Effect of Surface Roughness on Rehydration Kinetics of Spaghetti

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Surface roughness of spaghetti depends on the die material used during production, and affects the momentarily rehydrated amount of water. The calculated average roughness of spaghetti surfaces, \( R_a \), was evaluated for geometry measurements using a laser microscope. Smoothness of the spaghetti surface decreased, depending on the type of the die used during the preparation in the following order: Teflon, polypropylene, polycarbonate, aluminum, and bronze. For hypothetically smooth cylindrical spaghetti, the momentarily rehydrated amount of water per unit surface area was larger for spaghetti with larger \( R_a \) values. In contrast, the amount of water per surface area, which was estimated considering the roughness of the surface, did not affect the \( R_a \) value. This showed that the initial rehydration rate of spaghetti could be controlled by altering the surface roughness.

Key words: surface roughness, rehydration kinetics, spaghetti

1. Introduction

Spaghetti is a traditional Italian food. It is now being widely consumed in many countries and regions, including Japan. It is produced by extruding durum semolina dough through a die [1], although Japanese pasta, also known as \( \text{udon} \), is prepared by rolling wheat flour dough. Bronze dies have been traditionally used for spaghetti production; however, Teflon dies have recently been used primarily for elongating the usable period and improving the surface appearance [2–4]. Spaghetti prepared using bronze and Teflon dies have rough and smooth surfaces, respectively. The porosity, density, rupture strength, and water diffusivity during drying have been examined for spaghetti prepared using bronze and Teflon dies [5,6]. The effect of the die material on the water-sorption kinetics of spaghetti had not been reported. Therefore, we measured the water-sorption kinetics for spaghetti prepared using dies made of bronze, aluminum, polycarbonate, polypropylene, and Teflon [7]. The kinetics could be expressed by a hyperbolic function of time, and were characterized by the initial sorption rate and equilibrium amount of the sorbed water [8,9]. Because the die material did not affect the gelatinization temperature of starch in spaghetti, the equilibrium amount of the sorbed water did not depend on the material [7]. When dried spaghetti was rehydrated, a very rapid water intake was observed. The momentarily rehydrated amount of water, \( X_{t \rightarrow 0} \), was estimated by extrapolating the amounts of water sorbed per unit surface area in the initial 60 s, which was a good indication of the initial water sorption [7]. Although the \( X_{t \rightarrow 0} \) value was larger for spaghetti with a rougher surface [7], the explanation for this observation remains to be elucidated.

In this context, spaghetti with different surface roughness was prepared using dies made of different materials. The surface roughness of the spaghetti was measured using a three-dimensional laser microscope, which is generally applied to the roughness analysis, and the relation between the surface area and the momentarily rehydrated amounts of water per unit area were quantitatively examined.

2. Materials and Methods

2.1 Preparation of spaghetti

The spaghetti was prepared using a method described previously [7]. Durum semolina was supplied by Nisshin Foods, Inc., Tokyo, Japan. Briefly, durum semolina (700 g) and water (224 g) were mixed using a kitchen-aid blender (KSM150, FMI, USA) for 20 min. The mixture was put into a pasta-making machine (Magica, Bottene, Italy) equipped with a die made of Teflon, polypropylene, polycarbonate, aluminum, or bronze and extruded under reduced pressure (60 kPa) through the die to prepare raw spaghetti. The orifice diameter and length of each
A laser microscope (VK–8710, Keyence Corp., Osaka, Japan) was used to carry out geometry measurements of the spaghetti surface. The resolutions in the $xy$- and $z$-directions were 686 nm/pixel ($1024 \times 768$ pixel) and 1 nm/digit ($2^{24}$ digit), respectively. The surface of each spaghetti was measured at least five times, and the surface roughness and surface area were calculated from the height in the $z$-direction using Microsoft Excel© 2010. The surface roughness was expressed by the average roughness, $R_a$, determined using Eq. (1).

$$R_a = \frac{1}{l} \int_0^l f(x) \, dx \tag{1}$$

where $l$ is the reference length and $f(x)$ is the roughness curve. The roughness surface was divided into small triangles. For a triangle having the vertex coordinates $A(x_a, y_a, z_a)$, $B(x_b, y_b, z_b)$, and $C(x_C, y_C, z_C)$, its area $S$ was calculated by Eq. (2).

$$S = \frac{1}{2} \left| \begin{vmatrix} x_a & y_a & z_a & 1 \\ x_b & y_b & z_b & 1 \\ x_C & y_C & z_C & 1 \end{vmatrix} \right|$$

The surface area was calculated by summing the $S$ values of all the triangles.

### 3. Results and Discussion

Figure 1 shows the surface images of the spaghetti prepared with various dies, which were measured using the three-dimensional laser microscope. The $R_a$ values of spaghetti depended on the type of the die used during preparation; the values decreased in the following order: Teflon, polypropylene, polycarbonate, aluminum, and bronze. This trend was similar to that reported previously and measured using a digital microscope [7]. Despite the starch granules near the surface being rapidly gelatinized by water penetration through small cracks [10], there is a possibility that starch gelatinization affects the initial water-sorption rate. However, starch gelatinization would not affect the $X_{t\rightarrow0}$ value because the amount is estimated by extrapolating the amounts of water sorbed to 0 min. Furthermore, the die material does not affect the gelatinization temperature of starch in spaghetti. Therefore, the $X_{t\rightarrow0}$ value estimated here should be affected only by the surface roughness or inner structure of spaghetti.

The spaghetti with a rougher surface had the smallest...
bulk density [7]. However, the bulk density of spaghetti prepared using the Teflon die was 1.36±0.01 g/mL, which was the largest among the tested spaghetti and was similar to that (1.31±0.02 g/mL) of spaghetti prepared using the bronze die with the lowest bulk density. Water diffusivity within spaghetti was approximately $10^{-10}$ m²/s [11]. Therefore, the $X_{t\rightarrow 0}$ value was not controlled by the inner structure but by the surface roughness.

The momentarily rehydrated amounts of water were obtained from our previous report [7]. The amounts per unit area were calculated based on two different surface areas of spaghetti: one area was evaluated by $2r\pi L$ where $r$ and $L$ are the radius and length of the spaghetti sample, respectively, under the assumption that the spaghetti was a cylinder with smooth surface, and another was measured for spaghetti sample with rough surface using the laser microscope. The amounts based on the former and latter areas are expressed by $X_{t\rightarrow 0}$ (smooth) and $X_{t\rightarrow 0}$ (rough), respectively. Although the $X_{t\rightarrow 0}$ (smooth) was larger for spaghetti with a rougher surface and larger $R_a$ value, the $X_{t\rightarrow 0}$ (rough) did not depend on the $R_a$ value (Fig. 2).

The cooking time for the optimal rehydration of spaghetti is determined by both the initial water-sorption rate and the equilibrium amount of the sorbed water [8,9]. Earlier studies had shown that to control the equilibrium of the sorbed water, the raw material should be chemically modified; for example, by modifying the starch gelatinization property [8,9,12]. However, this study showed that the initial water-sorption rate can be controlled by modifying the surface roughness of spaghetti.

4. Conclusions

The calculated average roughness, $R_a$, of spaghetti depended on the type of the die used during preparation and decreased in the following order: Teflon, polypropylene, polycarbonate, aluminum, and bronze. The $X_{t\rightarrow 0}$ (smooth) value with a hypothetically smooth surface was larger for spaghetti with larger $R_a$ values; however, the $X_{t\rightarrow 0}$ (rough) value with rough surface did not depend on the $R_a$ values. This showed that the surface roughness of spaghetti can regulate the initial water-sorption rate.

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