Effects of Different Drying Conditions on Pasta Quality
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ABSTRACT
The differences in water absorption properties were investigated among three types of flat pastas (LT: pasta dried at low temperature 50°C for 20 hours; HT: pasta dried at high temperature 70°C for 11 hours; VHT: pasta dried at very high temperature 85°C for 4 hours). Pastas were soaked at different temperatures and for different times in a thermostatic bath to investigate moisture distributions. Water content was examined a dryer at 105°C for 72 hours. The pasta was then frozen in liquid N2 and cross-sectional images were taken to reveal the moisture profile. Pasta surfaces were observed by scanning electron microscope (SEM). Ultrasound phase difference was applied to analyse water absorption pattern of the three pasta types.
The three main results are as follows: 1.) At both low soaking temperature (40-55°C) and high soaking temperature (75-90°C), there were no significant differences in water absorption rate among LT-, HT- and VHT-dried pasta, but near the starch gelatinization temperature (60-65°C), LT-dried pasta had the largest water absorption rate. 2.) Analysis of ultrasound phase differences showed that when pasta samples processed under the same condition were soaked, phases of pasta soaked above the gelatinization temperature were larger than phases of pasta soaked below the gelatinization temperature. However, when pastas dried at different temperatures were soaked below the gelatinization temperature, phase differences of LT and HT-dried pasta were larger than phase differences of VHT-dried pasta. 3.) Phase not only reflects the absorption rate, but also the distribution of water content inside the pasta. We suggest that phase difference of pasta did not only depend on the drying temperature, but also water content and the gelatinization distribution.

Keywords: ultrasound; starch gelatinization; water absorption; drying temperature; pasta

INTRODUCTION
Pasta is produced by mixing durum semolina and water, extruding and drying. The latest trend in pasta production is the use of high temperatures in drying profiles [1-6]. Over the past two decades, producers have moved from the conventional slow-temperature drying profile to faster, high-temperature treatment [7]. The high temperature profile is economically advantageous because of its shorter process time but it requires a more accurate control to gain an acceptable product. The effects of pasta soaking water have been deeply researched. The equilibrium moisture content and the initial rate of water sorption were investigated [8]. Ultrasound is well known to have a significant effect on the rate of various processes in food industry. Ultrasound has also been applied as a pre-treatment prior to the drying of a range of vegetables [9]. Ultrasound applied to food industry was studied [10].
The objective of this work was to better illuminate the different water content among pastas dried at three different temperatures, and to obtain the economical drying process by applying phase difference from a ultrasound wave device to detect the difference among them.

MATERIALS & METHODS

Material
Flat pasta from Nisshin Foods, Inc., Tokyo, Japan (thickness: 0.8 mm ~ 0.9 mm, width: 23 mm, length: 230mm) was used in all experiments. Three drying profiles were applied: low temperature dried pasta (LT: 20hours at 50°C), high temperature dried pasta (HT: 11 hours at 70°C), very high temperature dried pasta (VHT: 4hours at 85°C). In the experiments, the three types of flat pastas were cut into 40mm-long samples.

Water content
To measure water absorption properties, samples of the three pasta were soaked in a thermostatic bath (ISOTEMP 228 Water Bath, Fisher Scientific, USA).They were soaked at (40, 50, 55, 60, 65, 75and 90°C) for periods ranging from 0 to 120 min. Surface water was lightly wiped off each soaked sample, and a 35 mm by 10 mm segments was cut from the centre, and put into an Al can. The weight of the pasta-can unit was measured, before it was dried in a 105°C oven (WINDY OVEN WFO-450D) for 72 hours and weighed again. The water content was calculated from the difference in weight.
Surface area
A picture of each dried segment was taken, and the height of the segment was measured with a multi-laser meter (KEYENCE LB-1010, Tokyo, Japan). The pictures were dimensionless analysed by programme ImageJ into length, width and surface area. According to the measured height, length, width and upside area, the total area was calculated.

Ultrasound phase difference
Frequency of 1,754,779Hz was passed through a cell containing a soaked pasta segment and water, or water only for reference. An FFT program was used to calculate phase differences which were expected to reflect the distribution of absorbed water. Compare to the phase difference between pasta and water, the status of pasta absorbing water could be caught.

Frozen Cross Sections of soaked pasta
Samples of each of the three-dried pasta types were soaked for 30 min at 40°C, 20 min at 50°C, 6 min at 60°C, or 2.5 min at 90°C. These temperature-time conditions were selected to achieve 60-70% water content. Surface water was lightly wiped off the soaked samples, and each samples was cut into halves. One half was immersed in liquid nitrogen, and imaged under a microscope. The other half was dried in the oven to check the water content. Images were analysed with the program Tview to differentiate portions which had absorbed water.

Surface SEM
Samples of each of the three pasta types were soaked at 40°C or 60°C for 4 min, frozen in liquid nitrogen and freeze dried in a vacuum freeze dryer. Starch granules on the surface of the dried samples were then observed by SEM(Scanning Electron Microscope). These images were compared to image taken of starch granules of uncooked past.

RESULTS & DISCUSSION

![Figure 1. Water content of LT-dried pasta(a) and water absorption rate of LT-, HT-, VHT-dried pasta (b)](image)

Figure 1. Water content of LT-dried pasta(a), LT-dried pasta was soaked at 90°C (●), 75°C (●), 65°C (●), 60°C (●), 55°C (●), and 40°C (●). Water content increased with the temperature and time, with a sharp increase between 60°C to 65°C. This can be explained by the gelatinization temperature of wheat starch, which is 52-63°C[11]. Applying the Kofler method to our pasta, only 2% of wheat starch was gelatinized when pasta was soaked at 52°C, but 98% was gelatinized when soaked at 63°C. Below the gelatinization temperature, the absorption of water by starch granules is reversible, and most of the water is held in the amorphous region, while above gelatinization temperature, the properties of starch granules are changed by the destruction of hydrogen bonds. Therefore, starch granules swell and absorb water irreversibly in both crystalline and non-crystalline phases, substantially increasing water content.

Water content
To investigate water absorption properties, LT-, HT-, and VHT-dried pasta were soaked at different temperature. As shown in Figure 1 a), the pasta’s water content increased with temperature and time. Water content of all pasta types exhibited a sharp increase between 60°C to 65°C. This can be explained by the gelatinization temperature of wheat starch, which is 52-63°C[11]. Applying the Kofler method to our pasta, only 2% of wheat starch was gelatinized when pasta was soaked at 52°C, but 98% was gelatinized when soaked at 63°C. Below the gelatinization temperature, the absorption of water by starch granules is reversible, and most of the water is held in the amorphous region, while above gelatinization temperature, the properties of starch granules are changed by the destruction of hydrogen bonds. Therefore, starch granules swell and absorb water irreversibly in both crystalline and non-crystalline phases, substantially increasing water content.

We can see further support of these processes if we examine the water absorption rate, which also increased with soaking temperature, as shown as Figure 1 (b). At 40°C and 50°C, there were no significant differences in the water absorption rates among the LT-, HT-, and VHT-dried pasta types. However, there was a significant increase in water absorption rate from LT- to VHT-dried pasta at 65°C and 75°C. The water absorption rate at
90°C was almost identical across LT-, HT-, and VHT-dried pasta types. Only near the gelatinization temperature (52-63°C) was there a significant difference among the LT-, HT-, and VHT-dried pasta’s water absorption rates. At 65°C and 75°C, pasta starch granules could be swollen and gelatinized. Moreover, near the gelatinization temperature, the differences in water absorption were reflected in the differences in water absorption rate. The lower water absorption and water absorption rate of VHT-dried pasta can be explained by the higher drying temperature. The higher drying temperature would cause more starch granules in the pasta surface to gelatinize, thus preventing water from soaking into the interior and slowing the water absorption rate.

Figure 2. Frozen Cross Sections of soaked pasta at 40°C, 50°C, 60°C, and 90°C.

**Frozen Cross Sections of soaked pasta**

LT-, HT-, and VHT-dried pasta were soaked at 40°C, 50°C, 60°C, and 90°C until they reached a water content of 60-70%d.b. and then frozen for imaging. Cross sections were then taken by USB digital microscope (YDU-4)600X (YASHIMA optical, made in Japan), as shown in Figure 2. Comparison of LT 40-90°C, HT 40-90°C and VHT 40-90°C shows that, even at fixed water absorption, pastas soaked below the gelatinization temperature water were soaked through to the interior. However, above the gelatinization temperature, the interior absorbed less or no water. This can be understood if we reason that below gelatinization temperature water diffused into the interior, while above the gelatinization temperature the swollen starch granules inhibited water from diffusing deeper.

As demonstrated in LT-, HT-, VHT-40°C and LT-, HT-, VHT-50°C below the gelatinization temperature, the pastas absorbed water well internally, and moisture distribution depended on drying temperature. The higher the drying temperature was, the less water the pasta absorbed in the interior; i.e. the pasta absorbed water in interior in the order of LT>HT>VHT dried pasta types. As demonstrated in LT-, HT-, VHT-60°C and LT-, HT-, VHT-90°C above the gelatinization temperature, this dependence of water distribution on drying temperature
was no longer found. We attribute this phenomenon to starch granules in the surface of pasta dried at higher temperatures preventing the diffusion of water to the inside at lower soaking temperatures. Above gelatinization temperature, all pasta samples were gelatinized regardless of drying temperature, which prevented water diffusion. This may explain the soaking temperature-dependent phase difference to be described below.

a) Water content and phase of LT-dried pasta  
b) phase of pasta soaked at 50°C  
c) phase of pasta soaked at 65°C

Figure 3. Relationship between water content and phase.  
90°C (□), 75°C (△), 65°C (□), 60°C ( ▽), 55°C ( △), 50°C ( ▽), 40°C ( △).

Phase difference

Relationship between water content and phase (LT-, HT- and VHT-dried pasta at 50°C & 65°C, middle and right) LT-dried pasta (black circle), HT-dried pasta (gray circle), VHT-dried pasta (white circle)  
Phase difference of both LT- and HT-dried pasta was larger than that of VHT-dried pasta. Gelatinized surface starch may affect water distribution of VHT-dried pasta (shown in LT-, HT-, VHT-40°C and LT-, HT-, VHT-50°C of Figure 2.) and explain the differences. Because the difference was only observed at water content of 30-120%d.b., we conclude that phase reflected the interior water distribution.

The relationship between water content and phase of LT-dried pasta is shown in Figure 3 a). Results of HT-, and VHT-dried pasta was similar to LT-dried pasta. The phase difference decreased exponentially with the increase of water content, approaching the phase of pure water phase (reference) as water content increased. As seen in the Figure 3. left pasta showed a tendency for phase to increase along a distinct curve, regardless of temperature. Hence, we suggest that the relationship between phase difference and water content does not depend on temperature. However, when pasta was soaked at between 60°C and 55°C to achieve a given water content in range of 30-120% d.b. phase differences among the three pasta types was observed. I.e., if we assume that the phase difference is smaller for gelatinized pasta than un-gelatinized pasta, than the phase data yields a gelatinization temperature in agreement with semolina starch’s gelatinization temperature of 52-63°C. This trend was seen in all three kinds of pasta, but particularly in LT pasta.

From Figure 3. (b), when soaked at 50°C for equal water content, VHT-dried pasta had the smallest phase difference of the three types. This trend was repeated in pasta soaked at 40°C, 55°C and 60°C. However three pasta types soaked at 65°C (Figure 3., c), phase differences could not be seen, the same happened when pasta soaked at 75°C, and 90°C.

To sum up, when pasta was soaked to achieve set water absorption of in the range of 30-120% d.b., the phase difference of un-gelatinized pasta was larger than that of gelatinized pasta. For pasta soaked below gelatinization temperature (below 55°C), the phase differences of LT-dried and HT-dried pasta types were larger than that of VHT-dried pasta. In addition, compared with pasta soaked at 40°C and 50°C, from the result of water content, no significant change in the three types of pasta, and the phase difference shared the similar trend to it. We conclude that phase difference reflected not only the water absorption, but also internal changes in pasta.
Surface SEM

SEM images were taken of starch granules on the surface of LT-, HT-, and VHT-dried pasta soaked at 40°C and 65°C, as shown in Figure 4. Pasta was soaked at 40°C for 4 min. Flat starch granules may have been created from gelatinized starch granules during drying process (Figure 4, LT-, HT-, VHT-40°C). As shown in Figure 4, LT-, HT-, VHT-65°C, when pasta was soaked at 65°C – in the vicinity of the gelatinization temperature, such remnants of gelatinized starch granules were found in all three pastas types. These artifacts of gelatinization increased with drying temperatures.

As mentioned above, when soaked in the vicinity of gelatinization temperature (52-63°C), VHT-dried pasta had the lowest water absorption and water absorption rate, which we attribute to a gelatinized starch layer precluding water from entering into the pasta. In contrast to LT-dried pasta (20 h at 50°C), HT- (11 h at 70°C) and VHT-dried pasta (4 h at 85°C) were dried above the gelatinization temperature of semolina starch. Although water is necessary for gelatinization, the initial moisture content of fresh pasta is about 30%, which is reported to be sufficient [12]. Thus, it we inferred that part of the HT- and VHT-dried pasta was gelatinized. We suggest that the degree of gelatinization of surface starch impacts absorption behavior.

CONCLUSION

In conclusion, the present study has indicated that the surface starch of pasta dried at low temperature (LT), high temperature (HT), very high temperature (VHT) was different and starch granules of VHT-dried pasta were the largest. We believe this inhibit water diffusion to the interior. Differences in drying processes were also reflected in the difference in phase among the three types of pasta. We suggest that information about water content and gelatinized area can be obtained by non-destructive phase analysis. Next step, we are going to measure the gelatinization rate of the three pasta types, investigate the surface friction and test the texture of the three types of pasta. Finally we are supposed to find out the most economical drying process.

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