Effect of d-allulose on rheological properties of chicken breast sausage

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ABSTRACT  d-Allulose (Alu), a rare sugar, was applied to chicken breast sausage as a sucrose (Suc) substitute. The ratio (w/w) of Alu to Suc in sugar that was added to the sausage batter was 0/1 (A0S1), 3/7 (A3S7), 7/3 (ATS3), and 1/0 (A1S0). The total amount of Suc used was 2.5% of the weight of minced chicken breast meat. Substituting Suc with Alu did not affect water content, cooking loss, breaking stress, breaking strain, and modulus of elasticity of chicken breast sausage, but a 100% substitution with Alu caused a 10% decrease in viscosity and a 31% decrease in expressible water. A significant difference appeared in the rheological properties of elasticity, viscosity, and water-holding capacity of chicken breast sausage frozen-stored (−20°C) for 90 d. Particularly, the modulus of elasticity for A1S0 chicken breast sausage was 19% higher than that of the control A0S1 chicken breast sausage, suggesting that Alu appreciably reduced the deterioration in elasticity that is caused by long-term frozen storage of sausage. The quality improvement of frozen-stored chicken breast sausage demonstrates the feasibility and benefits of the application of Alu to frozen foods.

Key words: chicken breast sausage, d-allulose, expressible water, frozen food, rare sugar

INTRODUCTION

Chicken breast sausage is widely consumed in many countries. Especially in Islamic countries, it is a main food commodity. In Indonesia, the country with the largest Islamic population in the world, chicken breast sausage occupies 43% of sausage market shares and the sausage market has grown 32.7% in five years, since 2007 (Wulandari et al., 2014). Chicken breast sausage is thought to be a healthful food because of its low fat content and high protein content (Ali et al., 2011). On the other hand, sausage in general contains large amounts of ingredients that are linked to lifestyle diseases, such as salt and sugar. Thus, excessive consumption of foods with high sugar/fat content can increase the risk of developing lifestyle-related diseases such as hypertension and type 2 diabetes (Johnson et al., 2009; Dominguez et al., 2015). Type 2 diabetes, in particular, has become a global problem. According to the International Diabetes Federation (IDF), 382 million people worldwide have diabetes, and more than 85% of the cases are type 2 diabetes. In 2013, 5.1 million people died of diabetes and cost $548 billion (USD) in health care spending (IDF, 2013). World Health Organization (WHO) guidelines recommend adults and children reduce their daily intake of free sugars to less than 10% of their total energy intake (WHO, 2015). Thus, consumers pay attention to foods with reduced sugar contents (Baker and Friel, 2014).

D-Allulose (Alu), also known as d-Psicose, is the C-3 epimer of d-fructose (Fru). It is a rare sugar that exists in small amounts in nature (Granstrom, et al., 2004). A method of mass production of Alu was developed by the Izumori research group (Takeshita, et al., 2000). According to Han (2015), Alu can be sold at less than $15 per pound in the United States. Alu has a caloric value of 0.39 kcal, which is roughly equivalent to 10% of the caloric value of sucrose (Suc) and suppresses the elevation of after-meal blood glucose levels (Matsumo et al., 2002; Hayashi et al., 2010; Hossain et al., 2015). Alu was approved and generally recognized as safe (GRAS) by the U.S. Food and Drug Administration (FDA) in June 2014 (GRAS Notice No. GRN 498) (Hossain et al., 2015), and it can be used as an ingredient in foods and dietary supplements (Mu et al., 2012).

Alu also has demonstrated promising applications for use in the food industry. It has been shown to improve the food properties of some processed foods and their materials. The application of Alu as a Suc substitute to meringue-based confectionery resulted in a crunchier texture and enhanced the antioxidant activity of baked...
meringue (O’Charoen et al., 2014). Custard pudding, utilizing Alu as a Suc substitute, demonstrated higher breaking strength and higher viscoelasticity than the control with Suc as well as with Fru (Sun et al., 2006). Furthermore, Alu demonstrated better foaming properties of egg white protein compared with Suc and Fru (Sun et al., 2008). However, there is little research on the effects of Alu on the processing characteristics of meat. In this study, we determined the effects of Alu as a Suc substitute on the rheological properties of chicken breast sausage. We also investigated the effects of Alu on frozen-storage of chicken breast sausage. This is the first report on the application of Alu to sausage.

MATERIALS AND METHODS

Materials

Chicken breast meat, salt, and Suc were purchased from a local market. Alu (PubChem CID: 441036) was obtained from the Rare Sugar Research Center, Kagawa University, Japan. Sodium polyphosphate was purchased from Wako Pure Chemical Industries, Tokyo, Japan. All other reagents used were of analytical grade.

Sausage Preparation

Chicken breast halves (3 kg) were diced and ground through a grinder (KitchenAid, Model KSM5; St Joseph, Michigan) with 4 mm plate. Cold water (40 mL), sodium chloride (3.6 g), sodium polyphosphate (1 g), and sucrose (5 g) were added to 200 g of the minced meat in a chilled bowl and mixed by hand for 3 min. The 4 chicken breast sausage treatments for sugar were 0:100 (A0S1), 30:70 (A3S7), 70:30 (A7S3), and 100:0 Alu:Suc (A1S0). The mixture was homogenized for 30 s with a food processor (TK-551; Tescom Co., Ltd., Tokyo, Japan). Then, the resulting meat batter was left for 10 min in a bowl on ice, and mixed again by sitting at room temperature for 3 h. After removal of the casing, the chicken breast sausages were thawed in a refrigerator (4°C) for 16 h before analysis or frozen at −20°C for 30 or 90 d before thawing in a refrigerator (4°C) for 16 h before analysis. The expressible water of sausages was measured by the method developed by Uresti et al. (2003). A 6 mm sausage slice was precisely weighed and placed between 2 layers of filter paper. The slice was sandwiched between the 2 filter papers placed at the bottom of a 50 mL centrifuge tube and centrifuged at 1,000 × g for 15 min at 15°C. Immediately after centrifugation, the compressed sausage slice was weighed. Expressible water of sausage was calculated using the following equation:

\[
\text{Expressible water} \approx \frac{(W_i - W_c)}{W_i} \times 100
\]

where \(W_i\) is the initial weight of the sausage slice and \(W_c\) is the weight of the compressed slice.

Cooking Loss

Cooking loss was calculated from the weight difference between uncooked and cooked samples (Jin et al., 2007). Cooking loss of sausage was calculated using the following equation:

\[
\text{Cooking loss} \approx \frac{(C_i - C_f)}{C_i} \times 100
\]

where \(C_i\) is the initial weight of uncooked sausage and \(C_f\) is the weight of cooked sausage.

Determination of Water Content

One gram of sausage pieces was precisely weighed in an aluminum pan. The pieces were dehydrated in a drying oven set at 105 ± 1°C until the sample weight reached a constant value. The dehydrate was cooled down in a desiccator in which silica gel had been placed and then weighed with a precision balance. The water content of the sausage was calculated using the following equation:

\[
\text{Water content} \approx \frac{(W_i - W_f)}{W_i} \times 100
\]

where \(W_i\) is the initial weight of sausage pieces (before drying) and \(W_f\) is the final weight of the dehydrate.

Rheological Properties

The rheological properties of sausage were assessed by 2 methods — a breaking test and a creep test — using a Rheomer II creep meter (RE 2-3305; Yamaden Co., Tokyo, Japan). The breaking test was
conducted using the creep meter equipped with a cylindrical plunger (diameter 5 mm). A piece of sausage was cut at intervals of 20 mm with a cutter knife to get cylindrical sausage gels (diameter 25 mm, height 20 mm). A cut gel sample was put on the stage of the rheometer and its breaking stress and breaking strain were measured at a penetration speed of 1.0 mm/s. The breaking stress and strain were represented as the stress (N/m²) and strain (%) at the top of the first peak of the stress vs. strain curve.

The creep test was conducted using the creep meter equipped with a 4 cm diameter plate plunger. A cylindrical sausage gel sample with the same size (diameter 25 mm, height 20 mm) was put on the stage of the creep meter and its creep measurement was carried out under uniaxial compression at 10 mm/s over a period of 2 min. According to Sun and Hayakawa (2002), the creep curve obtained was analyzed by a 6-element mechanical model as described by equation 1 based on the relationship between stress and strain:

\[
\varepsilon(t) = \frac{s}{E_0} + \sum_{i=1}^{n} \frac{s}{E_i} \left(1 - e^{-\frac{t}{\tau_i}}\right) + \left(\frac{s}{\eta_N}\right) t
\]

where \(\varepsilon(t)\) = strain (dimensionless), \(S\) = stress (N/m²), \(E_0\) = elastic modulus of a Hookean body (instantaneous modulus; N/m²), \(E_i\) = elastic modulus of a Voigt body (N/m²), \(\tau_i\) = retardation time (s), \(\eta_N\) = Newtonian viscosity (Pa·s), and \(t\) = time (s).

Viscoelastic parameters were calculated from the creep compliance data according to Eqs. 1 to 3 (Peleg, 1980):

\[
J(t) = \frac{\varepsilon(t)}{s}
\]

\[
J(t) = J_0 + \sum_{i=1}^{n} J_i \left(1 - e^{-\frac{t}{\tau_i}}\right) + t/\eta_N
\]

Differential Scanning Calorimetry

Thermal denaturation of proteins in the sausage batter was determined by differential scanning calorimetry (DSC). A Setaram Micro-DSC VII Commissioning/Utilizations (SETARAM Instrumentation, Caluire, France) was employed for DSC analysis. One hundred milligrams of sausage batter and 100 milligrams of Al2O3 were applied to a sample pan and a reference pan, respectively. The heating rate was 1.2°C/s in the temperature range of 20 to 90°C. The calorimetric data were analyzed using thermal analysis software provided with the DSC instrument.

SDS-Polyacrylamide Gel Electrophoresis

The protein profile of the sausage was analyzed by the Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis (SDS-PAGE) method. One gram of cooked sausage sample was minced and homogenized using a Nissei AM-8 homogenizer (Nihonseiki Kaisha Ltd., Tokyo, Japan) at 6,500 rpm for one min in 10 mL dissociation solution (0.6 M NaCl, 8.0 M urea, 1.25% SDS, and 20 mM sodium phosphate buffer, pH 8.0). The homogenate was then shaken with a SR-1 shaker (AS ONE Co., Osaka, Japan) at 4°C for 12 h before it was centrifuged at 4,500 × g for 20 min. The supernatant (40 µL) was mixed with 10 µL of SDS sample buffer (100 mM Tris-HCl buffer, pH 6.7, containing 5.0% SDS and 0.004% bromophenol blue with 2.0% β-mercaptoethanol) and the mixture was heated at 90°C for 5 min. The SDS sample solution thus prepared (10 µL) was put into wells of SDS-PAGE gel with 10% acrylamide separating gel. SDS-PAGE was carried out

4-layer cheese-cloth. The resultant pellet was re-extracted with 40 mL of HPLC grade water and then the combined supernatants were diluted to 100 mL with HPLC grade water. The extracted sugar solution (500 µL) was taken and mixed with the 2 ion exchange resins of strongly acidic cation-exchange resin DIAION™ SKIB (Mitsubishi Chemical Co., Tokyo, Japan) and strong basic anion-exchange resin Amberlite IRA411 (Organo Co., Ltd., Tokyo, Japan) and let stand for 30 min to remove charged substances. The sugar solution was filtered through a disposable membrane filter unit with pore size 0.2 µm. The pretreated sugar solution was subjected to sugar analysis with a Shimadzu HPLC system equipped with a RID-10A refractive index detector (Shimadzu Co., Kyoto, Japan) and a Hitachi Gel pack GL-C611 column (Hitachi Chemical Co., Ltd., Tokyo, Japan). Two hundred microliters of sugar solution were injected into the GL-C611 column and eluted with 0.1 mM NaOH at the flow rate of 1.0 mL/min (column temperature, 60°C). The concentrations of Suc and Alu were determined from calibration curves of their standards.

Concentrations of Alu and Suc in sausage were determined by the high-performance liquid chromatography (HPLC) method of Oshima et al. (2006) with slight modifications. Ten grams of sausage batter or the same weight of sausage pieces (2 × 2 × 2 mm³) were homogenized using a mini-chopping machine (Iwatani Int. Co., Tokyo, Japan). An appropriate amount of homogenate was precisely weighed in a beaker, to which 40 mL of HPLC grade water was added. Sugar contained in the sausage was extracted from the suspension using ultrasonic treatment (Sharp UT-204, Sharp Co., Tokyo, Japan) at 20°C for 10 min. The extracted sugar was centrifuged at 3,500 × g for 5 min and filtered through
Statistical Analysis

This experiment was set up using a completely randomized design (Oehlert, 2010). Four different chicken breast sausage treatments were tested with 3 replicates per experiment for each treatment. Each experiment consisted of 3 sample measurements. Statistical analysis was performed using the software SPSS 15.0 (SPSS Inc., Chicago, IL) by one-way analysis of variance (ANOVA) and the statistical difference of mean was determined by the Duncan multiple-range test with a significant level of 95%.

RESULTS AND DISCUSSION

Chemical Properties of Sausage

Table 1 shows water content, cooking loss, sugar content, and expressible water of the chicken breast sausage. Water content did not differ among A0S1, A3S7, A7S3, and A1S0. This shows that the substitution of Suc to Alu does not affect moisture retained in boiled sausage. Also, cooking loss of sausages did not differ significantly among all treatments. The cooking loss values of A0S1, A3S7, A7S3, and A1S0 were 10.67, 10.32, 10.45, and 9.93%, respectively.

Sugar content in chicken breast sausage was 24 to 33% lower than that of the sausage batters. The cooking loss of Alu was 29 to 33%, which was higher than that of Suc (24 to 29%). The higher loss in Alu may be due to the higher degree of Maillard reaction and the faster isomerization reaction of Alu, because Alu is a reducing sugar while Suc is a non-reducing sugar. Oshima et al. (2014) reported that in several foods Alu content decreased during cooking processing. Alu loss was 10.8% for sponge cake and 7.7% for baked meringue. The large difference in Alu loss is probably due to differences in cooking methods (baking and boiling). Unlike baking, boiling will cause sugar leakage from sausage batter to boiling water (Bach et al., 2013).

Sun et al. (2006) reported that Alu facilitated protein cross-linkage in heat-induced gel derived from egg white protein. To examine if a similar phenomenon occurs in chicken sausage, SDS-PAGE analysis of chicken breast sausage protein was carried out. As shown in Figure 1, the protein-band pattern was similar among A0S1, A3S7, A7S3, and A1S0. In all the samples tested, a slight band was observed at the top part in the stacking gel of SDS-PAGE, suggesting that high molecular weight protein complexes were formed via covalent bonding. The band intensity in the stacking gel was almost the same

![Figure 1. Sodium dodecyl sulfate-PAGE patterns of chicken breast sausage containing D-allulose (Alu).](image)

<table>
<thead>
<tr>
<th>Table 1. Water content, cooking loss, sugar content, and expressible water of sausages.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment</strong></td>
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<tr>
<td>----------------</td>
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<tr>
<td><strong>Water content</strong></td>
</tr>
<tr>
<td><strong>Cooking loss</strong></td>
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<tr>
<td><strong>Suc content before cooking</strong></td>
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<tr>
<td><strong>Suc content after cooking</strong></td>
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<tr>
<td><strong>Suc loss</strong></td>
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<tr>
<td><strong>Alu content before cooking</strong></td>
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<td><strong>Alu content after cooking</strong></td>
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<tr>
<td><strong>Alu loss</strong></td>
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<tr>
<td><strong>Expressible water</strong></td>
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</table>

N.D., not detected; N.A., not available; Data are presented as mean ± SD (n = 9) and values with different superscript letters (a and b) in a line show the significant difference (P < 0.05). A0S1 = 0% Alu and 100% Suc; A3S7 = 30% Alu and 70% Suc; A7S3 = 70% Alu and 30% Suc; A1S0 = 100% Alu and 0% Suc.
Table 2. Rheological properties of sausages.

<table>
<thead>
<tr>
<th>Item</th>
<th>A0S1</th>
<th>A3S7</th>
<th>A7S3</th>
<th>A1S0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking stress (10^5 N/m²)</td>
<td>2.26 ± 0.08</td>
<td>2.25 ± 0.24</td>
<td>2.23 ± 0.23</td>
<td>2.22 ± 0.29</td>
</tr>
<tr>
<td>Breaking strain (%)</td>
<td>37.49 ± 3.92</td>
<td>36.09 ± 2.40</td>
<td>37.59 ± 2.15</td>
<td>38.74 ± 1.96</td>
</tr>
<tr>
<td>Modulus of elasticity E₀ (10^5 N/m²)</td>
<td>1.66 ± 0.04</td>
<td>1.64 ± 0.08</td>
<td>1.62 ± 0.03</td>
<td>1.62 ± 0.04</td>
</tr>
<tr>
<td>Coefficient of viscosity η</td>
<td>5.01 ± 0.53</td>
<td>4.96 ± 0.04a</td>
<td>4.91 ± 0.20b</td>
<td>4.45 ± 0.07b</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD (n = 9) and values with different superscript letters (a and b) in a line show the significant difference (P < 0.05).

1A0S1 = 0% Alu and 100% Suc; A3S7 = 30% Alu and 70% Suc; A7S3 = 70% Alu and 30% Suc; A1S0 = 100% Alu and 0% Suc.

between A0S1 and A1S0. Thus, Alu seems not to facilitate protein cross-linkage in sausage.

Rheological Properties of Sausage

A comparison of the results is shown in Table 2. Substituting Suc with Alu did not affect breaking stress, breaking strain, or modulus of elasticity of chicken breast sausage. However, unlike chicken breast sausage, the breaking strength of custard pudding gel consisting of egg, milk, and sugar was affected by substituting Suc with Alu. Sun et al. (2006) showed that custard pudding gel containing Alu has higher breaking strength values than counterparts containing Suc. The discrepancy in the results between custard pudding and chicken breast sausage is due to the difference in gel forming protein (egg white protein and myofibrillar protein) and the difference in sugar content in the food systems (chicken breast sausage contains only one-sixth sugar content of custard pudding). On the other hand, substitution with Alu affected the coefficient of viscosity of chicken breast sausage. A 100% substitution with Alu resulted in an 11% decrease in viscosity.

A comparison of the expressible water of chicken breast sausage is shown in Table 1. The application of Alu did make a remarkable difference in expressible water. A higher substitution rate by Alu led to a lower expressible water. Expressible water of A1S0 sausage was only 69% that of A0S1 sausage. Although the decrease in expressible water seems not to be correlated closely with the decrease in viscosity of sausage gel, an indirect relationship might exist between the 2 parameters.

Water-holding capacity of gel is inversely associated with the percentage of water expressed by centrifugation (Das et al., 2008). The decrease in expressible water of chicken breast sausage by substituting Suc with Alu implies that Alu enhances the water-holding capacity of sausage, suggesting that Alu helps chicken breast sausage proteins to tightly interact with water molecules. The low expressible water of Alu-chicken breast sausage might be related to its lower viscosity.

Figure 2. Differential scanning calorimetry (DSC) thermograms of sausage batters.

Formation of heat-induced protein gel is initiated by heat-denaturation of protein. The effect of Alu on thermal denaturation of proteins in sausage batter was investigated by DSC. Figure 2 shows DSC thermograms of sausage batters. Three major endothermic peaks at 53, 62, and 69°C were observed in all the samples examined. According to Ali et al. (2015), chicken breast meat shows 3 endothermic transitions at peak temperatures — 53 to 55, 62 to 64, and 72 to 76°C — corresponding to the denaturation of myosin, connective tissue (together with sarcoplasmic proteins), and actin, respectively. Li et al. (2015) reported that DSC peaks of chicken breast meat batter containing salt are assigned to myosin (54.52°C), sarcoplasmic proteins/collagen (62.36°C), and actin (73.65°C). Thus, the peak at 53°C and the peaks at 62 and 69°C are presumed to originate in the denaturation of myofibril protein and the denaturation of sarcoplasmic protein/collagen and actin, respectively. Myofibrillar protein (especially myosin) is a key protein for gelation. That an endothermic peak at 53°C appeared in all the samples (A0S1, A3S7, A7S3, A1S0, and no sugar) indicates that Alu and Suc have no impact on the denaturation temperature of the myofibrillar protein that induces gel formation of sausage.
The denaturation enthalpy ($\Delta H$) of 53°C-peak, derived from myofibrillar protein, was calculated for all the samples. The $\Delta H$ values of A0S1, A3S7, A7S3, A150, and sausage batter without sugar were 0.1958, 0.1316, 0.0894, 0.0818, and 0.0395 J/g, respectively. Thus, substituting Suc with Alu results in a decrease in $\Delta H$. The thermal denaturation of many proteins is accompanied by aggregation (Johnson, 2013). The difference in $\Delta H$ value between A0S1 and A150 might be due to the difference in aggregation rate and/or aggregation manner of myofibrillar protein. Low $\Delta H$ values imply extensive unfolding of protein, which promotes its thermal gelation process (Kato, et al., 1990; Plancken et al., 2007). Thus, substituting Suc with Alu may cause myofibrillar protein to undergo more extensive unfolding, although it did not make a significant difference in the gel strength.

**Rheological Properties of Frozen-stored Sausage**

Frozen storage is an important preservation method of foods, especially in terms of bacterial growth. However, frozen storage causes deterioration in food texture (Ramadhan et al., 2012; Benjakul et al., 2005). Rheological properties of chicken breast sausage stored at $-20^\circ$C were evaluated to investigate the effect of Alu on the deterioration prevention of frozen sausage. The results of breaking test, creep test, and the measurement of expressible water are summarized in Figure 3. In all 4 samples tested, breaking stress decreased with the storage period (Figure 3a). Breaking stress of sausage frozen-stored for 90 d was slightly higher in A150 than in A0S1. In contrast to breaking stress, breaking strain increased with the storage period (Figure 3b). In the 3 storage periods of zero, 30, and 90 d, breaking strain of A150 was slightly higher than that of A0S1. Modulus of elasticity $E_0$ decreased with the storage period (Figure 3c). A significant difference appeared in $E_0$ values of sausages stored for 90 d. A3S7, A7S3, and A150 had 7, 16, and 19%, respectively, higher $E_0$ values than A0S1, suggesting that Alu appreciably suppresses the deterioration in elasticity that is caused by long-term frozen storage of sausage. The coefficient of viscosity $\eta_N$ also decreased with the storage period (Figure 3d). The decreasing rate of viscosity during frozen storage was lower in A150 than in A0S1, A3S7, and A7S3. A150 sausage produced only 17% decrement in $\eta_N$ by 90 d frozen storage, while A0S1 sausage had a much higher $\eta_N$ decrement of 32%. Thus, substitution of Suc with Alu was shown to greatly suppress deterioration in viscosity. Expressible water increased with the storage period (Figure 3e). This clearly shows that frozen storage of chicken breast sausage induces a decrease in water-holding capacity. The water-holding capacity of frozen-stored chicken breast sausage was significantly higher in A150 than in A0S1 and A3S7. Thus, a 100% substitution of Suc with Alu helps to prevent the water-holding capacity of sausage from decreasing by frozen storage. This high water-holding capacity of A150-chicken breast sausage may have produced a deterioration suppression in elasticity and viscosity.

Creep-compliance curves of A0S1 and A150 sausages are shown in Figure 4. An outstanding difference was seen in the creep recovery curve (time, 60 to 120 s) that represents elastic recovery. Fresh A0S1 sausage (zero d storage) showed a similar creep recovery curve to fresh A150 sausage, while creep recovery curves of frozen-stored sausages differed between the 2 sausages. Creep recovery curves of A0S1 sausage significantly shifted upward with the storage period. On the other hand, the upward shift of A150 sausage was 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. A similar effect is reported in a disaccharide trehalose. Ramadhan et al. (2012) reported that duck surimi-like material containing trehalose was able to retain the protein solubility, gel breaking force, and deformation after 4 mo of frozen storage due to the high water-holding capacity. The drip loss that takes place during thawing of frozen meat and meat products and concomitant texture deterioration are undesirable for frozen foods. Consequently, Alu is useful in frozen food application of sausage because Alu can suppress texture deterioration of sausage.

In conclusion, the substitution of Suc with Alu, a sweetener with no calories, believed to have health benefits, did not affect breaking stress, breaking strain, and modulus of elasticity of fresh chicken breast sausage, but 100% substitution with Alu caused a 10% decrease in viscosity and 31% decrease in expressible water. The deteriorations in the physical properties (elasticity, viscosity, water-holding capacity, and elastic recovery) of chicken breast sausage that are caused by frozen storage were greatly suppressed by the substitution of Suc with Alu. Thus, Alu was shown to confer resistance to freezing-related damage in sausage. In particular, the quality improvement of frozen-stored chicken breast sausage demonstrates the feasibility and benefit of application of Alu to frozen foods.

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Figure 3. Changes in rheological properties and expressible water of chicken breast sausages by frozen storage. (a) Breaking stress, (b) breaking strain, (c) modulus of elasticity, (d) coefficient of viscosity, and (e) expressible water. Different letters indicate significant difference between samples in the same storage period ($P < 0.05$).
Figure 4. Creep–compliance curves of sausages frozen-stored at –20°C. (a) A0S1 and (b) A1S0.

REFERENCES


