Preparation of Hypoallergenic Wheat Flour Noodles and Evaluation of Their Physical Properties

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Hypoallergenic wheat flour (HWF) in which gluten is partially hydrolyzed by enzymes has recently been developed. However, the manufacturing of HWF products is difficult compared to that of normal wheat products due to the marked physical property differences of HWF. In this study, we first investigated the manufacturing conditions of Japanese wheat noodles using HWF and then evaluated their physical properties. HWF noodles were prepared by combining HWF with sodium alginate, starch, curdlan, and salt solution, and then soaking in calcium lactate solution before boiling. The addition of sodium alginate increased rupture strength of HWF noodles, and the addition of starch and curdlan significantly improved rupture strength and hardness. However, rupture strength of HWF noodles was markedly lower than that of normal wheat flour noodles. These results suggest that HWF combined with sodium alginate, starch, and curdlan may be suitable for preparing noodles for wheat allergy patients.

Keywords: curdlan, hypoallergenic wheat flour, Japanese wheat noodles, starch, sodium alginate

Introduction

Food allergy is a serious worldwide problem. The three major grains, wheat, rice, and corn, are consumed as staple foods in almost all countries, but many cases of allergies caused by these grains have been reported (Breiteneder, 1998). There are a number of children and adults with grain allergies that are increasing year by year (Miyakawa et al., 1988; Ota, 1989; Parish, 1970; Sampson, 1989; Yamada et al., 1987). Wheat allergy is a serious problem because wheat is ubiquitously used in various processed foods. The major allergen of wheat flour is gluten, and gluten-sensitive enteritis, such as celiac disease, is induced by the ingestion of gluten contained in wheat flour (Howdle, 1984). Since wheat allergy patients are unable to eat processed foods prepared with wheat flour, the development of ingestible hypoallergenic wheat flour (HWF) is highly desirable for these patients. Watanabe et al. (1994a, 1994b) hydrolyzed gluten with enzymes, and successfully developed HWF. Tanabe et al. (1996) attempted to manufacture bread using HWF, sodium bicarbonate, and citric acid, and successfully manufactured an English muffin-like product. However, preparation of processed wheat foods with HWF for dough formation is very difficult because it requires formation of gluten, which has been enzymatically degraded during HWF development.

When HWF noodles were prepared by the same preparation method for normal wheat noodles, boiling caused the HWF noodles to dissolve, and the noodle structure could not be maintained. Thus, we first investigated the manufacturing conditions of preparing Japanese wheat noodles with HWF. We successfully manufactured a HWF noodle-like product by thermoirreversible gelation of HWF utilizing sodium alginate and a calcium ion exchange reaction (Grant et al., 1973). The gelation ability of sodium alginate and calcium lactate maintained the noodle structure after boiling. Then, we evaluated the physical properties of the HWF noodles to determine whether the HMF noodle is a model usable for people with wheat-associated allergies.

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Materials and Methods

Materials  Control noodles were prepared with medium flour (Kinsuzuran, Nisshin Seifun Group, Inc., Tokyo, Japan) and salt (regular salt, 95% or higher sodium chloride, Naikai Salt Industries, Okayama, Japan). HWF noodles were prepared with HWF (Omu Milk Products Co., Ltd., Fukuoka, Japan), salt (regular salt, ≥ 95% sodium chloride, Naikai Salt Industries), starch purified from tapioca (Tenjin 100, Oji Cornstarch Co., Ltd., Tokyo, Japan), sodium alginate (500-600 cp, Wako Pure Chemical Industries, Ltd., Osaka, Japan), L-calcium lactate (Shiraishi Calcium Kaisha, Ltd., Osaka, Japan), and curdlan (Kirin Food-Tech Co., Ltd., Tokyo, Japan) as described previously (Watanabe et al., 2001).

Noodle preparation  For the control noodles, medium flour (100 g) was combined with a salt solution (2 g salt in 37 g water) in a stainless mixer (Kenmix chef KM-300, Aicho, Saitama, Japan) and mixed for 10 min. The dough after mixing was rolled out 6 times using the roller of a noodle-making machine (Imperia, Baulu Co., Tokyo, Japan) adjusted to 2.5 mm in thickness. The dough was then passed through a 4-mm wide cutter (No.3). The noodles (20 g) were boiled in 400 mL water for 10 min until the noodles contained 70 to 75% water content and were suitable to eat. The boiled noodles were collected in a colander and cooled with water.

The quantities of the ingredients for preparing HWF noodles are described in Table 1. HWF, sodium alginate, starch, and curdlan were combined with the salt solution in a stainless mixer (Kenmix chef KM-300, Aicho) and mixed for 10 min. The dough was then rolled out and cut in the same manner as the control noodles. The uncooked noodles were soaked in 10% calcium lactate solution for 5 min immediately before boiling in the same manner as the control noodles. After cooling, noodles were placed on wet towels and covered with a plastic wrap to prevent them from drying. All boiled noodles (n = 10) were measured within 30 min.

Analysis of rupture strength and hardness  Noodles were cut into pieces about 2 cm in length, and evaluated for rupture strength and hardness using a creep meter (RE-3305S, Yamaden, Inc., Tokyo, Japan). Rupture strength (Watanabe et al., 2000), which is defined as the value of the first peak observed when samples are stressed up to 70% strain, was measured using a cylindrical plunger (diameter, 3 mm; speed, 10 mm/s; and retraction pitch, 0.1) and analyzed using rupture strength analysis software for Windows (BAS-3305(W)).

Hardness was measured using a cylindrical plunger (diameter, 3 mm; speed, 10 mm/s; and retraction pitch, 0.1) and analyzed using hardness analysis software for Windows (BAS-3305(W)).

Table 1. Recipe for Japanese wheat noodle with hypoallergenic wheat flour.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Salt solution</th>
<th>Wheat flour</th>
<th>HWF&lt;sup&gt;1)&lt;/sup&gt;</th>
<th>ST&lt;sup&gt;2)&lt;/sup&gt;</th>
<th>AL&lt;sup&gt;3)&lt;/sup&gt;</th>
<th>Water</th>
<th>CD&lt;sup&gt;4)&lt;/sup&gt;</th>
<th>Total addition of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.0</td>
<td>37.0</td>
<td>100</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>37.0</td>
</tr>
<tr>
<td>AL2%&lt;sup&gt;5)&lt;/sup&gt;</td>
<td>1.0</td>
<td>7.5</td>
<td>–</td>
<td>50</td>
<td>0.0</td>
<td>1.0</td>
<td>–</td>
<td>27.5</td>
</tr>
<tr>
<td>AL2%, ST20%</td>
<td>0.6</td>
<td>6.0</td>
<td>–</td>
<td>24</td>
<td>6.0</td>
<td>0.6</td>
<td>12.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Control</td>
<td>2.0</td>
<td>37.0</td>
<td>100</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>37.0</td>
</tr>
<tr>
<td>AL2%, CD0%</td>
<td>1.0</td>
<td>7.5</td>
<td>–</td>
<td>50</td>
<td>0.0</td>
<td>1.0</td>
<td>0.0</td>
<td>27.5</td>
</tr>
<tr>
<td>AL2%, CD1%</td>
<td>0.6</td>
<td>6.0</td>
<td>–</td>
<td>30</td>
<td>0.0</td>
<td>0.6</td>
<td>12.0</td>
<td>18.0</td>
</tr>
<tr>
<td>AL2%, CD1.5%</td>
<td>0.6</td>
<td>6.0</td>
<td>–</td>
<td>30</td>
<td>0.0</td>
<td>0.6</td>
<td>12.0</td>
<td>18.0</td>
</tr>
<tr>
<td>AL2%, CD2%</td>
<td>0.6</td>
<td>6.0</td>
<td>–</td>
<td>30</td>
<td>0.0</td>
<td>0.6</td>
<td>12.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

<sup>1</sup> HWF, hypoallergenic wheat flour  
<sup>2</sup> ST, starch  
<sup>3</sup> AL, sodium alginate  
<sup>4</sup> CD, curdlan  
<sup>5</sup> The values are the ratio of additives to the amount of HWF and ST.
ameter, 5 mm; strain, 80%; speed, 1 mm/s; and retraction pitch for 400-500 measurement points) (Kojima et al., 2004) and analyzed using texture analysis software for Windows (TAS-3305(W)).

Measurement of the noodle water content  The water content of the noodles was measured by the atmospheric heat-drying method (Tsutsumi et al., 1996). An aluminum foil container was prepared by folding a 36 cm × 8 cm aluminum foil piece to 18 cm × 8 cm and then folding the left and right sides about 2 cm; the foil container was then weighed (W0). Noodles were mixed in a vinyl bag, and 3 g of noodles were added to the aluminum container and weighed (W1). The other side of the aluminum container was folded about 2 cm, and the noodles were homogeneously spread by pressing and dried at 135°C for 2 h after the folded side was opened. After drying, the noodles were cooled in air for 1 h and weighed (W3). The water content, WC (%), was calculated by the following equation:

\[
WC = \frac{(W_1 - W_3)}{(W_1 - W_0)} \times 100 \quad \text{Eq.(1).}
\]

Cooking loss  The noodles made from normal wheat flour or HWF were boiled using 15 volumes of water in a 500-mL beaker for 10 min. After 10 min, the noodles was collected in a colander and cooled in a 500-mL beaker containing water. This procedure was repeated 3 times, and the product was lightly washed during the third cooling to remove slime. The cooking loss, CL (%), was calculated by the following equation:

\[
CL = \frac{W_3}{W_4} \times 100 \quad \text{Eq.(2),}
\]

where W3 (g) is dried residue in the boiled water (g) and W4 (g) is noodle weight before cooking (g).

Statistical analysis  All values were measured 8 times and are presented as the means ± standard error for each experimental group. After one-way layout analysis of variance, Duncan’s multiple comparison test was performed using statistical analysis software SPSS 9.0 J. Values of p < 0.05 were considered significant.

Results  

Effects of adding sodium alginate and starch  Rupture strength, hardness, water content, and cooking loss of noodles prepared by adding 2% sodium alginate and 20% starch to HWF are shown in Table 2. Compared to noodles with added sodium alginate alone, noodles with the added sodium alginate and starch showed significant increases in rupture stress and rupture energy, which were markedly lower than those of the normal wheat flour noodles (control). Hardness of the HWF noodles with added sodium alginate was significantly lower than that of the control. Moreover, hardness of the HWF noodles with added sodium alginate and starch showed a significant increase compared to that of the control. The water content after boiling showed no change in noodles with added sodium alginate and starch. Cooking loss was higher in HWF noodles than in the control but lower in the HWF noodles with added sodium alginate and starch than in the HWF noodles with added sodium alginate alone.

These findings suggest that the addition of starch to HWF increases rupture strength and hardness and inhibits cooking loss.

Effects of adding sodium alginate and curdlan  Rupture strength, hardness, water content, and cooking loss of noodles prepared by adding 2% sodium alginate and 1, 1.5, or 2% curdlan are shown in Table 3. Rupture stress was lower in all HWF noodles than in the control. Compared to the HWF noodles with added sodium alginate alone, the HWF noodles with added sodium alginate and curdlan at all concentrations showed significant increases in rupture stress. Rupture energy was lower in all HWF noodles than in the control. Compared to the HWF noodles with added sodium alginate alone, those with added ≥ 1.5% curdlan showed significant increases in rupture energy.

Hardness was higher in all noodles with added sodium alginate and curdlan than in those with added sodium alginate alone. Therefore, the addition of curdlan significantly increased hardness. The addition of (1.5% curdlan significantly decreased the water content of noodles after boiling. Cooking loss was higher in all HWF noodles with added

Table 2. Effect of the addition of sodium alginate and starch on the physical properties of hypoallergenic wheat flour noodles.

<table>
<thead>
<tr>
<th></th>
<th>Rupture stress (Pa×10^4)</th>
<th>Rupture energy (J/m^2×10^4)</th>
<th>Hardness (Pa×10^4)</th>
<th>Water content (g/100 g)</th>
<th>Cooking loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw</td>
<td>Boil</td>
<td></td>
<td>Raw</td>
<td>Boil</td>
</tr>
<tr>
<td>Control</td>
<td>21.6 ± 0.6^c</td>
<td>6.22 ± 0.14^c</td>
<td>11.8 ± 1.2^b</td>
<td>34.8 ± 0.1^b</td>
<td>8.15 ± 0.37^a</td>
</tr>
<tr>
<td>AL2%+ST0%</td>
<td>9.10 ± 0.49^a</td>
<td>2.72 ± 0.27^a</td>
<td>10.9 ± 0.3^a</td>
<td>33.8 ± 0.1^a</td>
<td>19.5 ± 0.8^c</td>
</tr>
<tr>
<td>AL2%+ST20%</td>
<td>12.0 ± 0.7^b</td>
<td>3.50 ± 0.22^b</td>
<td>15.2 ± 0.7^c</td>
<td>36.1 ± 0.3^e</td>
<td>16.5 ± 0.3^b</td>
</tr>
</tbody>
</table>

Values are means ± SE (rupture stress, rupture energy and hardness (n = 10), watercontent and cooking loss (n = 3)).
Values within a column with different superscript letters have a significant difference of p < 0.05.
For abbreviations see Table 1.
HWF noodles with curdlan added at ≤ 1.5% concentrations also increased. Cooking loss was higher in all HWF noodles than in the control, showing no effect of the addition of curdlan.

These findings suggest that the addition of curdlan increases rupture stress and hardness, but does not affect cooking loss.

**Discussion**

Wheat is one of the three major grains that is utilized as an ingredient of bread and noodles. The increasing number of wheat allergy patients has long been problematic. The main allergen of wheat allergy is gluten, as wheat allergy patients are unable to ingest its products. This study was performed to establish the manufacturing conditions of HWF products for wheat allergy patients. The manufacturing conditions were investigated by comparing the physical properties of noodles made from HWF with those made from normal wheat flour.

As the addition of sodium alginate alone showed marked decreases in rupture stress of HWF noodles compared to normal wheat noodles, improvement of the physical properties by the addition of tapioca starch was investigated. Comparing the addition of sodium alginate alone, the addition of starch increased the rupture stress and hardness, suggesting that the addition of tapioca starch, which has elasticity,
increases hardness. However, rupture stress of HWF noodles was not comparable to that of normal wheat noodles (Table 2).

As curdlan forms a thermoreversible gel when heated at \( \geq 50^\circ C \) and a thermoirreversible gel at \( \geq 80^\circ C \) (Kanno and Harada, 1991), further improvement of the physical properties of HWF noodles by the addition of curdlan was investigated. Compared to the addition of sodium alginate alone, the addition of curdlan improved the physical properties of HWF noodles (Table 3), suggesting that thermoirreversible gelation may increase rupture strength, as boiling occurred at about 100°C.

Next, the effects of the addition of starch and/or curdlan on the physical properties of HWF noodles retaining their structure with sodium alginate were investigated. However, rupture stress of HWF noodles was not comparable to that of normal wheat noodles (Table 4). Regarding the thermoirreversibility of curdlan, its viscosity has been reported to be determined by the presence of salts (Funami et al., 2007). Thus, altering the balance between salts and curdlan added to HWF products may improve their physical properties, although further investigation is necessary.

Cooking loss of all HWF noodles was higher than that of normal wheat noodles (Tables 1-3). However, compared to the addition of sodium alginate and starch, the addition of sodium alginate, starch, and curdlan improved cooking loss. Further studies are needed to determine other methods to improve cooking loss of HWF products.

Reduction of the serum cholesterol level due to sodium alginate-induced inhibition of the enterohepatic circulation of bile acid has been reported (Seal and Mathers, 2001). Further, curdlan-induced proliferation of intestinal Bifidobacterium bifidum improves the intestinal environment (Shimizu et al., 2001). Thus, the addition of sodium alginate and curdlan may also reduce the serum cholesterol level and control intestinal function.

The manufacturing of HWF products can provide wheat allergy patients with a broader diet. Furthermore, as rupture strength of HWF noodles is lower than that of normal wheat noodles, HWF products may be more easily consumed by elderly people with difficulty in chewing and swallowing. However, as hardness of HWF noodles is higher than that of normal wheat noodles, improving the hardness of HWF products may make ingestion easier.

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References

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