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Effects of pressurized cooking on the relationship between the chemical compositions and texture changes of lotus root (*Nelumbo nucifera* Gaertn.)

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Abstract

The texture of lotus root is hard and crispy, and the root can maintain its appearance and mouth feel after cooking at 100 °C for over 60 min. This study tried to elucidate relationships between pressurized cooking treatments (at 100 °C for 1, 3, 5, 10, 20, 30, 60 min and at 110 °C, 121 °C and 132 °C for 1, 3, 5, 10, 20, 30 min, respectively) and changes in its chemical composition and texture. Results showed that the contents of hemi-cellulose and cellulose of lotus root decreased with increasing pressurized cooking temperature/duration during heat treatment while lignin content remained almost the same. The NDF contents decreased more than did the ADF contents. Relative hardness of lotus root decreased with increasing pressurized cooking temperature/duration while solid loss increased ($P < 0.05$). These results could be used as references for the lotus root industry, as well as an academic basis for future development.

Keywords: Lotus root; Pressurized cooking; Dietary fibre; Relative hardness

1. Introduction

Lotus root (*Nelumbo nucifera* Gaertn.) is an aquatic vegetable, which is harvested in autumn in Taiwan. It contains abundant amount of protein, amino acids, dietary fibre, carbohydrates and vitamins C, B_1, and B_2 (Wu, 1987). It is widely favoured by Asian people because of its hard and crispy texture, special aroma and mouth feel. It is often used to make different dishes, such as salads, pickled vegetables, stir-fried food and confections. It is often used to make instant lotus powder, as a drink, thickener or as an ingredient for making desserts.

Texture is an important characteristic of food. It is used as the quality and price index of vegetables and fruits. Most plant cell walls are composed of cellulose, hemi-cellulose, lignin, pectin and a little protein, lipid and other substances (Northcote, 1958). The intercellular spaces are packed with moisture, generating cell turgidity on the flexible cell walls, forming the characteristics of plant texture (Meyer, 1976). Plant foods soften during heating because of the loss of water and cellular solutes (Femenia, Selvendran, Ring, & Robertson, 1999). In addition, heating facilitates the decomposition of pectin and intercellular adhesion substances, resulting in weakened cell walls, softened texture, and decrease of fracturability (Loh & Breene, 1982; Sterling, 1968). As the temperature increases, the texture of vegetables softens further. Besides, due to the differences in the chemical composition and histological structure of different fruits and vegetables, changes differ after heating (Reeve, 1970, 1977; Rojas, Delbon, Maragoni, & Gerschenson, 2002). Moreover, different cooking methods will cause different decreases in the dietary fibre of vegetables (Rehman, Islam, & Shah, 2003).

In Asia, lotus root is often cooked at 100 °C (boiling water) for several hours, to make lotus root tea and canned desserts. It can maintain its appearance and mouth feel even after being heated at high temperatures for a long

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time. There are very few researches on the processing methods and texture characteristics of lotus root. This study examined the changes and effects of pressurized cooking on the chemical composition and texture of lotus root, which could be used as references for the development of processed lotus root products.

2. Materials and methods

2.1. Materials

Lotus root was obtained from a local farmer and stored at 5 °C. Inedible parts, including nodes and peel, were removed manually with the help of a sharp knife. Edible parts of the lotus root were properly cut into dices of about $1 \times 1 \times 1\ \text{cm}^3$. All the chemicals in the investigation were of analytical grade and commercially available.

2.2. Proximate composition analysis

Proximate compositions of lotus root, including moisture, crude protein, crude fibre, crude fat and crude ash were analyzed according to AOAC methods (1990). Carbohydrate content was obtained by subtracting the percentage contents of moisture, crude protein, crude fibre, crude fat and crude ash from 100.

2.3. Pressurized cooking treatments

Lotus root samples (50 ± 0.5 g) were placed in a tin-plated can containing 150 g of distilled water and sealed with seamer and then placed in an autoclave (CYTM-102, Tung-Fung Machinery, Co., Taichung, Taiwan) and then pressurized-cooked at different temperatures and duration (at 100 °C for 1, 3, 5, 10, 20, 30, 60 min; at 110 °C, 121 °C, 132 °C for 1, 3, 5, 10, 20, 30 min, respectively). After pressurized cooking, the lotus root samples were cooled.

2.4. Texture analysis

A rheometer (Model CR-200 D, Sun Scientific Co., Tokyo, Japan) mounted with a plunger (adapter No. 7) was used. The adapter was placed 0.7 cm through the centre of each sample, then moved upward to the plunger at a speed of 20 mm/min. Twenty replicates from randomly selected samples were run for each treatment. The relative hardness unit was expressed as a percentage.

$$\text{Relative hardness}\ (\%) = \text{heated sample hardness}\ (\text{g/cm}^2) / \text{fresh sample hardness}\ (\text{g/cm}^2) \times 100.$$

2.5. Dietary fibre analysis

Contents of neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, hemi-cellulose and lignin of lotus root were determined by the continuous detergent analysis method of Van Soest and Wine (1967) and Rehman et al. (2003).

2.6. Pectin loss analysis

The pectin loss of the lotus root liquid, under different pressurized cooking conditions, was determined by the carbazole dyeing method of Bitter and Muir (1962) and expressed as anhydro-galacturonic acid unit (AGA).

2.7. Turbidity analysis

According to the methods of Chanlder and Robertson (1983), the cooked lotus root liquid was centrifuged (800*g*, 10 min, 4 °C) with a Hettich Model Mikro 22R centrifuge (Tuttlingen, Germany). The absorbance of the supernatant was measured at 660 nm with a Hitachi U-2800 A spectrophotometer (Tokyo, Japan) against distilled water as the blank.

2.8. Solid loss analysis

Cooked liquid (10 g) was obtained from the lotus root heated under different conditions (W_1), and then placed in an oven at 105 °C until equilibrium (W_2). A percentage of solid loss was found after the calculation as follows

$$\text{Solidloss}\ (\%) = [(W_1 - W_2)/W_1] \times 100.$$

All measurements were carried out in triplicate and expressed on a dry matter basis.

2.9. pH value analysis

Lotus root liquid (10 ml) was measured with a pH meter (inoLab pH Level 1, Suntex instruments Co., LTO, Taichung, Taiwan) at room temperature (25 °C).

2.10. Statistical analysis

The data were examined by the analysis of variance (ANOVA) of the Statistic Analysis System (SAS Institute, Cary, NJ). Duncan's multiple range test (DMRT) was used to determine the significance of the means at $P < 0.05$.

3. Results and discussion

Fresh lotus root contains 83.2% moisture, 1.51% crude protein, 0.62% crude fat, 1.23% crude fibre, 0.87% crude ash and 12.6% carbohydrate (Table 1). It contains more moisture than most plants. The carbohydrate content is greater than the crude protein, crude fat and crude ash contents. The pH of lotus root liquid is 6.18. The relative hardness decreased with the increasing heating temperatures/duration during heat treatment ($P < 0.05$) (Table 2). When heated at 100 °C, 110 °C, 121 °C and 132 °C, for a duration of 1 min, the relative hardness values were 92.50%, 78.39%,

Table 1
Proximate composition of fresh lotus root

Composition[1]	Content (%)[2]
Moisture	83.20 ± 0.63
Crude ash	0.87 ± 0.14
Crude fat	0.62 ± 0.08
Crude fibre	1.23 ± 0.16
Crude protein	1.51 ± 0.42
Carbohydrate	12.6 ± 0.46

[1] Based on fresh weight.
[2] Each value is expressed as mean ± standard deviation ($n = 3$).

60.39%, and 51.54%, respectively. When the duration was increased to 10 min, these significantly decreased to 72.42%, 47.37%, 17.51%, and 7.59%, respectively. After the duration increased to 30 min, the relative hardness values dropped to 45.57%, 30.37%, 13.62%, and 6.51%, respectively. The differences in the cell wall composition and contents are the major factors for determining the texture of many plant foods. Heating treatments will cause the textures of fruits and vegetables to soften and break down.

Table 3 shows the changes in solid loss during the pressurized cooking of lotus root. When heated at 100 °C for 1, 10, and 30 min, the solid losses were 0.52%, 4.72% and 8.83%, respectively ($P < 0.05$). After the temperature was increased to 110 °C, the solid losses at 10, 20, and 30 min were 9.12%, 11.24% and 11.40%, respectively. There were no apparent changes at 110 °C for 20 and 30 min. When heated at 121 °C and 132 °C for 10 min, the solid losses were 14.13% and 15.21%, respectively. The increase in the percentage of solid loss was not apparent after extending the duration to 30 min.

Table 2
Effects of pressurized cooking on relative hardness of lotus root

Cooking time (min)	Relative hardness (%)			
	100 °C	110 °C	121 °C	132 °C
0	100.00 ± 0.11[a1]	100.00 ± 0.21[a]	100.00 ± 0.13[a]	100.00 ± 0.16[a]
1	92.50 ± 0.50[b]	78.39 ± 0.42[b]	60.39 ± 0.54[b]	51.54 ± 0.50[b]
3	90.58 ± 0.52[c]	73.54 ± 0.50[c]	43.39 ± 0.34[c]	32.54 ± 0.38[c]
5	84.50 ± 0.50[d]	56.26 ± 0.65[d]	30.39 ± 0.31[d]	14.44 ± 0.71[d]
10	72.42 ± 0.38[e]	47.37 ± 0.55[e]	17.51 ± 0.55[e]	7.59 ± 0.36[e]
20	58.49 ± 0.50[f]	37.52 ± 0.18[f]	15.38 ± 0.72[f]	7.52 ± 0.42[e]
30	45.57 ± 0.52[g]	30.37 ± 0.22[g]	13.62 ± 0.48[g]	6.51 ± 0.55[f]
60	43.39 ± 0.54[h]	–	–	–

[1] Each value is expressed as mean ± standard deviation ($n = 3$). Mean values in a column with different letters are significantly different at $P < 0.05$.

Table 3
Effects of pressurized cooking on solid loss of lotus root

Cooking time (min)	Solid loss (%)			
	100 °C	110 °C	121 °C	132 °C
1	0.52 ± 0.02[f1]	1.73 ± 0.02[d]	3.78 ± 0.02[e]	5.17 ± 0.11[e]
3	0.88 ± 0.04[ef]	3.12 ± 0.03[c]	8.62 ± 0.07[d]	7.62 ± 0.06[d]
5	1.36 ± 0.01[e]	8.64 ± 0.04[b]	13.18 ± 0.05[c]	12.81 ± 0.06[c]
10	4.72 ± 0.03[d]	9.12 ± 0.02[b]	14.13 ± 0.07[b]	15.21 ± 0.06[ab]
20	6.58 ± 0.01[c]	11.24 ± 0.06[a]	14.65 ± 0.10[ab]	14.93 ± 0.16[b]
30	8.83 ± 0.02[b]	11.40 ± 0.10[a]	14.92 ± 0.09[a]	15.58 ± 0.20[a]
60	9.78 ± 0.09[a]	–	–	–

[1] Each value is expressed as mean ± standard deviation ($n = 3$). Mean values in a column with different letters are significantly different at $P < 0.05$.

Loh and Breene (1982) and Sterling (1968) pointed out that heating decomposes intercellular mucilage, resulting in weakened cell wall, softened texture, and decreased fracturability. It was, therefore, speculated that heating would cause the loss of water-soluble polysaccharides, leading to decrease of fracturability. The experimental results showed that the decrease in relative hardness had an important relationship with the percentage of solid loss. The solid loss of most fruits and vegetables, after heating, might involve soluble components, such as polysaccharides, proteins and a small fraction of the water-soluble vitamins and minerals.

The amount of each dietary fibre component (NDF, ADF, hemi-cellulose, cellulose and lignin) was determined from fresh and cooked lotus root. Fresh lotus root contains 25.0% NDF and 11.7% ADF, whereas, the amounts of hemi-cellulose, cellulose and lignin were 13.3%, 10.4%, and 1.3%, respectively (Table 4). Reductions in these dietary fibre components in each heated lotus root sample were observed to vary by cooking under different conditions. There was a gradually decreasing trend in the NDF and ADF contents when the heating time was increased.

With heating at 100 °C for 1–3 min, the NDF decreased from 24.8% to 24.2% and for 5–60 min, it decreased to 23.3–23.7%. There were no apparent changes in either case. ADF also had a decreasing trend. When heated at 110 °C for 10 and 30 min, the NDF values were 21.2% and 20.6%, respectively; at 121 °C they were 22.4% and 19.6%, respectively, and, at 132 °C, 21.7% and 19.3%, respectively. It is apparent from these results that reductions in NDF contents were comparatively greater than those of ADF contents, as a result of pressurized cooking. Extents of losses of these dietary fibre components became higher under the severe conditions of temperature and pressure involved during this cooking process. There were familiar changes in many fruits and vegetables during heat treatment (Rehman & Shah, 1994; Rehman et al., 2003; Vidal-Valverde, Frias, & Esteben, 1992).

The hemi-cellulose, cellulose, and lignin contents of lotus root changed under different pressurized-cooking treatments and there was a decrease in the dietary fibre content. When heated at 100 °C, there were no obvious changes in the hemi-cellulose or cellulose content, but the pectin loss of lotus root liquid, when heated at 100 °C for 60 min, increased from 0.016 mg/ml to 3.72 mg/ml; after heating at 110 °C, 121 °C and 132 °C for a duration of 30 min, the pectin losses of the liquid were 2.31, 2.87, and 3.21 mg/ml, respectively. With increase in pressurized cooking temperatures, the decreases in hemi-cellulose and cellulose were significant when heated for 5 min ($P < 0.05$), but changes in the lignin content were not apparent. As the pressurized

Table 4
Effects of pressurized cooking on major components of lotus root

Cooking temperature (°C)	Cooking time (min)	NDF (%)[1]	ADF (%)[2]	Major cell wall components			Cooked liquid	
				Hemi-cellulose (%)	Cellulose (%)	Lignin (%)	Pectin (mg/ml)	Turbidity
Fresh		25.0 ± 1.00[a][3]	11.7 ± 0.99[a]	13.3 ± 1.22[a]	10.4 ± 0.98[a]	1.3 ± 0.11[a]	0.016 ± 0.001[a]	0.004 ± 0.001[a]
100	1	24.8 ± 0.60[a]	11.5 ± 1.01[a]	13.3 ± 1.09[a]	10.4 ± 0.72[a]	1.1 ± 0.09[ab]	0.032 ± 0.001[b]	0.061 ± 0.004[b]
	3	24.2 ± 0.45[a]	11.1 ± 0.42[b]	13.1 ± 0.85[a]	10.3 ± 0.59[a]	0.8 ± 0.07[b]	1.47 ± 0.055[e]	0.151 ± 0.044[c]
	5	23.7 ± 0.60[ab]	11.2 ± 0.51[b]	12.5 ± 0.71[b]	10.1 ± 0.52[b]	1.1 ± 0.06[a]	1.64 ± 0.072[e]	0.143 ± 0.013[c]
	10	23.5 ± 0.21[b]	11.0 ± 0.79[b]	12.5 ± 1.03[b]	10.2 ± 0.81[ab]	0.8 ± 0.04[b]	1.86 ± 0.107[f]	0.148 ± 0.015[c]
	20	23.6 ± 0.14[b]	11.1 ± 0.32[b]	12.5 ± 0.96[b]	10.0 ± 0.64[b]	1.1 ± 0.06[ab]	2.11 ± 0.141[f]	0.333 ± 0.024[e]
	30	23.7 ± 0.30[b]	10.9 ± 0.71[b]	12.8 ± 0.71[b]	9.8 ± 0.61[b]	1.1 ± 0.07[ab]	2.24 ± 0.146[g]	0.453 ± 0.022[f]
	60	23.3 ± 0.44[b]	11.2 ± 0.65[b]	12.1 ± 1.03[c]	9.9 ± 0.34[b]	1.3 ± 0.08[a]	3.72 ± 0.224[h]	0.481 ± 0.034[f]
110	1	23.7 ± 0.30[b]	11.1 ± 0.62[ab]	12.6 ± 1.11[ab]	10.1 ± 0.84[ab]	1.0 ± 0.09[b]	0.942 ± 0.044[c]	0.115 ± 0.009[bc]
	3	23.1 ± 0.80[bc]	10.9 ± 0.84[b]	12.2 ± 0.67[b]	9.9 ± 0.72[b]	1.0 ± 0.04[b]	1.03 ± 0.067[d]	0.167 ± 0.011[c]
	5	22.8 ± 0.31[c]	10.7 ± 1.02[b]	12.1 ± 0.71[b]	9.8 ± 0.88[b]	0.9 ± 0.01[b]	1.53 ± 0.144[e]	0.215 ± 0.021[d]
	10	21.2 ± 0.40[d]	10.5 ± 0.71[b]	10.7 ± 0.84[c]	9.4 ± 0.42[c]	1.1 ± 0.03[ab]	1.75 ± 0.149[e]	0.241 ± 0.016[d]
	20	21.3 ± 0.42[d]	10.7 ± 0.53[b]	10.6 ± 0.24[c]	9.7 ± 0.51[b]	1.0 ± 0.04[b]	1.85 ± 0.121[f]	0.457 ± 0.028[f]
	30	20.6 ± 0.31[d]	9.9 ± 0.42[c]	10.7 ± 0.84[c]	8.8 ± 0.71[d]	1.1 ± 0.01[ab]	2.31 ± 0.175[g]	0.541 ± 0.019[g]
121	1	23.4 ± 0.40[b]	10.5 ± 1.01[b]	12.9 ± 0.71[a]	9.5 ± 0.41[b]	1.0 ± 0.05[b]	1.29 ± 0.013[de]	0.136 ± 0.011[bc]
	3	23.2 ± 0.61[b]	10.1 ± 0.72[bc]	13.1 ± 1.03[a]	9.2 ± 0.64[b]	0.9 ± 0.03[b]	1.47 ± 0.101[e]	0.141 ± 0.012[c]
	5	22.1 ± 0.34[c]	9.7 ± 0.44[cd]	12.4 ± 1.03[b]	8.8 ± 0.31[cd]	0.9 ± 0.07[b]	1.66 ± 0.136[ef]	0.255 ± 0.018[d]
	10	22.4 ± 0.41[c]	10.2 ± 0.51[bc]	12.2 ± 1.21[b]	9.3 ± 0.48[b]	0.9 ± 0.04[b]	1.98 ± 0.141[f]	0.387 ± 0.014[e]
	20	20.4 ± 0.33[d]	9.3 ± 0.41[d]	11.1 ± 1.09[c]	8.3 ± 0.55[d]	1.0 ± 0.08[b]	2.43 ± 0.197[g]	0.447 ± 0.014[f]
	30	19.6 ± 0.51[e]	9.2 ± 0.56[d]	10.4 ± 0.51[d]	8.2 ± 0.49[d]	1.0 ± 1.12[b]	2.87 ± 0.213[gh]	0.552 ± 0.017[g]
132	1	23.3 ± 0.16[b]	10.2 ± 0.71[b]	13.1 ± 0.73[a]	9.1 ± 0.62[b]	1.1 ± 0.07[ab]	1.02 ± 0.047[d]	0.157 ± 0.011[c]
	3	23.0 ± 1.23[b]	10.4 ± 0.81[b]	12.6 ± 0.84[ab]	9.3 ± 0.77[b]	1.1 ± 0.05[ab]	1.51 ± 0.126[e]	0.197 ± 0.016[cd]
	5	21.5 ± 0.71[c]	9.7 ± 0.62[bc]	11.8 ± 0.41[bc]	8.7 ± 0.54[bc]	1.0 ± 0.06[b]	1.73 ± 0.127[ef]	0.229 ± 0.014[d]
	10	21.7 ± 1.23[c]	9.6 ± 0.52[c]	12.1 ± 1.07[b]	8.7 ± 0.68[bc]	0.9 ± 0.01[b]	2.28 ± 0.155[g]	0.342 ± 0.029[e]
	20	20.6 ± 1.75[d]	9.2 ± 0.63[d]	11.4 ± 0.86[c]	8.1 ± 0.71[d]	1.1 ± 0.06[ab]	2.86 ± 0.106[gh]	0.459 ± 0.030[f]
	30	19.3 ± 0.58[e]	9.3 ± 0.87[d]	10.0 ± 0.54[d]	8.3 ± 0.62[d]	1.0 ± 0.05[b]	3.21 ± 0.110[h]	0.592 ± 0.021[g]

[1] NDF = hemicellulose + cellulose + lignin.
[2] ADF = cellulose + lignin.
[3] Each value is expressed as mean ± standard deviation ($n = 3$). Mean values in a column with different letters are significantly different at $P < 0.05$.

cooking temperature increased, the pectin loss of lotus root liquid apparently increased ($P < 0.05$); likewise, the turbidity of the lotus root liquid also increased ($P < 0.05$). When heated at 100 °C for 60 min, the turbidity of the lotus root liquid increased from 0.004 to 0.481; after heating at 110 °C, 121 °C and 132 °C for 30 min, the turbidity of the liquid were 0.541, 0.552, and 0.597, respectively. The turbidities of cooked vegetable and fruit liquids also increases during heat treatment (Greeve, Shackel, Ahmadi, MCArdle, & Labaritch, 1994; Keith, Andraw, Parr, Ng, & Parker, 1997).

From the experimental results, it appears that, due to the effects of heat and pressure during the heating process, the dietary fibre in the cell wall changes. Due to the pectin loss of lotus root liquid, damaged carbohydrates and soluble contents of lotus root, solid loss in the cooking solution increased, causing a rapid decrease in the texture of the lotus root. These results were consistent with the studies of earlier scholars who observed that the contents of cellulose and hemi-cellulose in vegetables and legumes were greatly reduced as a result of boiling (Rehman et al., 2003). Moreover, pressurized cooking will cause a faster decrease in the NDF, ADF contents, hemi-cellulose and cellulose (Anderson & Clydesdale, 1980; Rehman et al., 2003; Vidal-Valverde & Frias, 1991). Therefore, during the heating process, decrease in dietary fibre is one of the factors that causes the changes in texture of the lotus root. The results of this study can be used as references for lotus root researches and processing of lotus root products.

4. Conclusions

The insoluble dietary fibre components, hemi-cellulose and cellulose decreased differently with increasing temperature and duration of pressurized cooking. However, lignin contents of lotus root remained almost unchanged as a result of pressurized cooking treatments. During the heating process, pectin loss increased, causing an increase in solid loss and softening of the texture. In order to minimize the losses of insoluble dietary fibre components and to maintain a good appearance and texture, it seems necessary to heat at 100 °C and 110 °C for 1 h and 30 min or at 121 °C and 132 °C for less than 10 and 5 min, respectively.

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