論文題目　　　Glass Transition and Texture Properties of Deep-Fried Foods
(フライ食品のガラス転移と食感に関する研究)

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Deep-fried foods are very popular throughout the world due to it's unique flavor, appearance, and texture. Dry carbohydrate food products e.g. deep-fried foods are commonly found in a glassy amorphous state where glassy porous structure is the most important factor affecting their brittle texture. But this brittle texture is gradually undergoing evident rheological changes to ductile texture at a critical temperature, known as a glass transition temperature (T_g). The T_g has been understood as the temperature at which an amorphous material change physically from a glassy (elastic) state to a rubbery (viscoelastic) state. At constant temperature, the glass transition depends on the water content or water activity as the T_g of a hydrophilic amorphous material decreases with the increase in water content because of water plasticizing effect. A glassy material changes to a rubbery material due to water sorption when its T_g is below the ambient temperature. Therefore, it's a crucial need to understand the T_g –curve (effect of water content on T_g) along with critical water content and critical water activity of glassy food products to control and predict the spontaneous texture change over storage and increase shelf-life stability.

Differential scanning calorimetry (DSC) has been widely used to evaluate T_g of amorphous

materials. However, it is commonly difficult to detect T_g of food systems by DSC. In that case, mechanical approaches such as thermal rheological analysis (TRA) are mostly effective. Conversely, there has been no clear information about the glass transition properties of deep-fried food products because deep-fried food has a large amount of oil which makes studies more challenging.

Different types of additives such as starch or low-molecular weight carbohydrate (like sugar) are being used to modify the physical properties of dry carbohydrate food. T_g of amorphous materials strongly depends on the T_g of each ingredient. As, T_g of food products can be controlled by the types and amount of additives. Therefore, the effects of carbohydrate addition on the textures of deep-dried foods should be understood. However, experimental evidence of this hypothesis is lacking for the above-mentioned reasons. The purpose of the study was to understand the T_g of deep-fried foods and its impact on their textural properties.

Chapter 1 provided the general background and purpose of the study.

Chapter 2 provided fundamental information and reviews the relevant existing literature on deep-fried foods, water activity, glass transition, and texture of low moisture foods with a literature review.

Chapter 3 established the T_g–determination approach of the deep-fried samples and relates the glass transitions to their textural changes. For this purpose, commercial tempura crumbs (bits of deep-fried tempura batter) were firstly employed as a deep-fried food model. The T_g of the deep-dried sample could not be determined by DSC. On the other hand, the T_g of the deep-dried sample was successfully evaluated by TRA of the bulk sample. The a_{wc} determined from the water sorption isotherm and the T_g-curve was validated by isothermal mechanical relaxation measurements. Furthermore, it was suggested that glucose appeared to

be an effective textural modifier of the deep-fried samples because of its anti-plasticizing effect and reduction of oil absorption.

Chapter 4 investigated the effect of trehalose and corn starch on the water sorption, glass transition, and textural properties of hand-made deep-fried samples containing different oil percentages. It was found that both water and oil reduced the T_g of deep-fried samples. For the same water and oil contents, the T_g was highest in the trehalose-added (WT) samples. Consequently, the W_c and a_{wc} were much higher in WT sample than in the other samples because of the highest T_g, indicating that the trehalose-added sample resisted textural softening induced by water sorption. On the other hand, the WT sample had lower fracture energy and higher number of fracture peaks. This suggests that trehalose contributed as linkages of starch segments and the linkages provided lower fracture energy and higher number of fracture peaks.

Chapter 5 summarized the study findings and suggests the ways of improving the physical stability of deep-fried foods. Future study should investigate how the type and amount of low-molecular-weight additives alter the physical properties of deep-fried food samples based on the glass-transition concept. This knowledge will be useful for understanding the texture control of not only deep-fried foods, but also of other low-moisture starchy foods.

Keywords: Deep-fried foods, Water sorption isotherm, Thermal rheological analysis, Glass transition temperature, Critical water content, Texture properties