INTRODUCTION
AZUKI PRODUCTS ARE COMMON IN MANY ASIAN COUNTRIES. ABOUT 70% of azuki consumed in Japan is used to make sweetened bean paste, either with or without the seed coat (Japan Bean Fund Association, 1987). Sweetened azuki paste is used as a filling in steamed rice rolls, donuts and sweet rice paste (mochi) (Sperbeck, 1981; McClary et al., 1989; Lumpkin and McClary, 1994).

In azuki paste production, cooking beans is the most important process affecting yield and quality of paste (Nissin Sugar Manufacturing Co., 1989; Dae Doo Food’s Co., 1992). During boiling, beans absorb water, and pectic compounds in the middle lamella are solubilized so that each cotyledon cell is separated (Drager, 1983). If beans are undercooked, part of the cotyledon is removed with the seed coat during the straining process, decreasing paste yield. In overcooked beans, the cotyledon cell membrane is broken so that starch and protein are dispersed into the cooking media and subsequently washed off, decreasing paste yield and resulting in sticky sweetened paste (Abe, 1987).

Limited research has been reported on factors influencing azuki paste yield and quality, including cultivar, physical and chemical characteristics of beans and cooking time. The Japan Bean Fund Association (1989) reported influences of cultivar and growing location on particle size of azuki paste, and also the relationship between particle size of paste and perceived smoothness of sweetened paste. Soma (1988) determined particle size distribution of azuki paste prepared from different cultivars and reported that median particle size of paste ranged from 142 to 157 mesh. Paste particle size is an important quality parameter of azuki paste and its determination is mainly by a long and laborious sieving test.

Therefore, our objectives were: to evaluate chemical and physical characteristics of beans, and yield and particle size of unsweetened paste from a newly bred azuki cultivar, WSU 262 and cv Erimo (the only cultivar commercially grown in Washington); to investigate effects of cooking time on paste yield, composition and particle size of unsweetened paste; and to develop a simple and fast test for determination of particle size of paste.

MATERIALS & METHODS
Materials
Azuki cv Erimo grown in 1993 in the state of Washington was purchased from Columbia Bean and Produce Co. (Moses Lake, WA). WSU 262, grown in the state of Washington in 1994, was obtained from Dr. Thomas Lumpkin, Dept. of Crop & Soil Sciences, Washington State Univ., Pullman, WA.

Beans were soaked for 12h and seed coats removed by hand. Cotyledons were frozen and lyophilized. For the determination of chemical composition, whole beans and dried cotyledons were ground on a Udy cyclone sample mill (Udy Co., Fort Collins, CO) fitted with a perforated screen with 0.5 mm round openings. Unsweetened paste was lyophilized for chemical analysis and sedimentation testing.

Chemical analysis
Protein contents (N × 6.25) of whole beans and paste were determined with a Leco instrument (Leco Corp., St. Joseph, MI) equipped with a thermoconductivity detector. Moisture content was determined by forced air convection oven drying for 1h at 130°C (AACC Method 44-15A, 1983), ash by dry combustion for 16h at 580°C (AACC Method 08-01, 1983) and free lipid by petroleum ether extraction, followed by evaporation to constant weight under vacuum (AACC Method 30-25, 1983). Total dietary fiber content was determined by the procedure of Prosky et al. (1988). Starch content was determined after its enzymatic conversion to glucose by successive treatment with α-amylase, protease and amyloglucosidase (Prosky et al., 1988). The released glucose was determined with glucose oxidase-peroxidase reagent (Lloyd and Whelan, 1969).

Physical characteristics
Thousand seed weight, water absorption of beans during soaking and cooking, and hardness of cooked beans were determined. Beans (50g) were soaked in 250 mL distilled water for 24h in 2h intervals. Weight increases in the soaked beans were determined and expressed as percentage of initial unsoaked beans.

Water absorption of beans during cooking was determined at cooking times from 10 to 60 min in 10 min intervals and expressed as percent weight increase. Hardness of cooked beans was measured using a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). A single bean was placed between two flat plates and compressed by 50% at a speed of 1.0 mm/sec. Twenty randomly chosen beans were tested and mean results were recorded.

Hardness of beans cooked from 60 min to 120 min in 15 min intervals was determined using the FTC Model TMS-90 Texture Test System (Food Technology Co., Rockville, MD) equipped with a universal cell, Model CE-1. Watanabe et al. (1983) cooked azuki for 90 min for production of paste. The universal cell consisted of a cylinder measuring 57.4 mm dia and 76.5 mm in ht, a close-tolerance piston measuring 57.4 mm dia and an extrusion grid measuring 57.4 mm in dia with 11.24 mm parallel slots. The extrusion grid was fitted into the bottom of the cylinder to support the cooked beans. Cooked beans (30g) were placed in the cylinder and compressed with the piston at a...
speed of 2 mm/sec to 5 mm. Peak force was recorded as hardness of cooked bean.

Preparation of unsweetened paste

Unsweetened azuki paste was prepared according to the methods described by Nissin Sugar Manufacturing Co. (1989) and Dae Doo Food’s Co. (1992), with modifications in crushing and screening processes. Beans (1000g) were cooked in 13L of distilled water from 60 to 120 min in 15 min intervals using a Compak V’S Drive® steam cooker (Reliance Electric Co., Cleveland, OH). Both cooked beans and cooking water were decanted to a container and cooled to about 60°C by adding ~7L of cold water while monitoring the temperature. Cooked beans, together with the added water, were passed through a Pulp Finisher (LangskenKamp Co., Indianapolis, IN) fitted with a 1 mm round opening perforated screen to crush cooked beans and remove seed coats. Cotyledon particles that passed through the screen were collected into a container with water. Separated seed coats were dispersed in 10L water and passed through the pulp finisher a second time to collect cotyledon particles. The particles were combined and allowed to settle for 15 min. The supernatant was decanted and water was added to bring the total volume to 10L. Cotyledon particles were dispersed well and passed through the pulp finisher fitted with 0.5 mm perforated screen to further remove seed coat particles. After settling for 15 min, the supernatant was decanted. The particles were further washed twice by adding 15L water, dispersing them, letting the particles settle and decanting the supernatant. Excess water was removed from the slurry of the cotyledon particles using a Whatman® #4 filter paper with vacuum. The resulting particles had about 68% moisture, as determined by oven drying for 12h at 105°C. Paste yield (dry weight basis) was determined based on the initial weight of whole beans before cooking.

Paste particle size

Wet sieving method. Unsweetened paste (100g) was dispersed in 500 mL water using a magnetic stirrer, then poured onto a USA standard #140 sieve with 106 µm openings in a plastic container. Water (4L) was added, and the unsweetened paste was sieved by hand, shaking the screen 350 times under water. Excess water from paste fractions, one on the screen and the other in the water, were removed by filtering on preweighed Whatman® #4 filter paper with vacuum. Wet paste fractions on the filter paper were dried at 105°C for 12h. The percentage weight of paste particles that passed through the 106 µm openings was calculated and used as an index of particle size of unsweetened paste.

Sedimentation volume test. The sedimentation volume was developed as a simple and fast method to estimate mean particle size of unsweetened azuki paste. Weight of unsweetened paste and reading time for the sedimentation volume test was optimized by running the test on unsweetened pastes prepared from cv Erimo cooked for 60, 70 or 90 min. Weight of unsweetened paste ranged from 1 to 10 g and sedimentation volume was read every 1 min for 5 min.

Freeze-dried unsweetened paste was dispersed in 50 mL water in a 100 mL stoppered graduated glass cylinder and shaken vigorously 10 times. Immediately after shaking, water was added to bring the total volume to 100 mL and the content was mixed by inverting the cylinder 10 times. After the last inversion, the cylinder was placed in an upright position and the volume of the sedimented paste was read every 1 min for 5 min. Sedimentation tests of pastes from beans cooked from 60 to 120 min in 15 min intervals were conducted by reading the volume at 2 min after shaking with 6 g unsweetened paste, as described.

Scanning electron microscopy of unsweetened paste particles

Unsweetened paste particles were sprinkled on double-sided carbon tape adhered to an aluminum stub, coated with gold using a Hummer sputter coater (Technics, Inc., San Jose, CA) and viewed under a Hitachi S-570 scanning electron microscope (Hitachi, Japan) operated at 20 KV.

Statistical analysis

Data were statistically analyzed with the SAS computer software package (SAS Institute, Inc., 1986) using analysis of variance, Fisher’s least significant difference (LSD) procedure and Pearson correlation coefficient. Significance was defined at P<0.05. All determinations were made at least in duplicate and means are presented.

RESULTS & DISCUSSION

Characteristics of azuki

Two azukis, cv Erimo and WSU 262 were different in size and chemical composition (Table 1). Cultivar Erimo was much smaller than WSU 262. Thousand seed weight was much lower for cv Erimo (115.7g), and higher for WSU 262 (200.8g) than data reported by Soma (1988), where 1000 bean weight ranged from 138 to 172 g for five azuki cultivars, including cv Erimo.

Protein contents of beans were 24.2% for cv Erimo and 23.4% for WSU 262, within the range of 6 azuki cultivars, including Takara, Erimo, Kotobuki, Hayate, Hatsune and Otori, as reported by Tjahjadi and Breene (1984) and Yoshida et al. (1988). Ash contents of beans were 4.24% for cv Erimo and 3.95% for WSU 262, higher than reported by Kay (1979), Harukawa (1990) and Hsieh et al. (1992). Free lipids and starch contents of both cultivars were comparable to reports by Kay (1979), Tjahjadi and Breene (1984), Harukawa (1990) and Hsieh et al. (1992). Total dietary fiber contents of cv Erimo and WSU 262 were 19.2% and 17.8%, respectively, similar to the result of Hsieh et al. (1992), but much smaller than reported by Su and Chang (1995). Large seeded WSU 262 was lower in protein, ash and fiber, but higher in starch than cv Erimo.

Azuki cotyledons, 90.8% of whole beans for cv Erimo and 92% for WSU 262, were higher in protein, lipid and starch, but lower in ash and fiber than whole beans. Similar to whole beans, protein and ash of cotyledons were higher for cv Erimo than WSU 262 (Table 1). However, there was no difference in fiber content of cotyledon between the two azukis. Again, cotyledons of WSU 262 were higher in starch content than those of cv Erimo.

Water absorption patterns of beans during soaking, for both cv Erimo and WSU 262, followed a sigmoid curve (Fig. 1). Similar water absorption patterns of azuki cultivars were reported by Soma (1988). However, cv Erimo absorbed more water more quickly during soaking than WSU 262. This confirmed previous reports that small beans absorb water faster than larger beans (Shiota et al., 1983; Yoshida et al., 1989).

Fig. 1 — Water absorption of azuki during soaking.
Water absorption of beans during cooking increased almost linearly up to 50 min in cv Erimo and up to 60 min for WSU 262 (Fig. 2). Again, cv Erimo absorbed more water more quickly than WSU 262. Less water absorption at 60 min for cv Erimo and at 70 min for WSU 262 was due to ruptured seed coats and consequent losses of cotyledon cells into cooking water.

Hardness of cooked beans, determined by the single bean test, decreased as cooking time increased except for WSU 262 cooked for 10 min (Fig. 3A). Cultivar Erimo was lower in hardness scores for cooked beans from 20 min to 60 min than WSU 262. Low hardness value of WSU 262 cooked for 10 min was due to the breakage susceptibility. After 50 min cooking, the seed coat broke open and the cotyledon began to disintegrate, especially for cv Erimo. Therefore, the hardness test of single cooked beans no longer produced reproducible results. Hardness of beans cooked longer than 60 min was determined by a bulk test, compressing 30 g of cooked beans instead of a single bean.

Hardness by that test decreased consistently as cooking time increased from 60 to 120 min in 15 min intervals for cv Erimo and from 60 to 90 min in 15 min intervals for WSU 262. There were no changes with further cooking (Fig. 3B). In the production of azuki paste, cooked beans are first crushed to facilitate the sieving separation of paste particles from the seed coat. Since the bulk test of cooked bean hardness simulates the crushing process during azuki paste production, this test could be used to estimate optimum cooking time of azuki for paste production.

**Cooking time and azuki paste production**

Effects of cooking time on yield and composition of unsweetened paste were summarized (Table 2). Azuki paste yield ranged from 68.6% to 71.9% for cv Erimo and 57.3% to 75.6% for WSU 262, higher by 3% to 7% than reported by Abe (1987). Generally, the longer the cooking time, the higher the yield of unsweetened paste for both cv Erimo and WSU 262. However, extending cooking time did not increase paste yield for cv Erimo. The largest increase in yield of unsweetened paste was 2.4% between 60 min and 75 min cooking. In contrast to cv Erimo, there were increases in yield of paste from 60 to 90 min cooking for WSU 262 (18.3% increase from 57.3% at 60 min cooking). The results proved that WSU 262 required longer cooking time for paste production and that WSU 262 produced a higher yield of unsweetened paste than cv Erimo.

The ash content of azuki paste (0.75–1.01%) was ¼ that of whole beans (3.95–4.24%), because of loss of minerals from whole beans during paste production. The ash content of paste decreased for cv Erimo as beans were cooked from 60 to 120 min, but increased for WSU 262 as beans were cooked from 60 to 90 min. Protein content of unsweetened paste increased from 26% to 28.4% for cv Erimo as beans were cooked from 60 to 120 min, but increased for WSU 262 as beans were cooked from 60 to 90 min. Protein content of unsweetened paste increased from 26% to 28.4% for cv Erimo and from 25.6% to 26.8% for WSU 262 as beans were cooked from 60 min to 120 min. This result was consistent with the report by Su and Chang (1995). Overall, protein content of unsweetened paste was higher for cv Erimo than WSU 262.

The starch content of unsweetened paste was lower than expected and was not consistent as cooking time increased for both cv Erimo and WSU 262. Since gelatinization of starch granules inside cotyledon cells in the unsweetened azuki paste is suppressed by the cell wall.

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**Table 1—Characteristics of azuki whole beans and cotyledons**

<table>
<thead>
<tr>
<th>Samples</th>
<th>1000 Seed wt (g)</th>
<th>Protein (%)</th>
<th>Ash (%)</th>
<th>Free lipid (%)</th>
<th>Starch (%)</th>
<th>Total dietary fiber (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cv Erimo</td>
<td>115.7b</td>
<td>24.2a</td>
<td>4.24a</td>
<td>0.32a</td>
<td>55.8b</td>
<td>19.2b</td>
</tr>
<tr>
<td>WSU 262</td>
<td>200.8a</td>
<td>23.4a</td>
<td>3.95b</td>
<td>0.37a</td>
<td>59.3a</td>
<td>17.8a</td>
</tr>
<tr>
<td>Cotyledon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cv Erimo</td>
<td>—</td>
<td>26.2a</td>
<td>3.96a</td>
<td>0.36a</td>
<td>60.2b</td>
<td>10.4b</td>
</tr>
<tr>
<td>WSU 262</td>
<td>—</td>
<td>24.6b</td>
<td>3.36b</td>
<td>0.38b</td>
<td>62.2b</td>
<td>10.3b</td>
</tr>
</tbody>
</table>

a-b Values with different letters in the same column for whole beans and for cotyledon separately are significantly different (P<0.05).

**Table 2—Yield, ash, protein and starch contents of unsweetened azuki pastes at selected cooking times**

<table>
<thead>
<tr>
<th>Cooking time (Min)</th>
<th>Yield (%)</th>
<th>Ash (%)</th>
<th>Protein (%)</th>
<th>Starch (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cv Erimo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>68.6b</td>
<td>1.01a</td>
<td>26.0c</td>
<td>51.5b</td>
</tr>
<tr>
<td>75</td>
<td>71.0b</td>
<td>0.87a</td>
<td>25.9g</td>
<td>56.4f</td>
</tr>
<tr>
<td>90</td>
<td>71.0b</td>
<td>0.87a</td>
<td>26.2e</td>
<td>52.9g</td>
</tr>
<tr>
<td>105</td>
<td>71.6d</td>
<td>0.75d</td>
<td>27.4e</td>
<td>52.1d</td>
</tr>
<tr>
<td>120</td>
<td>71.9c</td>
<td>0.80c</td>
<td>28.4d</td>
<td>57.0h</td>
</tr>
<tr>
<td>WSU 262</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>57.3c</td>
<td>0.78c</td>
<td>25.6c</td>
<td>47.3c</td>
</tr>
<tr>
<td>75</td>
<td>70.2b</td>
<td>0.85b</td>
<td>25.4d</td>
<td>44.6f</td>
</tr>
<tr>
<td>90</td>
<td>75.6de</td>
<td>1.01e</td>
<td>25.3c</td>
<td>47.1f</td>
</tr>
<tr>
<td>105</td>
<td>76.6e</td>
<td>1.00e</td>
<td>26.7c</td>
<td>56.4g</td>
</tr>
<tr>
<td>120</td>
<td>74.2de</td>
<td>0.98e</td>
<td>26.8c</td>
<td>55.7h</td>
</tr>
</tbody>
</table>

a-d Values with different letters in the same column are significantly different (P<0.05).
(Fujimura and Kugimiya, 1993), the use of an enzymatic assay may have underestimated the starch content of unsweetened paste. Tovar et al. (1990) reported that limited enzymatic accessibility to starch in cooked red kidney bean flour influenced the accuracy of starch determination by enzymatic procedures. Also, determination of starch content is affected by paste granule damage and particle size. Higher starch contents in pastes from WSU 262 cooked 105 and 120 min could be due to increased paste particle damage and increases in the amount of gelatinized starch by extended cooking, which allow starch granules to be more easily attacked by α-amylase.

There were differences in percentages of unsweetened paste particles <106 µm, determined by the wet sieving test, between cv Erimo and WSU 262 (Fig. 4). The percentage of unsweetened paste passed through the 106 µm sieve was >40% for cv Erimo and <25% for WSU 262. Soma (1988) determined particle size distribution of paste from 4 azuki cultivars by a wet sieving test using sieves with 64, 73, 106 and 150 µm openings and reported that percentage of unsweetened paste particles <106 µm ranged from 42.18 to 63.60%. Therefore, while particle size distribution of paste from cv Erimo was comparable to the data of Soma (1988), WSU 262 produced larger paste particles. For cv Erimo, percentage of unsweetened paste particles <106 µm increased as beans were cooked from 60 to 90 min and decreased with further cooking. Decrease in percentage of unsweetened paste particles <106 µm at 105 and 120 min cooking for cv Erimo was due to damaged and leached starch granules in the unsweetened paste, which clog the openings of sieves or glue paste particles together. Percentage of unsweetened paste particles passed through 106 µm was not affected by cooking time for WSU 262.

Unsweetened paste particles from beans cooked for 90, 105 or 120 min were further examined using scanning electron microscopy (Fig. 5). There were large differences in paste particle size between cv Erimo and WSU 262 at each cooking time. Cultivar Erimo produced much smaller paste particles than WSU 262, which confirmed results...
Particle Size of Unsweetened Azuki Paste . . .

of the wet sieving test using 106 μm sieve. However, there was no evident difference in particle size among pastes from beans cooked for different times for both cv Erimo and WSU 262.

**Sedimentation volume test of azuki paste**

Freeze-dried unsweetened paste particles prepared from cv Erimo cooked for 60, 75 or 90 min were used to develop a sedimentation volume test for the simple and fast estimation of mean particle size of paste. Independent of unsweetened paste weight, clear reading of sedimentation volume could be obtained at 2 min after the cylinder was placed in an upright position. Also, there were largest differences in mean square of variability in sedimentation volumes among the pastes at 2 min reading time with 6 g of paste. Therefore, a 2 min reading time and 6 g were considered as optimum condition for the sedimentation volume test of unsweetened azuki paste in a 100 mL graduated cylinder.

Sedimentation volumes of unsweetened pastes at selected cooking times (Fig. 6) showed a similar trend to percentage of unsweetened paste particles <106 μm (Fig. 4). The sedimentation volume of unsweetened paste was higher for cv Erimo than for WSU 262 at all cooking times. Sedimentation volume of paste prepared from cv Erimo increased as cooking time increased from 60 to 90 min, but decreased when beans were cooked longer than 90 min. Sedimentation volume of paste prepared from WSU 262 was not affected by cooking time. There was a highly significant correlation (r = 0.918**) between percentage of unsweetened paste particles <106 μm and sedimentation volume of unsweetened paste (Fig. 7). However, when the two azukis were considered separately, correlation between percentage of paste particles <106 μm and sedimentation volume test was not significant (r = 0.305) for WSU 262. Particle size of unsweetened pastes from WSU 262 cooked from 60 to 120 min were similar and not affected by cooking time, as indicated by percent particles <106 μm and sedimentation volume. However, in cv Erimo, there was highly significant correlation (r = 0.914**) between percentage of particles <106 μm and sedimentation volume of paste

**REFERENCES**


Harukawa, A. 1990. Standard Tables of Food Consumption in Japan. Joshi Eiyo Daigaku (Ladies Nutrition University), Shappan Bu (Publishing Department), Tokyo, Japan.


Soma, S. 1988. Quality and Constituents of Beans. Hokkaido Association for the Advancement of Beans, Hokkaido Agricultural Experiment Station, Japan.


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