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Decomposition kinetics of umami component during meat cooking

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ABSTRACT

We developed a kinetic model for the decomposition reaction of inosine monophosphate (IMP), which is a umami component, and obtained kinetic parameters based on the amount of IMP in an isothermal experiment. The amount of remaining IMP decreased with heating time, and its reduction rate was the highest at 40 °C. We assumed that the activity of IMP decomposition enzyme is temperature-dependent above 40 °C, and constant below 40 °C. The predicted results using this kinetic model are in good agreement with the experimental ones. Unsteady-state three-dimensional heat transfer analysis of meat during *sous-vide* cooking was conducted, and the distribution of remaining IMP was predicted. By the end of *sous-vide* cooking, the ratio of the amount of IMP in the interior of the meat decreased, whereas at the surface region, it was almost the same as the initial value, because the surface temperature reached the inactivation temperature immediately.

1. Introduction

Taste, which consists of saltiness, sweetness, bitterness, sourness, and umami, is an important sensory property of foods, along with many other characteristics, including texture and flavor. The improvement in taste is related to the increase in the amount of free amino acids and peptides in meat, and the increase in the amount of free amino acids containing glutamic acid contributes to the enhancement of umami taste by inosine monophosphate (IMP) (Kawai et al., 2002; Fujimura et al., 1996; Okumura et al., 1996; Lin, 1993; Manabe et al., 1991; Nishimura et al., 1988; Maga, 1983). IMP is a major nucleotide in postmortem muscle, and contributes to both taste and flavor in meat (Maga, 1983). Therefore, many studies have investigated the relationship between the temperature and the amount of IMP in meat and fish muscle (Kuo et al., 2005; Shimada et al., 1992; Nishimura et al., 1988). Kuo et al. (2005) investigated the relation between the storage temperature and the amount of IMP in a pork sample. They found that IMP decomposition was negligible at −2 °C, while the IMP decomposition rate increased in a sample stored at 25 °C. In the case of thermal processing such as cooking, IMP decomposition correlated with the heating rate and the activity of the enzyme that decomposes IMP (Tomioka et al., 1993). In addition, several factors such as water activity, pH, and the addition of salt or sucrose were considered to affect the IMP decomposition (Kavitha and Modi, 2007; Sasaki et al., 2007; Yamazaki et al., 2006; Vani et al., 2006; Chikun et al., 2002; Ishii et al., 1995; Tomioka et al., 1993). Sakaguchi et al. (1991) suggested that acid phosphatase is one of the enzymes associated with the IMP decomposition in meat, although they did not specify the enzyme by isolating it.

Previous studies have focused on the factors related to IMP decomposition, but neither the kinetics of IMP decomposition nor the prediction of the amount of remaining IMP in meat during heating has been described. Moreover, although there are many reports about heat transfer analysis during various meat cooking processes (Singh et al., 1984; Chen et al., 1999; Obuz et al., 2002; Van der Sman, 2007; Gõni and Salvadori, 2010), there are very few reports on predicting the distribution of factors related to meat quality, such as color (Nakamura et al., 2011; Matsuda et al., 2013), protein denaturation (Ishiwatari et al., 2013), and IMP content. Therefore, we determined the kinetic model of IMP decomposition reaction, obtained the kinetic parameters via an isothermal experiment, and described the prediction of the IMP distribution in meat with heat transfer during cooking. We then verified whether this model could be applied to a piece of meat cooked using a vacuum-packing method (*sous-vide*). *Sous-vide* cooking is widely used in restaurants, hotels, and other establishments that have a central kitchen. Although many different dishes can be prepared by the *sous-vide* method with various treatment temperatures and cooking times, two basic steps are common. First, the food is sealed in a plastic bag using a vacuum-packing machine. Then, the food in the bag is heated to the exact optimal cooking temperature using a water bath or a steam convection oven (Schellekens, 1996). While many studies have reported the advantages of the *sous-vide* method, such as retention of flavor and original

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Nomenclature

A_E	enzyme activity ratio (−)
C_{E0}	total enzyme concentration (M)
C^*_{E0}	total enzyme concentration before deactivation (M)
C_I	IMP concentration at time t (mol/g_{meat})
C_0	initial IMP concentration in unheated meat (mol/g_{meat})
C_S	substrate concentration (M)
E_a	activation energy of IMP decomposition reaction (J/mol)
E_E	activation energy of the enzyme activity decrease reaction (J/mol)
k	reaction rate constant (1/min)
k^*	rate constant of the IMP decomposition including enzyme deactivation (1/min)
k_E	rate constant of the enzyme activity decrease reaction (1/min)
k_I	rate constant of the IMP decomposition reaction in consideration of the enzyme activity (1/min)
K_m	Michaelis–Menten constant (M)
R	gas constant (J/(mol K))
t	time (s)
T	temperature (°C)
T_a	ambient temperature (°C)
T_s	surface temperature (°C)
v	rate of product formation (M/min)
V_m	maximum rate of reaction (M/min)
X_I	remaining IMP ratio (−)
Z	pre-exponential factor of the IMP decomposition reaction (1/min)
Z_E	pre-exponential factor of the enzyme activity decrease reaction (1/min)

Greece symbol

α	thermal diffusivity (m^2/s)

appearance of the food and avoidance of the use of excess fat and water (Garcia-Fernandez, 2005; Vansagna et al., 2002; Schellekens, 1996), there is little information on the distribution of temperature and the factors that influence the quality of meat. The most important factor in *sous-vide* cooking is controlling the heat treatment, and in the case of meat, the heating temperature is usually 70 °C (Schellekens, 1996). Thus, the meat lump cooked by the *sous-vide* method has uneven distribution of IMP, because the degree of enzyme activity changes at 70 °C or below. Therefore, to describe the characteristics of temperature distribution and meat quality, we simulated unsteady-state three-dimensional heat transfer in a roast beef sample cooked by the *sous-vide* method and calculated and visualized the amount of IMP in the samples.

2. Materials and methods

2.1. Materials

Japanese beef from female cattle, supplied to us by the retail store, was 3–5 days old following slaughter. The meat was preserved at 5 °C for 3 days in the slaughterhouse and then stored in the retail store at 5 °C for 2 days. We used meat from five cattle in the isothermal heating experiment and meat from three cattle in the cooking experiment for repetition.

2.2. Isothermal heating experiment

We used sliced top round (not bottom round) samples of Japanese beef. Meat samples sliced to 1.0 mm thickness were vacuum-packed and kept at 5 °C before using in the experiment. Samples were heated in a water bath at several target temperatures for 15, 30, 45, and 60 min. After heating, the samples were quenched in iced water until the core temperature reached 20 °C and were kept at 5 °C until they were used for analysis. Repetition of isothermal experiments was conducted on five beef cattle samples.

2.3. Cooking experiment

Beef rump weighing 460 ± 1.2 g was cooked to roast beef according to the *sous-vide* method using the following procedure: (1) Each surface of the meat was browned for 60 s using a frying pan heated at 180 °C. The frying pan made of stainless steel and coated with Teflon was heated by gas. (2) The meat was put in a blast chiller (NR-B172 J, Panasonic Co., Ltd.) until its core temperature reached 10 °C or less. (3) The meat was put in a plastic bag (CP30/NY15/SPE15/LLD60, Meiwa Pax Co., Ltd.) and vacuum-packed by using a vacuum-packing machine (FVC-II, Furukawa MFG Co., Ltd.). (4) The meat was then cooked at 80 °C in a water bath (Thermal Robo TR-4, As One Co., Ltd.). When the core temperature of the meat reached 58 °C, it was immediately transferred into a water chiller (Cool Ace CA-1200, Tokyo Rikakikai Co., Ltd.) set to 2 °C, and cooled until the core temperature dropped to 4 °C. During the cooking, we collected the temperature history for both the core and the surface of the meat, as follows:

① *Core temperature*: A thermocouple (*T*-type, 1 mm in diameter) was inserted into the *sous-vide* bag and positioned in the core of the sample.
② *Surface temperature*: A thermocouple (*T*-type, 1 mm in diameter) was placed on the surface of *sous-vide* sachet.
③ *Ambient temperature*: Thermocouples were placed in the water bath and the water chiller.

After cooking, a 1.0-cm-thick cross-section at half-height including the core was taken from the sample. As shown in Fig. 1, the surface, the central part, and the middle part were separated from the sample and subjected to chemical analysis.

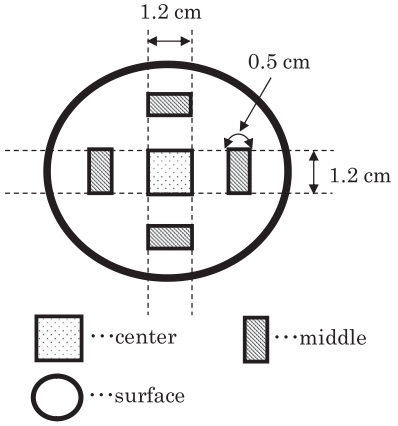

Fig. 1. Diagrammatic illustration of the cross-section of a meat sample used for chemical analysis.