学 位 論 文 の 要 旨

(Summary of Dissertation)

論文題目　Effect of trehalose on the mechanical properties of deep-fried foods

(トレハロースがフライ食品の力学的性質に及ぼす影響)

広島大学大学院統合生命科学研究科
Food and AgriLife Science プログラム
学生番号　D201930
氏　　名　LE NGOC DANG TRINH

Deep-frying is one of popular cooking methods to produce dry foods having desirable and characteristic flavor and texture. Deep-frying is achieved by immersing food stuff into the heated oil (approximately 150 ºC~200 ºC). In case of *tempura*, *tempura* is cooled down at room temperature, and the fry coating becomes glassy state at least at the outer part. The glassy fry coating shows a favorable brittle texture. When storage time is prolonged, the fry coating changes from brittle texture to ductile texture because glass to rubber transition (briefly, glass transition) occurs through water sorption originating from the atmosphere moisture and/or from the food stuff. Temperature of which glass transition occurs is denoted as glass transition temperature (T_g). Food product is glassy state at a lower temperature than the T_g, and the glassy porous food shows brittle texture because of its high elasticity. The glassy food becomes rubbery state at a higher temperature than the T_g, and the rubbery food shows ductile texture because of the reduced elasticity. Glass transition also occurs even at a constant temperature when water content change, because the T_g of hydrophilic amorphous materials decreases with an increase in the water content because of water plasticizing effect. Water content of which the T_g becomes 25 ºC (typical room temperature) has been described as critical water content (w_c). In addition, water activity (a_w) of which the T_g becomes 25 ºC has been described as critical water activity (a_{wc}). The higher w_c and a_{wc}, the greater resistance to the physical deteriorations induced by water sorption. To maintain brittle texture of fry coating as long as possible, it is important to elevate the w_c and/or a_{wc} of fry coating.

Differential scanning calorimetry (DSC) is the most common technique to determine the T_g of amorphous materials. However, it is difficult to determine the T_g of starchy foods because unclear glass transition behavior is observed in a broad temperature range. In this case, thermomechanical approach is more effective. In a previous study, it was demonstrated that the glass transition of fried batter particles (*agedama*) could be detected by thermal rheological analysis. It is known that thermal T_g determined by DSC does not always agree with the T_g determined by thermomechanical approaches. Thus, the T_g determined by thermomechanical approaches is distinguished as "mechanical T_g".

It is known that the T_g of amorphous materials can be controlled by the compositions. For example, T_g of amorphous polymers decreases with an increase in small molecules because of their plasticizing effect. However, the plasticizing effect of small molecules on the mechanical T_g of the fried batter particles does not always obey to the plasticizing behavior. In our previous study, it was demonstrated that the mechanical T_g of fried batter particles could be elevated by the addition of trehalose. As one of possibilities, it is suggested that trehalose filled the defects in the amorphous amylopectin (the major component of the fried batter particles) and the mechanical strength was enhanced. This suggestion is based on "anti-plasticizing effect" explained in the previous studies.

To clarify physical modification effect of trehalose on the fried batter particles in more detail, this study aimed to understand effect of trehalose content on the mechanical properties of fried batter particles. In addition, freeze-dried waxy starch (amylopectin) was employed as a model of fried batter particles. The freeze-dried starch solid has numerous pores formed by ice sublimation; the glassy porous solid is similar structure to fried batter particles. Amylopectin is the major component of fried batter particles, and chemical reactions and thermal degradation are highly diminished by freeze-drying. Thus, freeze-dried waxy starch was expected to be an effective model for the better understanding of the physical modification induced by trehalose addition.

Chapter 1 stated the background and purpose of this study.

Chapter 2 showed fundamental details regarding materials and experimental techniques used in this study.

Chapter 3 reported effect of trehalose content on the oil content, water content, a_w, mechanical glass transition, and texture properties of fried batter particles. Wheat flour and chilled water were mixed at the weight ratio of 1.0 : 1.6, and trehalose (0, 5, 10, 20%, against dry wheat flour) was added into there in an iced water bath. The batter was dropped into heated oil and fried at 180 ºC for 4 min. The 10% trehalose sample was the lowest oil content, water content, and a_w. In addition, 10% trehalose sample was higher mechanical a_{wc}, lower first fracture force, and higher number of fracture peaks than 0% and 5% trehalose samples. There were similar effects on the mechanical a_{wc} and fracture properties between 10% and 20% trehalose samples. This suggests that 10% trehalose is an optimum additive content for the brittle texture of deep-fried foods. The results convey the molecular mechanism involved in the physical modification of trehalose on fried batter particles.

Chapter 4 reported the effect of trehalose content on the texture properties and true density of freeze-dried waxy starch. Waxy starch was put into a vial, and distilled water was added. For the preparation of the samples containing trehalose, 5%, 10%, 20%, and 40% trehalose (on dry weight basis) was added. Starch in the mixture was gelatinized, and the gelatinized mixture was freeze-dried. The first fracture force and the number of fracture peaks of freeze-dried porous solids were an almost equivalent behavior to those observed in fried batter particles. In addition, it was demonstrated that freeze-dried powder containing 10% trehalose sample was significantly higher true density than the others. This result strongly supports the suggestion based on the anti-plasticizing effect; trehalose fills the defects in the amorphous amylopectin and the mechanical strength is enhanced.

Chapter 5 claimed the general discussion according to the results. When gelatinization of wheat starch occurs in the presence of trehalose, the trehalose is partially incorporated into the gelatinized wheat starch because of the hydrophobic interaction induced by oil. Thus, the trehalose molecules will act as "internal trehalose". The trehalose except for internal trehalose, on the other hand, will locate at the interfacial parts of amylopectin. Since internal trehalose can fill the gap spaces of amylopectin, oil uptake is reduced. In addition, evaporation of water is promoted because water molecules are excluded from gelatinized wheat starch by internal trehalose. The fact that freeze-dried amylopectin containing 10% trehalose was the highest true density suggests that the gap space of amylopectin is almost saturated by 10% trehalose addition. This corresponds to the lowest oil content, water content, and a_w of 10% trehalose sample. In addition, the fact that 10% trehalose sample was higher mechanical a_{wc} than 0% and 5% trehalose samples is explained.

Since fractures intrinsically occur at the physically weak points in the structure, interfacial trehalose plays a role of fracture points. Thus, the first fracture force decreased, and the number of fracture peaks increased by the addition of trehalose.

Water is a much lower molecular size and much higher molecular mobility than trehalose.

Water molecules within the glassy polymer are mobile at ambient temperature. Thus, there will be an unclear distinction between internal and interfacial water molecules in glassy amylopectin. Water molecules will fill gap spaces in the internal and interfacial part of amylopectin that trehalose cannot sufficiently fill, and thus fracture points attributed to interactions between interfacial trehalose and amylopectin can be physically strengthened by water. Consequently, the first fracture force increased linearly, and the number of fracture peaks decreased linearly with increasing a_w, even in the glassy state.

Chapter 6 gave the conclusion for this study and outlook for the future subject. This study employed fried batter particles as a fry coating model. Fry coating coats wet food stuff, and thus diffusion of water molecules from the food stuff to the fry coating occurs quickly. Since deep-fried foods are in non-steady state, there is a gradation of water content and temperature between inner and outer parts. It is practically important to understand the kinetic properties of fry coating.