Structural changes in starch granules affect the water holding capacity, which governs moisture migration in noodles during cooking

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Structural changes in starch granules affect the water holding capacity, which governs moisture migration in noodles during cooking

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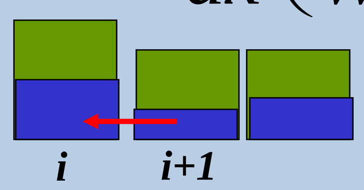
【Introduction】

- Starch granules in noodles undergo structural changes in a series of different stages during cooking; these changes include gelatinization, macromolecular dispersion, and release into the liquid continuous phase. Moreover, the water holding capacity (WHC) of starch-based foods depends on the state of the starch granules. Starch gelatinization predominantly occurs at the surface of the noodles because of the water rich environment and this region holds the most water. Consequently, it is not easy for water molecules to migrate from the exterior to the interior region of the noodle. This is the reason for the long time required for the moisture transfer in starch-based foods.
- The relative water content model to describe the moisture migration in the starchy food suggested that water diffuses in proportion to the gradient of the relative water content m/m^+, acquired by dividing the water content m by the standard water content m^+, that is WHC [1] In this work, we propose the new modified relative water content model which is based on the WHC related with the state of starch gelatinization and dispersion.

Relative Water Content Model

$$water\ \ flux \propto \frac{d}{dx}\left(\frac{W}{W^+}\right)$$

$$\left.\frac{W}{W^+}\right|_i < \left.\frac{W}{W^+}\right|_{i+1}$$



【Materials and Methods】

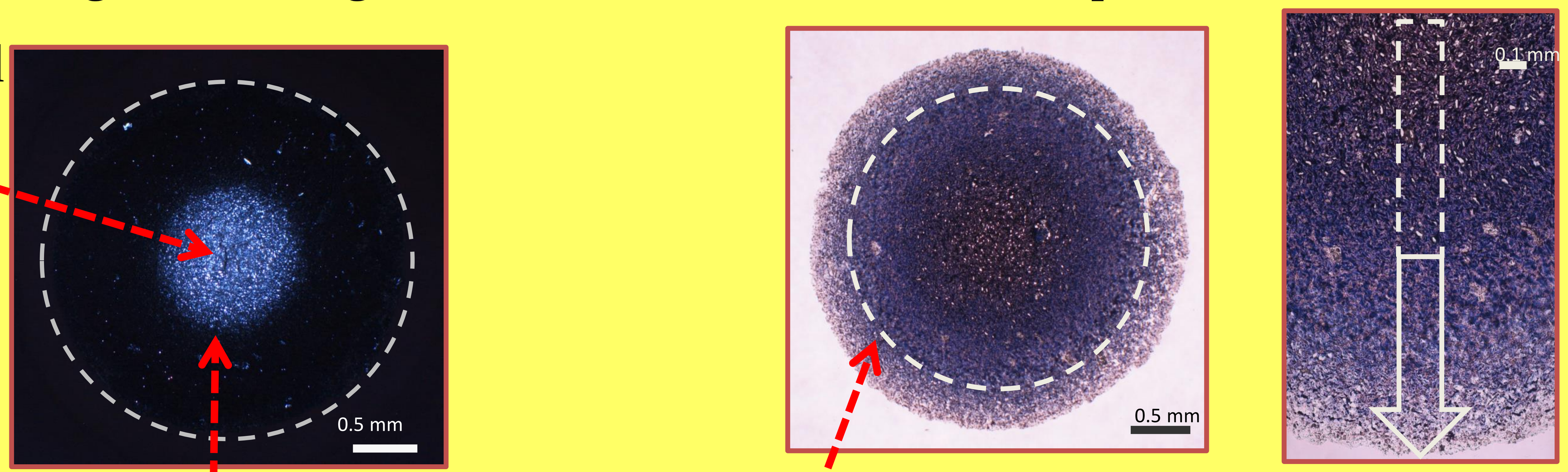
- The dry spaghetti (Ma·Ma spaghetti Blue φ2.2mm, Nisshin Foods Inc., 0.072 g water/g solid of water content) cut into 120 mm in length was used in this experiment. Recommended boiling time by the manufacturer is 17 minutes. 4g of noodles were boiled in a stockpot with 1L of 0.6wt% NaCl solution.
- We investigated the changes in the moisture profile and state of starch granules in the noodles during cooking by using magnetic resonance imaging (MRI) and microscopic observation. ^{1}H MRI was performed using an NMR spectrometer (9.4T) equipped with a micro-imaging accessory. The polarization microscopy and light microscopy with an iodine–starch staining was conducted.

【Results and Discussion】

1. State of starch granule and moisture profile in noodle

Structures of starch granule contained in the cooked noodle were mainly divided into three stages; that is non-gelatinized, gelatinized and macromolecule dispersion

Non-gelatinized region

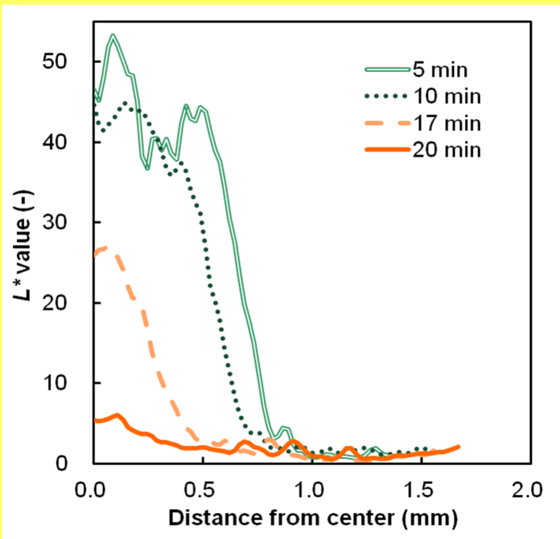


Gelatinized region

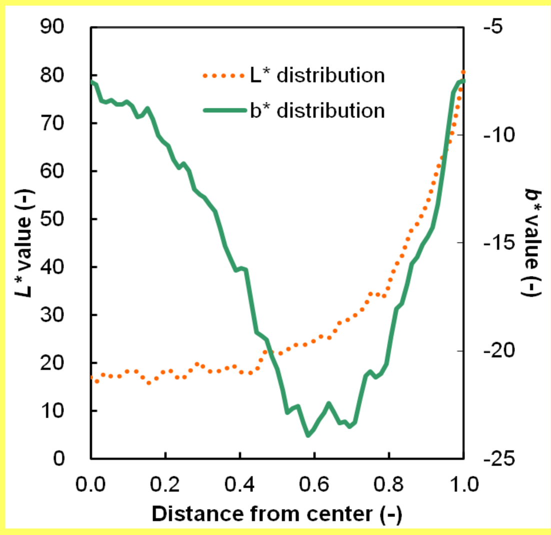
Macromolecular dispersion

Fig.1 Light micrographs of cross-section of spaghetti boiled for 17 min. Under the polarized light (left). After dyeing treatment(right).

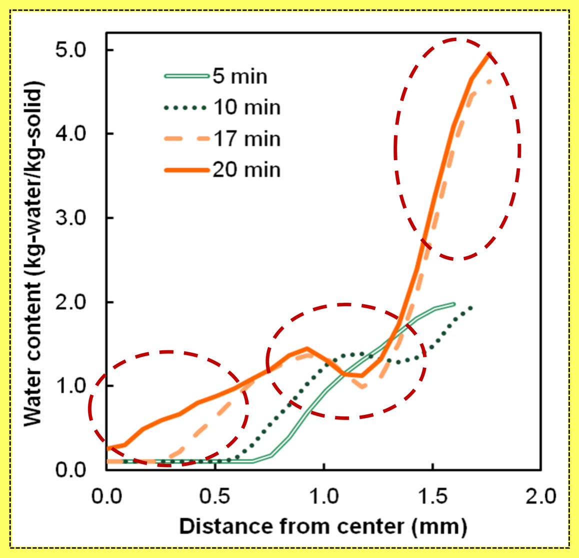
Conversion of the RGB image to CIE $L^*a^*b^*$



We obtained the digital image in $L^*a^*b^*$ color space from RGB image. L^* value corresponds to the gelatinization degree and macromolecular dispersion can describe by b^* value.



[1] H. Watanabe, Y. Yahata, M. Fukuoka, T. Sakiyama, T. Mihori, The thermodynamic basis for the Relative Water Demand Model that describes non-Fickian water diffusion in starchy. J. Food Eng., 83, (2007) 130-135.



- Three characteristic patterns in moisture profile were observed
- The gradient of moisture content was formed in the inner part.
- The plateau region was existed.
- At the later in the cooking time (cooked for 17 min and 20min), the surface moisture content dramatically increased.

Fig.2 Moisture profile of the noodle obtained by MRI (cooked for 5,10,17 and 20min)

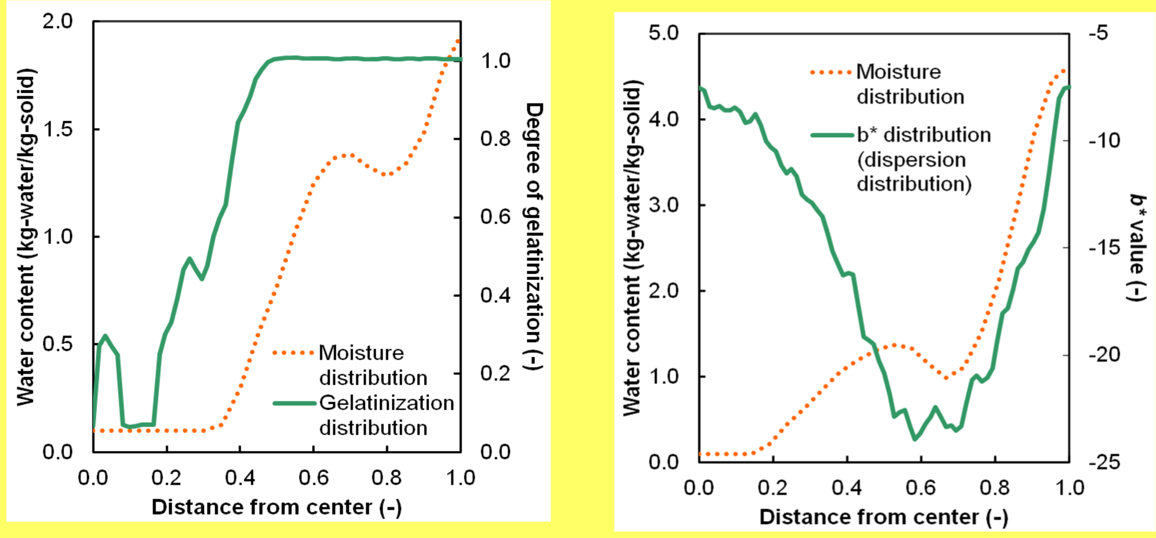


Fig.2 Comparison between the moisture distribution and state of starch granule of the noodle (cooked for 17min)

Moisture distribution clearly showed a characteristic feature. corresponding to the state of the starch granules in each element of the noodles. Water migration of starchy food is affected by WHC (Water Holding Capacity; W+). WHC becomes large when the starch dispersion occurs.

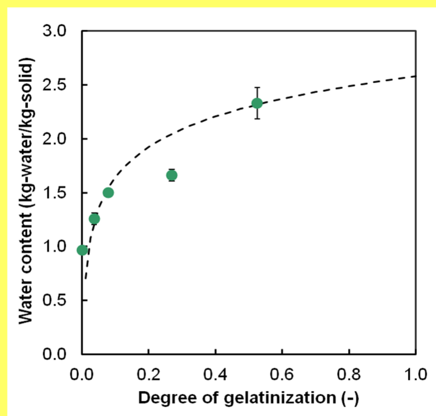
2. Simulation of the moisture migration by modified relative water content model

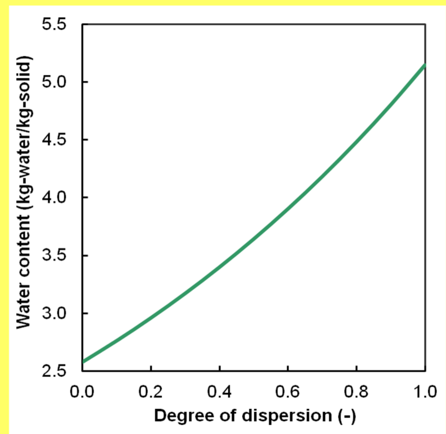
Governing equation for moisture transfer

$$\bar{\rho}_s \frac{\partial W}{\partial t} = \frac{1}{r}\left\{\frac{\partial}{\partial r}\left(D_w W_{clg} r \bar{\rho}_s \frac{\partial}{\partial r}\left(\frac{W}{W_{clg}}\right)\right) + \frac{\partial}{\partial z}\left(D_w W_{clg} r \bar{\rho}_s \frac{\partial}{\partial z}\left(\frac{W}{W_{clg}}\right)\right)\right\}$$

$$for\ gelatinization\ stage\ \ W_{clg} = 0.4069\log(F_c) + 2.5802 \quad \text{(at } F_c < 0.8\text{)}$$

$$for\ dispersion\ stage\ \ W_{clg} = \exp(0.69 X_d + 0.94) \quad \text{(at } F_c \geq 0.8\text{)}$$





W: moisture content (kg-water/kg-solid), W_{clg}: ceiling moisture content (kg-water/kg-solid), ρ_s: density(kg m^{-3}), D_w: moisture diffusivity(m^2 s^{-1}), F_c: gelatinization degree(-), X_d: dispersion degree (-)

Reaction kinetics

$$\frac{dX_g}{dt} = -k_1 X_g, \qquad F_c = \mathrm{TEG}(1.0 - X_g) \qquad \frac{dX_d}{dt} = k_2 X_d \quad \text{(at } F_c \geq 0.8\text{)}$$

TEG: terminal extent of gelatinization(-), X_g: gelatinization degree at TEG base (-), F_c: gelatinization degree (-), X_d: degree of dispersion (-), k_1 & k_2 : rate constant(s^{-1})

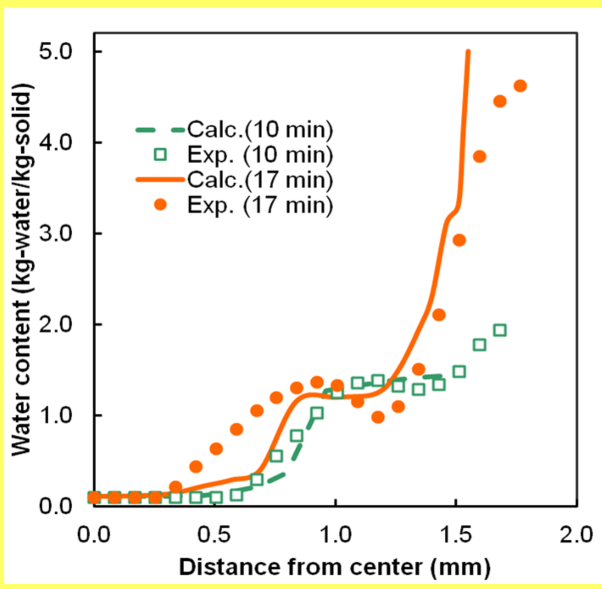


Fig.3 Comparison between the measured moisture profile and the calculated one.

We conducted mass transfer analysis by using "the modified relative water content model" together with the two kind of reaction kinetics. In the model, the WHC was expressed as a function of the state of the starch granule, where it was assumed that the WHC increases when starch dispersion occurs. The measured moisture profile and the simulated one were consistent; therefore, we concluded that the new water content model could be describing the moisture migration in noodles during cooking.

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