3.00 ± 0.82^{c}
3 : 1	4.25 ± 1.26^{b}	7.00 ± 0.82^{a}	2.50 ± 0.58^{bc}	3.00 ± 1.41^{c}
5 : 1	4.50 ± 0.58^{b}	6.25 ± 0.50^{b}	2.00 ± 0.82^{bc}	3.00 ± 0.82^{c}
7 : 1	6.25 ± 0.50^{a}	5.25 ± 0.96^{b}	3.50 ± 1.00^{b}	5.25 ± 1.26^{b}
10 : 1	6.25 ± 0.50^{a}	3.25 ± 0.96^{c}	5.75 ± 0.50^{a}	6.75 ± 1.26^{a}

$^{a\text{-}c}$Superscript letters indicate significant difference at α=0.05 as determined by Duncan's multiple range test.

Table 4. Intensity evaluation of *Dioscorea batatas* powder treated with each single additives

Group	Brightness	Texture	Sweetness	Sourness
Control-T	3.83 ± 2.14^{c}	7.00 ± 0.71^{a}	5.33 ± 1.97^{b}	3.50 ± 2.07^{a}
Erythritol-T	6.00 ± 2.83^{ab}	4.40 ± 1.52^{b}	8.00 ± 1.79^{a}	2.17 ± 1.17^{ab}
Mannitol-T	7.33 ± 1.97^{ab}	4.40 ± 0.89^{b}	7.00 ± 2.00^{ab}	2.83 ± 1.94^{ab}
Maltitol-T	7.75 ± 0.50^{a}	4.00 ± 1.22^{b}	7.75 ± 0.96^{ab}	1.50 ± 0.58^{b}
Sorbitol-T	6.75 ± 1.71^{ab}	3.20 ± 2.68^{b}	5.25 ± 1.71^{b}	2.50 ± 3.00^{ab}
Xylitol-T	3.17 ± 1.47^{c}	2.80 ± 0.84^{b}	7.50 ± 2.35^{ab}	3.00 ± 2.53^{ab}
Citric acid-T	5.25 ± 1.26^{abc}	4.40 ± 2.07^{b}	2.75 ± 1.50^{cd}	5.00 ± 2.16^{ab}
Fumaric acid-T	4.67 ± 2.58^{bc}	3.20 ± 2.17^{b}	3.00 ± 1.10^{c}	4.50 ± 1.76^{ab}
Malic acid-T	6.17 ± 1.17^{ab}	3.20 ± 1.92^{b}	2.83 ± 1.33^{cd}	5.33 ± 2.42^{ab}
Succinic acid-T	6.25 ± 1.71^{ab}	3.00 ± 1.00^{b}	1.00 ± 0.00^{d}	7.00 ± 0.82^{ab}
Tartaric acid-T	6.75 ± 2.36^{ab}	2.40 ± 0.55^{b}	2.25 ± 2.50^{cd}	7.00 ± 0.82^{ab}

$^{a\text{-}d}$Superscript letters indicate significant difference at α=0.05 as determined by Duncan's multiple range test.

of the solution treated with maltitol showed the highest value with a significant difference. The solutions treated with all sugar alcohols except for xylitol were twice as brighter as the control, which was in agreement with the Hunter L-values.

The control sample was determined to be the roughest in the texture tests, which was conducted by allowing the sample to remain on the tongue after the samples were tasted, where those samples containing the additives were softer than the control. However, no significant differences were observed among the different treatments.

Powders treated with erythritol were the sweetest and most refreshing, which was a typical characteristic of samples treated with sugar alcohols (data were not shown). The sour taste was highest in succinic acid and tartaric acid treated samples among the organic acid treatments and the excessive sour taste of these treatment decreased the overall taste of the powder (data were not shown).

The preference tests (Table 5) in terms of the color of the powdered *Dioscorea batatas* had similar values without significant difference. The taste preference was the highest for the sample treated with erythritol among all the sugar alcohol treatments. In the case of organic acid treatments, treatment with succinic acid and tartaric acid had the lowest preference in taste. However, powders treated with citric acid had a higher taste preference and this treatment significantly improved the flavor of *Dioscorea batatas*.

Table 5. Preference evaluation of *Dioscorea batatas* powder treated with each single additives

Group	Preference	
	Color	Taste
Control-T	4.67 ± 1.37^{ns}	5.83 ± 1.83^{abcd}
Erythritol-T	5.00 ± 2.83	7.67 ± 1.63^{ab}
Mannitol-T	6.33 ± 1.97	7.33 ± 1.75^{ab}
Maltitol-T	5.25 ± 0.50	6.75 ± 2.06^{abc}
Sorbitol-T	5.75 ± 0.96	5.75 ± 2.22^{ab}
Xylitol-T	4.33 ± 2.34	6.67 ± 2.16^{abcd}
Citric acid-T	4.25 ± 2.06	7.33 ± 2.42^{a}
Fumaric acid-T	5.00 ± 2.10	5.50 ± 0.58^{abcd}
Malic acid-T	5.00 ± 2.53	5.17 ± 0.98^{bcd}
Succinic acid-T	5.00 ± 1.83	4.25 ± 0.50^{cd}
Tartaric acid-T	4.50 ± 2.65	5.25 ± 0.96^{d}

$^{a\text{-}d}$Superscript letters indicate significant difference at α=0.05 as determined by Duncan's multiple range test.
ns: not significantly different.

Therefore, erythritol of all the sugar alcohols and citric acid of all the organic acids were determined to be the additives that could most improve the sensory and physicochemical characteristics of *Dioscorea batatas* subjected to the hot-air drying, since they had higher brightness, solubility, swelling power and taste preferences.

Preparation of *Dioscorea batatas* powder with mixed additives and measurement of physicochemical properties

Based on the previous experiments described above, erythritol and citric acid were chosen for further ex-

Table 6. Color value, water solubility, and swelling power of *Dioscorea batatas* powder treated with mixed additives

Group	Color value			Water solubility (%)	Swelling power (g/g)
	L (lightness)	a (redness)	b (yellowness)		
M-T[1)]	87.01±0.37*	0.67±0.11*	10.00±0.09*	11.43±0.55*	8.64±0.06*
Control	79.41±1.63	3.25±0.40	19.28±1.92	5.94±0.07	4.12±0.02

[1)]M-T: Powder of *Dioscorea batatas* treated with mixed additives.
*Superscript letters indicate significant difference at α=0.05 as determined by Student's t-test.

Table 7. Intensity evaluation of *Dioscorea batatas* powder treated with mixing additives

Group	Brightness	Texture	Sweetness	Sourness
M-T[1)]	6.50±3.00*	6.00±1.71*	7.00±2.58*	5.50±1.91
Control	3.83±2.14	7.00±3.00	5.33±1.97	3.50±2.07

[1)]M-T: Powder of *Dioscorea batatas* treated with mixed additives.
*Superscript letters indicate significant difference at α=0.05 as determined by Student's t-test.

perimentation and placed into a mixed powder. Sliced *Dioscorea batatas* were dipped in a solution made with a mixture of erythritol and citric acid at a ratio of 10:0.2 for 1 hr and grinded into a powder state using a 200 mesh after drying at 60°C. The Hunter L, a, and b-value, solubility and swelling powder were analyzed in the control and powder treated with the mixed additives.

The results (Table 6) results of this analysis showed that the powder treated with the mixed additives (M-T) had a lower browning reaction than the control. The Hunter L (87.01), a (0.67), and b values (10.00) were similar to the powder treated with the additives alone. However, the mixed additive treatment resulted in a higher solubility and swelling power (8.64%) than treatment with the individual additives (erythritol－10.37% and 7.58%, and citric acid－6.34% and 5.07%, respectively) (Table 2).

Sensory evaluation of mixed additives powder

In regards to the intensity characteristics (Table 7), the powders treated with M-T (6.50) were twice as brighter as the control (3.83) with a significant difference.

The texture of the control showed a higher value than the samples treated with the mixed additives and this treatment had an adverse effect on swallowing. The sweet and sour taste was higher in the mixed additives while no significant difference was observed in terms of the sour taste.

In the preference test (Table 8), there was no significant difference in the color preference between the control and treatment with the mixed additives (M-T), which was same results obtained when the powder was treated with each individual additives. The taste preference was higher in the sample treated with the mixed additives than the control with a significant difference. Treatment with the mixed additives had higher color values, solubility, swelling power and sensory characteristics than the control when hot-air drying without any additives was used. Thus, sugar alcohols and organic acids were identified as new functional additives that could prevent changes in color during hot-air drying and improve taste preferences when consumed.

Table 8. Preference evaluation of *Dioscorea batatas* powder treated with mixing additives

Group	Preference	
	Color	Taste
M-T[1)]	5.25±2.87	7.50±1.00*
Control	4.67±1.37	5.83±1.83

[1)]M-T: Powder of *Dioscorea batatas* with mixing treatment of additives.
*Superscript letters indicate significant difference at α=0.05 as determined by Student's t-test.

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