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学位論文全文に代わる要約
Extended Summary in Lieu of Dissertation

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Name

学位論文題目：
Title of Dissertation

Effect of D-Ketohexoses on Rheological Properties of Chicken Gel Products
（鶏肉および鶏卵のゲル状食品の物性に及ぼすD−ケトヘキソースの添加効果とその機構に関する研究）

学位論文要約：
Dissertation Summary

Sucrose (**Suc**) is the most popular sugar in food processing, because it gives comfortable sweetness to foods, improves the rheological properties of processed foods, and sometimes suppresses the growth of bacteria in foods. But excessive consumption of Suc and other conventional sugars, such as D-glucose (**Glc**) and D-fructose (**Fru**), increases the risk of developing lifestyle disease, *e.g.* diabetes. Rare sugar, monosaccharides and their derivatives being rarely in nature, may reduce the risk, because some of rare sugars, *e.g.* D-allulose (**Alu**), are non-calorie and suppress postprandial blood sugar elevation and body fat accumulation. Chicken meat and chicken egg are popular food materials and they are extensively used in producing gelling foods, such as sausage and scramble eggs, in many countries.

The main objective of this thesis was to investigate the effects of rare ketohexoses (Alu, D-tagatose/**Tag**, and D-sorbose/**Sor**) on the rheological properties of chicken gel products and to compare the effects of rare ketohexoses on frozen storage of chicken gel products with Glc, Suc, and trehalose (**Tre**).

Chapter 3 shows the effect of Alu as sugar substitute on rheological properties of chicken breast sausage. The total amount of Suc used was 2.5% of the weight of minced chicken breast meat. The four chicken breast sausage treatments for sugar were 0:100 (**A0S1**), 30:70 (**A3S7**), 70:30 (**A7S3**), and 100:0 Alu:Suc (**A1S0**). The results show that substitution of Suc with Alu did not affect breaking stress, breaking strain, and elasticity modulus of chicken breast sausage, but 100% substitution with Alu caused a 10% decrease in viscosity and 31% decrease in expressible water. Although the physical properties (elasticity, viscosity, water-holding capacity, and elastic recovery) of chicken breast sausage are deteriorated by frozen storage, the deterioration was greatly suppressed by the substitution of Suc with Alu. Creep-compliance curves of A0S1, A3S7, A7S3, and A1S0 sausages are shown in **Fig. 1**. An outstanding difference was seen in the creep recovery curve (time, 60 to 120 s) that represents elastic recovery. Fresh A0S1 sausage (0 d storage) showed a similar creep recovery curve

to fresh A3S7, A7S3, and A1S0 sausages; while creep recovery curves of frozen stored sausages differed between the four sausages. Creep recovery curve of A0S1 sausage significantly shifted upward with the storage period. On the other hand, the upward shift of A1S0, A7S3, and A3S7 sausages were much less than that of A0S1 sausage. The data indicate that Alu markedly suppresses the loss of elastic recovery induced by frozen storage. The suppressive effect of elastic recovery loss is probably due to the high water-holding capacity that Alu confers to sausage. Thus, Alu was shown to confer resistance to freezing-related damage in sausage. In particular, the suppression of the quality deterioration of frozen-stored sausage demonstrates the feasibility and benefit of application of Alu to frozen foods.

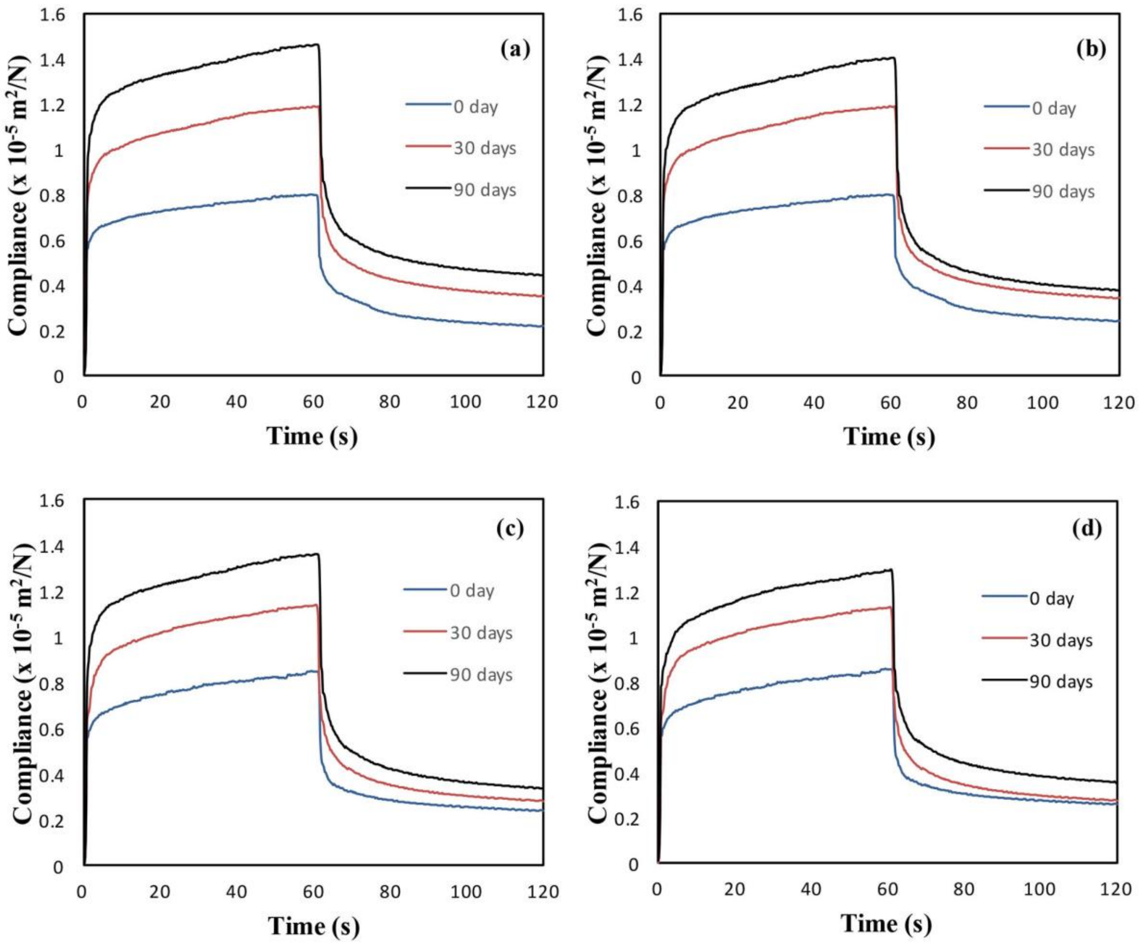

Figure 1. Creep-compliance curves of sausages frozen-stored at −20ºC. (a) A0S1, (b) A3S7, (c) A7S3, and (d) A1S0.

Chapter 4 shows the application of D-ketohexoses to heat-induced egg white (**EW**) gel. The aim of this chapter was to examine the rheological properties of chicken EW gels containing 10% (w/v) D-ketohexose (Alu, Tag, Sor and Fru) and to compare the effects of D-ketohexoses on freeze-thawing of EW gels. The results show that D-ketohexoses can improve the rheological properties and water holding capacity of EW gels compared with Suc, Glu, and Tre.

Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis (**SDS-PAGE**) method was used to analyze protein-protein interaction in EW gels containing sugar. Egg proteins were extracted from EW gels using solubilization buffer containing SDS and urea. The SDS-PAGE pattern of proteins extracted from EW gels is shown in **Fig. 2**. A thick protein band at the molecular mass of 45kDa corresponding to ovalbumin (**OVA**) was observed in the lanes of all the sugar-gels. However, ketohexose-gels had thinner OVA band than the other sugar-gels, suggesting that more covalent-crosslinks of OVA molecules were formed in ketohexose-gels. The intensified covalent-crosslinks of OVA probably contribute to the resilient gel networks of ketohexose-gels, as seen in the results of breaking stress and breaking strain. Maillard reaction in EW gels did not examined, but the color of all the ketohexose-gels was a slightly more yellowish than Glc-, Suc- and Tre-gel, suggesting that the Maillard reaction in ketohexose-gels proceeds faster than in Glc-, Suc-, and Tre-gel. The Maillard reaction is a non-enzymatic browning reaction that occurs by heating of a mixture of sugar and egg protein. D-Ketohexoses may facilitate Maillard reaction with egg proteins, probably resulting in high gel strength of ketohexose-gels.

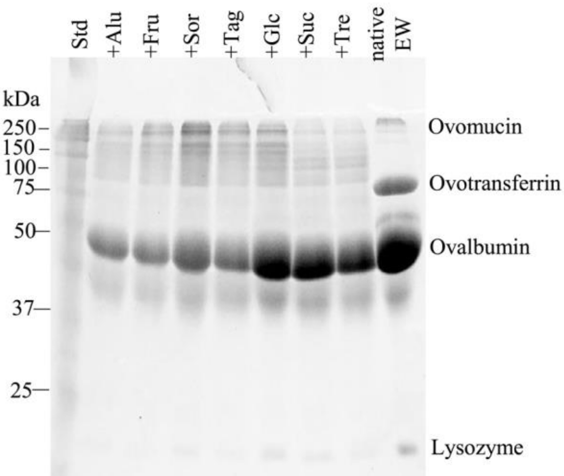

Figure 2. SDS-PAGE patterns of protein extracted from EW gels

Frozen storage is one of the major methods for preservation of foods, especially foods with high water content. However, freezing and the subsequent thawing cause undesirable rheological changes in gel-like foods, *e.g.*, a lowering of gel elasticity and drip loss. So, freeze-thaw cycles were used to examine the effect of D-ketohexoses on rheological changes of EW gel by frozen storage. The cylindrical EW gels were employed to evaluate the effects of sugar on freeze-thawing of EW gels. The cylindrical EW gels were frozen at −20ºC in a still freezer and they were stored for five days. After that, the frozen gels were thawed in a refrigerator (4ºC) for

16 h. The elastic modulus of EW gels decreased as the number of freeze-thaw cycle increased. In each cycle, ketohexose-gels except Sor-gel had higher elastic modulus than Suc-gel. Thus, decrease in gel elasticity by freeze-thaw cycles is more effectively suppressed by ketohexoses except Sor than by the disaccharide Suc. Also, the viscosity of ketohexose-gels declined in a similar manner. Up to the two cycles, ketohexose-gels had higher viscosity than Glc-, Suc-, and Tre-gel; but all the sugar-gels after three cycles had almost same coefficient of viscosity. The breaking stress value of EW gels decreased with freeze-thaw cycle. The decrease ratio by a single freeze-thaw cycle was 53% in the first cycle of Glc-gel, which was largest in all the sugar-gels tested. Comparison of breaking stress values in each cycle showed that ketohexoses-gels have higher breaking stress value than Glc-, Suc-, and Tre-gel. On the other hand, the breaking strain of EW gels showed a slight upward trend. In each cycle of freeze-thaw cycles, breaking strain value of ketohexose-gels was higher than that of Glc-, Suc- and Tre-gel. **Figure 3** shows the expressible water of freeze-thawed EW gels. Expressible water of EW gels escalated with freeze-thaw cycle. A significant difference in the expressible water of gel after the first freeze-thaw cycle was observed between ketohexose-gels and the other sugar-gels (Glc-, Suc-, and Tre-gel). Much higher amount of water was expressed from single freeze-thawed Glc-, Suc-, and Tre-gel, suggesting that ketohexose-gels possess higher water-holding capacity against freeze-thawing. EW gels after the two cycles, however, did not differ substantially between sugars. Thus, ketohexoses exert predominance in preventing syneresis of EW gel by freeze-thawing, but they are effective only in the first cycle. So, D-Ketohexoses appreciably reduced the deterioration in the rheological properties of EW gels by freeze-thawing and possessed higher water-holding capacity against freeze-thawing than the other sugars. Thus, D-ketohexoses are useful to enhance storage stability of frozen gel-type foods containing EW.

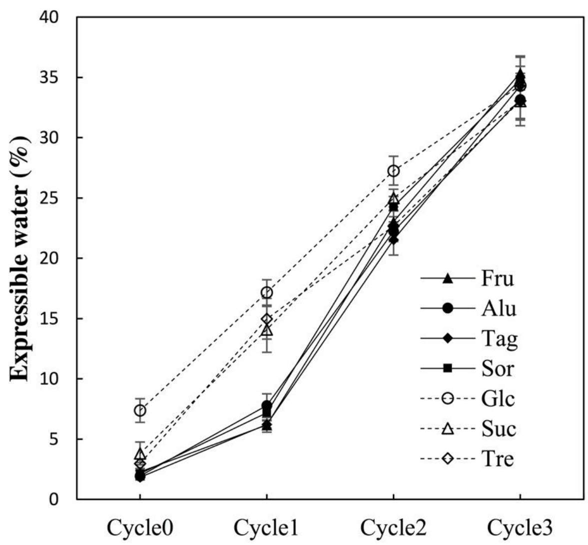

Figure 3. Effects of freeze-thaw cycles on water-holding capacity of EW gels containing ketohexoses.

Chapter 5 shows the application of D-ketohexoses to whole egg (**WE**) gel. WE gel with D-ketohexose showed similar viscoelastic properties to a WE gel with Glc, Suc, or Tre. But the breaking strength of ketohexose-gels was higher than that of the other sugar-gels suggesting that D-ketohexoses confer fracture resistance to WE gel. The cylindrical WE gels after freeze-thawing were subjected to physical analyses. The expressible water of WE gel showed little change by one freeze-thaw cycle, but it rose by two and three cycles **(Fig. 4**). The comparison of expressible water at each cycle resulted in no significant difference among sugar-gels. Thus, unlike the case of EW gels, ketohexoses did not show predominance in preventing syneresis of WE gel by freeze-thawing. It follows that coefficient of viscosity of WE gels decreased as the number of freeze-thaw cycles increased. Alu was superior to all the other sugars (Tag, Sor, Fru, Glc, Suc, and Tre) in terms of the suppression of viscosity change of WE gel by freeze-thawing. Fru-gel also had a similar effect, but the suppression effect was restrictive only in the first freeze-thaw cycle. In addition, ketohexose-gels, especially Alu-gel, retained higher breaking stress value than Glc-, Suc-, and Tre-gel did.

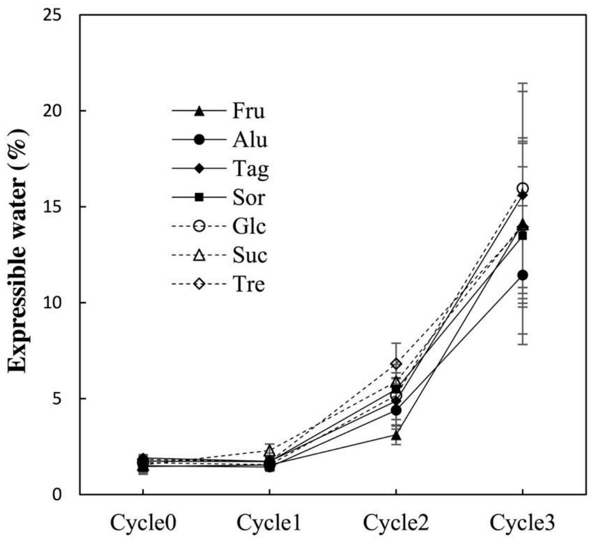

Figure 4. Effects of freeze-thaw cycles on water-holding capacity of WE gels containing ketohexoses.

Chapter 6 shows the mass transfer phenomena and diffusion coefficient of Alu into potato. In both Alu and control sugar Suc, uptake into potato in the immersion period of 0-2 h was higher than that in the immersion period of 6-8 h. The value of Alu content in potato was 2.81% after 8 h immersion. On the other hand, the value of Suc content in potato was 1.75% after 8 h immersion. Diffusion coefficient of Alu was 6.43 x $10^{-10}m^2s^{-1}$ which is much higher than that of Suc (2.83 x $10^{-10}m^2s^{-1}$), suggesting that Alu has the higher penetration rate into potato than Suc. The acceleration movement of Alu into food material may be useful in

food processing and preservation such as curing process of meat and fish.

In conclusion, substitution of Suc with rare ketohexoses can improve the rheological properties of chicken gel products. Also, rare ketohexoses are useful to enhance storage stability of frozen chicken gel products. The application of rare ketohexoses to frozen foods will contribute to improvement of texture, suppression of quality deterioration, and reduction of the risk of developing lifestyle diseases.