Analysis of Physicochemical Factors Related to the Automatic Pellicle Removal in Korean Chestnut (*Castanea crenata*)

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Analyses were carried out for condensed tannin content, soluble sugar content, color, firmness, and peeling ratio of the pellicle of 14 varieties of Korean chestnut. The correlation between these physicochemical components and the peeling ratio was measured. The total soluble sugar content ranged from 4.20 to 11.83%. Condensed tannin contents in the inner and outer chestnut shells were 7.83−71.42% and 0.31−2.04%, respectively. In the outer shell of chestnut, CIE L* value was 26.98−33.34, CIE a* value was 7.56−14.90, and CIE b* value was 7.36−15.67. Firmness of chestnut was 4.41−9.20 kg. Peeling ratio of the pellicle by the peeling machine was significantly different with variety. The average peeling ratio was 63.79%, and that of the Okkwang variety was the highest at 85.29%. A negative correlation was found between tannin content of inner shell and peeling ratio ($r = -0.57$*), but the correlation coefficients between other components and the peeling ratio were not significant.

Keywords: *Chestnut; condensed tannin; soluble sugar; color; firmness; peeling ratio; correlation*

INTRODUCTION

The chestnut is one of the world's popular nuts; it is eaten roasted or boiled, or is processed into syrup pack and marrons glacés (chestnuts preserved in vanilla-flavored syrup).

Annual world chestnut production was maintained at about 450,000 tons in the 1990s, which was lower than the average production of 500,000 tons in the 1980s. The main chestnut-producing countries are China, Korea, Turkey, and Italy, which account for 75% of the global chestnut production. Among these, Korea is the second-highest chestnut-producing country, contributing about 100,000 tons annually. Furthermore, about 30% of the total chestnut production in Korea is processed manually as peeled chestnut. However, the manual operation involved in peeling the outer and inner shell of chestnut is very difficult because of the adhesive characteristics of the Korean chestnut shell. About 70% of chestnut-processing time is spent in this process, which raises the production cost.

To make this peeling operation easier, several studies have examined the problem from physical or chemical viewpoints (*1*−*3*). More recently, Kim et al. (*4*) devised a new machine. This machine has the ability to peel off the inner and outer shells using a combination of high temperature and mechanical scraping. However, there are some problems which remain to be overcome in terms of its further practical application.

It is well-known that the pellicle of the chestnut is rich in tannin, and generally tannin interacts with proteins or minerals to form complexes (*5*−*6*). In the chestnut pellicle, such interaction may be a functional aspect of pellicle adhesion, as Hiromichi et al. (*7*) suggested that the adhesive force between the pellicle cells and the cotyledon depends on tannin accumulation in the pellicle cells. But few reports have addressed the phenolic components of the pellicle (*8*−*9*).

Thus, the origin and mechanism of adhesion between the pellicle and flesh must be studied in detail by making clear the chemical and physical characteristics of chestnuts.

In this paper, the physicochemical properties of Korean chestnut were analyzed, and the correlation between the various physicochemical characteristics and the peeling ratio of the pellicle by the peeling machine was measured for fourteen varieties of Korean chestnuts.

MATERIALS AND METHODS

Materials. Fourteen varieties of chestnuts (*Castanea crenata*), harvested in the middle of October 1999, were obtained from the Korean Forestry Research Center. All sample chestnuts were cleaned carefully and stored in a cold room at 0 ± 1 °C until further analysis.

Chemical Standards. The chemicals used were of the highest purity commercially available. Catechin and glucose standards were obtained from Sigma-Aldrich (Sydney, Australia).

Total Soluble Sugar Analysis. The flesh of the chestnut was ground and then extracted with 80% ethanol for 1 h at 60 °C in a water bath. The soluble sugar of the extract was determined with the phenol−sulfuric acid method. Absorbance was read at 490 nm using a UV/Vis spectrophotometer (V-550, JASCO, Japan). A glucose standard curve was used to calculate the sugar level.

Condensed Tannin Content Analysis. Tannin levels were determined in the inner and outer shells of chestnuts using the vanillin HCl procedure (*10*). Absorbance was read at 500 nm. A catechin standard curve was used to calculate the tannin level.

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Table 1. Soluble Sugar and Condensed Tannin Contents of 14 Chestnut Varieties

variety	soluble sugar (% w/w, wet base)[a] flesh	condensed tannin (% w/w, dry base) inner shell	outer shell
Ungi	4.20 ± 1.70^{e}	62.47 ± 1.56^{b}	0.88 ± 0.02^{g}
Chukpa	7.03 ± 1.71^{cd}	28.62 ± 0.76^{f}	1.97 ± 0.04^{b}
Okkwang	5.74 ± 1.02^{de}	10.82 ± 0.00^{l}	1.88 ± 0.11^{c}
Yuma	6.44 ± 0.11^{cd}	41.90 ± 0.10^{e}	1.15 ± 0.02^{e}
Ichi	10.70 ± 1.20^{a}	44.42 ± 2.66^{e}	0.51 ± 0.01^{j}
Ipyung	11.08 ± 1.66^{a}	15.16 ± 0.62^{h}	0.60 ± 0.02^{i}
Daekukjosaeng	9.78 ± 0.58^{ab}	7.83 ± 0.18^{j}	0.94 ± 0.04^{f}
Chundaejunjosaeng	10.78 ± 0.18^{a}	19.66 ± 1.92^{g}	0.66 ± 0.01^{h}
Shinmyung	11.83 ± 1.79^{a}	26.14 ± 1.13^{f}	2.04 ± 0.01^{a}
Nokjo	10.86 ± 0.89^{a}	41.59 ± 3.59^{e}	0.68 ± 0.00^{h}
Daap	7.70 ± 1.22^{cdef}	52.69 ± 0.29^{c}	1.76 ± 0.02^{d}
Gyunchung	7.87 ± 1.79^{bcd}	48.98 ± 1.37^{d}	0.31 ± 0.01^{k}
Sukchoo	8.40 ± 1.31^{bc}	53.96 ± 2.43^{c}	1.84 ± 0.02^{c}
Daedanpa	8.59 ± 0.47^{bc}	71.42 ± 3.19^{a}	0.70 ± 0.02^{h}
F-value	11.77*	391.4*	1021.94*

[a] Mean values within a column followed by same letter are not significantly different at a =0.05. [b] * Means significant at $p = 0.001$.

Measurements of Surface Color. Color (CIE L*, a*, and b*) values were measured by a Minolta color difference meter (CM-3500d, Minolta Co., Japan). Chroma $[(a^{*2} + b^{*2})^{1/2}]$ and hue angle ($\tan^{-1}$ b*/a*) were calculated from tristimulus values CIE L*, a*, and b*. The results reported are the average of at least 20 replications.

Texture Analysis. Firmness of chestnut flesh was measured using a texture analyzer (TA-XT2, Stable Micro System Ltd., England) under the following conditions: probe diameter, 3.0 mm; compression speed, 1.5 mm/s; and strain, 60%. Maximum force was used as an index of firmness. Readings were averaged for 20 replicates, and results were assessed by analysis of variance (ANOVA) using SAS.

Peeling of the Pellicle from the Kernel. The peeling machine invented by Kim et al. (*4*) was used to peel the chestnut outer and inner shells. The chestnut-peeling machine consisted of a flame peeler and a continuous frictional skin peeler.

Chestnuts were dried at 60 °C in a drying oven for 40 min and were passed through the flame-peeling system. For this experiment, the flame chamber temperature was 720 ± 10 °C, the discharging time of the flame chamber was 30 ± 1 s, and the rotational speed of the rotor for the continuous frictional skin peeler was 175 rpm.

Flame-peeled chestnuts were divided into four groups according to the percentage of area peeled. Groups designated N0, N1, N2, and N3 indicate peeled areas of under 50% (N0), within 50 to 79% (N1), within 80 to 99% (N2), and greater than 99% (N3), respectively. The peeling ratio was calculated as follows:

$$\text{Peeling ratio (\%)} = \frac{(0 \times n0) + (0.5 \times n1) + (0.8 \times n2) + (1 \times n3)}{(n0 + n1 + n2 + n3)} \times 100$$

where $n0$, $n1$, $n2$, and $n3$ express the numbers of chestnuts belonging to the groups N0, N1, N2, and N3, respectively. An average of 50 measurements was obtained for each variety.

Statistics. All results represented the means of triplicates; if otherwise the numbers of replication are specifically mentioned. All results were assessed by analysis of variance (ANOVA) using the SAS. SAS was used to analyze the correlation between physicochemical factors (tannin content, soluble sugar content, firmness, and color value) and the peeling ratio.

RESULTS AND DISCUSSION

Total Soluble Sugar Content. Table 1 shows the total soluble sugar contents of chestnuts by variety. The total soluble sugar contents were significantly different among varieties. The sugar contents in the Ichi, Ipyung, Chundaejunjosaeng, Shinmyung, and Nokjo varieties were higher than those of the others; the Ungi variety was proved to have the lowest sugar content at 4.2%. These results are almost identical to those reported by Nah et al. (*11*) who determined that the soluble sugar content of Ungi variety was 4.81%.

Condensed Tannin. Condensed tannin contents of the inner and outer shells of chestnuts are also shown in Table 1. Tannin contents of the inner and outer shells were significantly different between varieties. Tannin contents in the inner and outer shells of chestnuts were 7.83−71.42% and 0.31−2.04%, respectively. For the inner shell, the tannin content of Daedanpa variety was the highest and that of Daegukjosaeng variety was the lowest. For the outer shell, the tannin content of the Shinmyung variety was highest and that of Gyunchung was the lowest.

The tannin of chestnut flesh is mainly gallic acid and consists of 3,6-digalloyl glucose, pyrogallol (*12*), and resorcinol (*13*). Nicolas et al. (*13*) studied the composition of commercial chestnut bark tannin extract, and the tannin type of chestnut is mainly ellagitannins. But very few studies have addressed the tannin content of the chestnut inner and outer shell.

Color. Chestnuts were separated into their anatomical parts (outer shell, inner shell, and flesh), and CIE L*, a*, and b* color values for each part were measured using a Minolta color difference meter (CM-3500d, Minolta Co., Japan). Results are shown in Tables 2−4.

In the outer shell, CIE L*, a*, and b* values were significantly different between varieties ($p > 0.001$). As an objective evaluation of chestnuts, CIE L* values appear to be important and sensitive to color evaluation. The L* value, which can be an indicator of lightness of color, appeared to be as variable (CV = 17.11) as the other color parameters in chestnuts. L* values ranged from 26.98 to 33.34. Chukpa and Nokjo varieties had slightly higher values, and Daap and Okkwang varieties had lower values. The CIE a* value indicates the redness (positive a*) and greenness (negative a*). As shown in Table 2, the CIE a* value ranged from 7.56 to 14.90; Ipyung had the lowest value at 7.56. The CIE b* value indicates the yellowness, and they ranged from 7.36 to 15.67.

Table 2. CIE L*, a*, and b* Color Values for the Outer Shell of Chestnuts

variety	L* [a]	a*	b*	hue (h*)	chroma (c*)
Ungi	31.75bc	14.37a	13.56bcd	0.73	19.77abc
Chukpa	33.34a	14.57a	15.67a	0.54	21.41a
Okkwang	26.98f	11.28e	8.21fg	1.15	13.98h
Yuma	29.74de	12.54cd	12.11d	0.74	17.51ef
Ichi	30.87bcd	12.35cde	13.25cd	0.57	18.18cdef
Ipyung	32.16ab	7.56f	7.36g	2.46	10.62i
Daekukjosaeng	31.76bc	14.11ab	14.53abc	0.65	20.35ab
Chundaejunjosaeng	30.16de	13.14bc	9.64ef	1.30	16.39fg
Shinmyung	30.58cde	13.10bc	11.99d	0.81	17.82def
Nokjo	33.16a	13.97ab	14.79abc	0.59	20.41ab
Daap	28.10f	11.71de	10.20e	0.85	15.55gh
Gyunchung	29.73de	13.92ab	11.97d	0.88	18.39cde
Sukchoo	30.99bcd	14.90a	15.19ab	0.63	21.31ab
Daedanpa	29.48e	14.24ab	13.16cd	0.76	19.40bcd
F-value[b]	16.89***	27.52***	19.41***	1.09	24.09***

[a] Mean values within a column followed by same letter are not significantly different at $a = 0.05$. [b] *, **, and *** mean significant at $p = 0.05$, 0.01, and 0.001, respectively.

Table 3. CIE L*, a*, and b* Color Values for the Inner Shell of Chestnuts

variety	L* [a]	A*	b*	hue (h*)	chroma (c*)
Ungi	53.67ab	14.98abc	24.39ab	−0.08bcd	28.66abc
Chukpa	52.68b	12.90cd	20.18cd	0.00bc	23.96e
Okkwang	51.92b	15.85ab	24.49ab	0.02b	29.19abc
Yuma	52.15b	13.99bcd	23.54b	−0.15bcd	27.44bcd
Ichi	52.94b	13.57bcd	23.49b	−0.25d	27.19bcd
Ipyung	56.35a	13.44cd	24.28ab	−0.25d	27.76abcd
Daekukjosaeng	55.06ab	11.99d	20.66cd	−0.16bcd	23.91e
Chundaejunjosaeng	48.22c	13.44bcd	24.28cd	0.05b	24.86de
Shinmyung	53.48ab	13.98bcd	24.73ab	−0.21cd	28.42abc
Nokjo	52.38b	13.27cd	22.46bc	−0.13bcd	26.11cde
Daap	53.72ab	16.35a	25.00ab	0.04b	29.90ab
Gyunchung	42.58d	13.89bcd	18.26d	0.20c	23.08e
Sukchoo	53.09b	13.56bcd	23.99ab	−0.25d	27.59abcd
Daedanpa	52.39b	15.93ab	26.23a	−0.10bcd	30.72a
F-value[b]	11.48***	2.96***	7.55***	4.77***	5.82***

[a] Mean values within a column followed by same letter are not significantly different at $a = 0.05$. [b] *, **, and *** mean significant at $p = 0.05$, 0.01, and 0.001, respectively.

Table 4. CIE L*, a*, and b* Color Values for the Flesh of Chestnuts

variety	L* [a]	a*	b*	hue (h*)	chroma (c*)
Ungi	78.21	1.90abc	33.00abc	1.36	33.06
Chukpa	78.77	3.01abc	35.46ab	−5.32	35.60
Okkwang	75.93	3.72ab	35.45ab	−1.29	35.68
Yuma	80.38	2.28abc	36.53ab	8.84	36.61
Ichi	80.89	1.96abc	32.66ab	2.18	32.73
Ipyung	77.26	3.24abc	38.20a	0.16	38.11
Daekukjosaeng	80.21	2.12abc	36.76ab	0.29	36.84
Chundaejunjosaeng	77.66	3.51ab	36.02ab	1.44	36.21
Shinmyung	80.30	1.36c	31.80bc	1.03	31.84
Nokjo	80.79	1.78bc	35.54ab	0.72	35.59
Daap	76.05	3.77a	33.69ab	−9.02	33.92
Gyunchung	76.22	3.53ab	28.52c	−0.73	28.79
Sukchoo	81.09	2.17abc	35.97ab	−3.56	35.74
Daedanpa	78.46	1.29c	34.14ab	0.69	34.17
F-value[b]	1.52	2.32*	2.49**	1.42	1.75

[a] Mean values within a column followed by same letter are not significantly different at $a = 0.05$. [b] *, ** and *** mean significant at $p = 0.05$, 0.01, and 0.001, respectively.

In the inner shell, all color values were significantly different ($p > 0.001$) with varieties. The L* value ranged from 42.58 to 56.35; the Ipyung variety was highest and the Gyunchung variety was the lowest at 42.58. The CIE a* value range was 11.99−16.35 and the b* value range was 18.26−26.23.

For the chestnut flesh, a* and b* values were significantly different ($p > 0.001$), but the L* value did not differentiate among varieties.

Texture. The textural results of the chestnut flesh analyzed using a puncture test are shown in Table 5. ANOVA analysis of the results revealed that the firmness of chestnut flesh was significantly different among varieties. The firmness of the Ungi variety was highest at 9.20 kg, and Gyunchung was the lowest at 4.41 kg.

Peeling Ratio. Table 6 shows the peeling ratios by variety. Peeling ratios were significantly different among varieties. The average peeling ratio was 63.79%, and the Okkwang variety was the easiest to peel with a peeling ratio of 85.29%. Ungi, Ichi, Shinmyung, Gyunchung, Sukchoo, and Daedanpa varieties had low peeling ratios.

Table 5. Firmness of the Chestnut Flesh

variety	firmness (kg)[a]
Ungi	9.20 ± 0.76[a]
Chukpa	5.17 ± 0.61[fg]
Okkwang	5.25 ± 0.42[efg]
Yuma	4.89 ± 0.51[gh]
Ichi	5.86 ± 0.65[cde]
Ipyung	6.53 ± 0.73[b]
Daekukjosaeng	5.47 ± 0.63[defg]
Chundaejunjosaeng	5.25 ± 0.56[efg]
Shinmyung	6.11 ± 0.72[bc]
Nokjo	5.45 ± 0.56[defg]
Daap	5.14 ± 0.74[fg]
Gyunchung	4.41 ± 0.41[h]
Sukchoo	6.02 ± 0.44[bcd]
Daedanpa	5.74 ± 0.71[cdef]
F-value[b]	36.10***

[a] Mean values within a column followed by same letter are not significantly different at $a = 0.05$. [b] *, **, and *** mean significant at t $p = 0.05$, 0.01, and 0.001, respectively.

Table 6. Peeling Ratio of 14 Chestnut Varieties

variety	peeling ratio (%)[a]
Ungi	55.47 ± 3.17[efg]
Chukpa	74.14 ± 5.03[b]
Okkwang	85.29 ± 3.69[a]
Yuma	71.28 ± 11.93[bc]
Ichi	50.25 ± 5.68[g]
Ipyung	67.21 ± 0.93[bcd]
Daekukjosaeng	61.58 ± 3.21[cdef]
Chundaejunjosaeng	69.54 ± 5.20[bcd]
Shinmyung	58.32 ± 16.71[defg]
Nokjo	66.29 ± 4.66[bcde]
Daap	63.49 ± 8.35[bcdef]
Gyunchung	53.17 ± 13.91[fg]
Sukchoo	58.82 ± 7.37[defg]
Daedanpa	58.27 ± 1.67[defg]
F-value[b]	7.68***

[a] Mean values within a column followed by same letter are not significantly different at $a = 0.05$. [b] *** means significant at $p = 0.001$.

Table 7. Pearson Correlation Coefficients between Physicochemical Factors and Peeling Ratio

physicochemical factor	peeling ratio[a]
tannin content of inner shell	−0.57*
tannin content of outer shell	0.43
CIE L* for inner shell	0.13
CIE a* for inner shell	0.11
CIE b* for inner shell	0.01
CIE L* for outer shell	−0.22
CIE a* for outer shell	−0.31
CIE b* for outer shell	−0.39
soluble sugar content in flesh	−0.25
firmness	−0.31

[a] * means significant at $p = 0.5$.

Correlation Coefficients. The correlations between tannin content, color value, soluble sugar content, and firmness, and the peeling ratio were analyzed; results are shown in Table 7.

A negative correlation was found between the tannin content of the inner shell and the peeling ratio ($r = -0.57$*), whereas a positive correlation was found between peeling ratio and the tannin content in the outer shell ($r = 0.43$). The chestnut with the higher tannin content of the inner shell has the lower peeling ratio. The condensed tannins in the chestnut inner shell may form complexes with protein or carbohydrate in chestnut flesh. Hiromichi et al. (*7*) and Tanaka et al. (*15*) suggested that the adhesive force between the pellicle cells and the flesh depends on tannin accumulation in the pellicle cells, and our results support these findings.

A negative correlation was found between the CIE L*, a*, and b* color values of the outer shell and the peeling ratio ($r = -0.22$, −0.31, and −0.39, respectively). But a positive correlation was found between the CIE L*, a*, and b* values of the inner shell and the peeling ratio ($r = 0.13$, 0.11, and 0.01, respectively). The higher CIE L*, a*, and b* values of chestnut outer shell showed the lesser peeling ratio, whereas the higher CIE L*, a, and b* values of chestnut inner shell showed the higher peeling ratio.

A negative correlation exists between the soluble sugar content in the chestnut flesh and peeling ratio ($r = -0.31$). The chestnut containing high soluble sugar in the flesh was difficult to peel.

Among the analyzed physicochemical factors, the tannin content of the inner shell was found to have highest correlation coefficient (r =−0.57*) with the peeling ratio. From these results, it was suggested that the tannins in the pellicle led to difficulty in peeling off the pellicles of chestnut.

In the future, it will be necessary to clarify the mechanism of binding between the pellicle and embryo, and the structure of the most influencing tannin. And these data may be used to develop a new cultivar, with a pellicle easily peeled off, which might be bred by introducing the character of less condensed tannin content.

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