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

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学位論文題目： Effect of D-allulose on fermentation of bread dough, and physicochemical, and organoleptic properties of bread
Title of Dissertation (パン生地の発酵およびパンの物理化学的性質と官能特性に及ぼすD-アルロースの影響)

学位論文要約：
Dissertation Summary

Bread has remained the staple food for human diets in many countries since then until now due to it is a convenient product serving with nutrients. Bread is produced from dough which is a mixture of wheat flour, salt, yeast, and water as the fundamental ingredients. Bread making is mainly divided the following four steps: bread dough formation, fermentation, baking process, and cooling process. Methods and ingredients have continuously developed and modified into different types of bread such as white bread, sourdough bread, French bread and so on. Therefore, producers have to provide the high quality of bread in terms of health and sensory qualities (appearance, texture and flavor). Sugar, such as disaccharides and monosaccharides, is frequently used as an additional ingredient in bread production as it makes positive impacts on the quality of bread in terms of flavor, odor, color, texture, and preservation. The taste of bread is greatly affected by the intensity and taste quality in sweetness of sugar added. Additional sugar improves the odor and color of the bread, that is depending on the rate Maillard and Caramelization reaction in baking process (Pico et al., 2015). Moreover, it also improves the bread texture. This is due to the following two factors: The first is carbon dioxide gas produced during yeast fermentation, and the added sugar allows the bread expansion to increase by the CO_2, which results in softer and spongier bread (Ortolan & Steel, 2017). The other factor is the effect on wheat starch. Suc increases the gelatinization temperature during baking process which allows the bread to fully expand and improve the texture of final bread (Allan et al., 2018; Bolger et al., 2021). In addition, sugar is reported to improve the bread preservation that is, delaying the change of bread texture and preventing spoilage through reducing water activity (Pateras, I.M.C., 2007). This is why sugar is widely used in the production of bread. However, the effectiveness on bread quality parameters greatly depends on the type of sugar added.

Rare sugar is defined as monosaccharides and their derivatives that are presented in the limited quantities in nature. Izumori (2006) developed the method for the mass production of rare sugars known as “Izumoring”. The success of rare monosaccharides in mass production is D-allulose (Alu), D-tagatose (Tag), D-allose (All), and so on. Among those rare sugars, the most widely studied rare monosaccharie is Alu. Alu is the C-3 epimer of Fru and is considered a good alternative to Suc due to it has low calories and it is about 70% sweetness of Suc. Due to the development of

Izumoring, however, the large quantities production of Alu was started in late 2020s, and Alu has been selling in the market in many countries. Many studies have been demonstrated that Alu could be able to prevent many diseases, for instant, anti-obesity by inhibiting the anti-fatty acid synthesis and fatty acid oxidation (Nagata et al., 2015), anti-diabetes by reducing the postprandial glucose levels (Hossain et al., 2015) and anti-inflammation and anti-oxidation (Han et al., 2020 & Murata et al., 2003). Due to its low calories and disease-preventing effect, Alu has been as a substitute for those common sugar in many foods. Several studies have revealed that the addition of Alu to foods enhances food properties as well as confer disease prevention, which attract the healthy lifestyle consumers. Moreover, Alu was also expected to be used as a low calorie sweetener in many foods including bakery products. However, there is little information regarding the effect of Alu on fermented bakery products. Therefore, this research aims to investigate the effects of Alu addition on each processing process of bread including yeast fermentation and the influences of Alu on bread quality, by comparing with Suc. Alu used as a bread ingredient was applied to bread dough in the following three forms: In chapter 2, Suc as an ingredient was 100% replaced with Alu; in chapter 3, Suc was partially (25, 50, and 75%) replaced with Alu; and in chapter 4, Suc at the two levels of Brix value (°Bx) of 2 and 20 was 100% replaced with Alu-containing syrup RSS.

In Chapter 2, first we investigated if baker's yeast *S. cerevisiae* uses the rare sugar Alu as a source of carbon. Alu was not utilized under the presence of other sugar; but utilizing Alu at a very low rate under a condition without other sugar. Thus, the yeast does not produce CO_2 from Alu much. The hypothesized phenomenal of the mechanism of alcoholic fermentation of *S. cerevisiae* inhibited by Alu is depicted in Fig. 1. The use of 100% Alu for bread materials instead of Suc resulted in higher hardness and gumminess values than sugar-free and Suc-bread due to the low rate of CO_2 production by baker's yeast and the low expansion rate of dough, which was not related to the action of Alu on gluten rheology. 100% Alu-substituted bread had less hardening rate of crumb part during storage which associated with the low moisture loss. In addition, there was the high content of Alu remaining in bread after baking which is expected to promote the health benefits. However, a negative result in bread texture was obtained for 100% Alu-substituted bread.

As shown in Chapter 2, replacing Suc with 100% Alu interfered the quality of the bread in appearance and texture as some reasons including the inhibition of yeast metabolism in bread dough. This is probably ascribed to that metabolic enzymes in yeast cell are inhibited by the presence of Alu. To test this hypothesis, it came to investigate the fermentability of bread dough and the bread quality under coexistence of Alu with Suc. Therefore in chapter 3, breads in which 25%, 50%, 75% and 100% of Suc was replaced with Alu were prepared and their physical properties, volatile compounds and sensory properties were compared with 100% Suc-bread. Furthermore, the effects of Alu substitution on the hardening of the bread during storage were assessed. The replacement Suc with Alu up to 75% did not change physical and texture properties of the bread from those of 100% Suc-bread. The volatile compounds in the bread samples were classified into four chemical groups —

alcohols, ketones, aldehydes, and others. The amount and types of volatile compounds produced from 100% Alu-bread differed from those sugar-free bread and 100% Suc-bread. The Alu-substitution breads, especially the Alu100 bread, had lower ethanol concentrations than the Suc bread. Seven ketone compounds were detected in all the Alu-substituted breads. 2, 2′-bifuran, 3,5-dihydroxy-6-methyl-2-3-dihydro-4H-pyran-4-one, maltol, acetylfuran, and 2,3-pentanedione were presented in much higher amounts in the Alu-substituted breads than in the Suc100 bread which are characterized as a caramel-like aroma, roasted-like aroma, and sweet-butter scent. Furfural was a major aldehyde in the Alu bread. Moreover, acetic acid and propylene glycol ethyl ether were also found in a large amount in the Alu100 bread. The bread prepared with 100% Alu without Suc adversely affected the physical properties, resulting in a lower liking score. In contrast, using a mixture of Alu and Suc (both sugars contained at least 25% weight ratio) had comparable physical properties to the 100% Suc bread, leading to an acceptable level of preference. Moreover, bread using a mix of Alu and Suc retarded bread hardening during storage. The present results suggest that Alu substitution up to 75% allows the development of healthy bread with a high consumer overall acceptability and high storage stability.

In chapter 4, rare sugar syrup (RSS), a commercial syrup containing Alu, was applied to the bread making and the quality of the final bread products were compared to that of breads added with high fructose corn syrup (HFCS) and Suc syrup (SS). Rare sugar syrup (RSS), has been developed from HFCS through alkaline isomerization, and is commercialized in some countries including Japan in 2011 (Takamine et al., 2015). The sugar composition of RSS is as follows: 45% Glc, 29% Fru, 13% rare sugars including 5% Alu, 5% Sor, 2% Tag, 1% All, and 13% oligosaccharide (Shintani et al., 2017). Having those health and food processing advantages of rare sugars, RSS has been applied to beverages and bakery products like donut and cakes, which are available in the food market in Japan. Although RSS is employed for many bakery products, there are little scientific reports on the effects of RSS on the bread processing steps and the bread qualities. This chapter investigated the effects of RSS containing several rare monosaccharides on the baker’s yeast fermentation ability, and the physicochemical, texture characteristic, and consumer acceptance of bread. The addition of 2°Bx RSS to bread dough did not show any differences on bread physical characteristic and texture properties from SS- and HFCS-bread. The addition of 20°Bx RSS, in comparison with 20°Bx SS, resulted in a reduction in loaf height and volume, MC, and aw and increase in hardness and gumminess of bread crumb, which was similar result as HFCS-bread. 20°Bx RSS-bread generated lower amounts for most alcohols, ketones and aldehydes but higher amount for acetic acid than 20°Bx HFCS-bread but did not affect the aroma preference. Twenty-five Kagawa University students (62 % female and 38 % male) with the averages ages 22 years old were recruited as panelists. The breads were firstly evaluated the perception of external characteristic then after consuming the crumb parts of the three sample breads was investigated using the hedonic scales. The appearance, crumb color, crust color, and aroma, their preference score of all the bread samples were above the score of 3.0 which represents “neither like nor dislike". The preference scores of the six items, softness, elasticity, sweetness, flavor, overall preference of 20°Bx RSS-bread had by 0.32 - 0.72 lower scores than 20°Bx SS-bread, suggesting that the RSS-bread has slightly inferior impression to the SS-bread. However, the other items including sweetness, flavor, overall preference, and intension of consumption were not different between HFCS- and RSS bread. Moreover, all the bread samples showed no significant difference in intention of consumption. 20°Bx RSS-bread, although not preferable compared to 20°Bx SS-bread, seems to be similar preference to 20°Bx HFCS-bread. The content of the saccharides that are added to bread dough is reduced by such the bread processes as alcohol fermentation and baking. Analysis of the residual sugars in 2°Bx sugar-breads showed that no saccharide has been detected in RSS-bread, which was the same as SS- and HFCS-bread. The low amount (2°Bx) of saccharide added to bread dough had been mostly degraded by alcohol fermentation with yeast or the Maillard and caramelization reaction induced with the baking treatment due to bakery yeast. On the other hand, Glc, Fru, Alu, and Sor were detected in 20°Bx RSS-bread. The healthy rare sugar Alu was remained with relatively high rate in 20°Bx RSS-bread. Therefore, the use of RSS at the relatively high concentration could be beneficial for bread making.

To be concluded, single use of Alu as a sugar ingredient has negative impact on bread texture. On the other hand, a mixture of Alu and Suc (both sugars contained at least 25% weight ratio) had comparable physical properties to the Suc bread, leading to an acceptable level of preference. It is recommended that adding a mixture of 75% Alu and 25% Suc to bread dough is preferable to develop healthy bread (low calorie and anti-obesity effect) with a high consumer overall acceptability and high storage stability.

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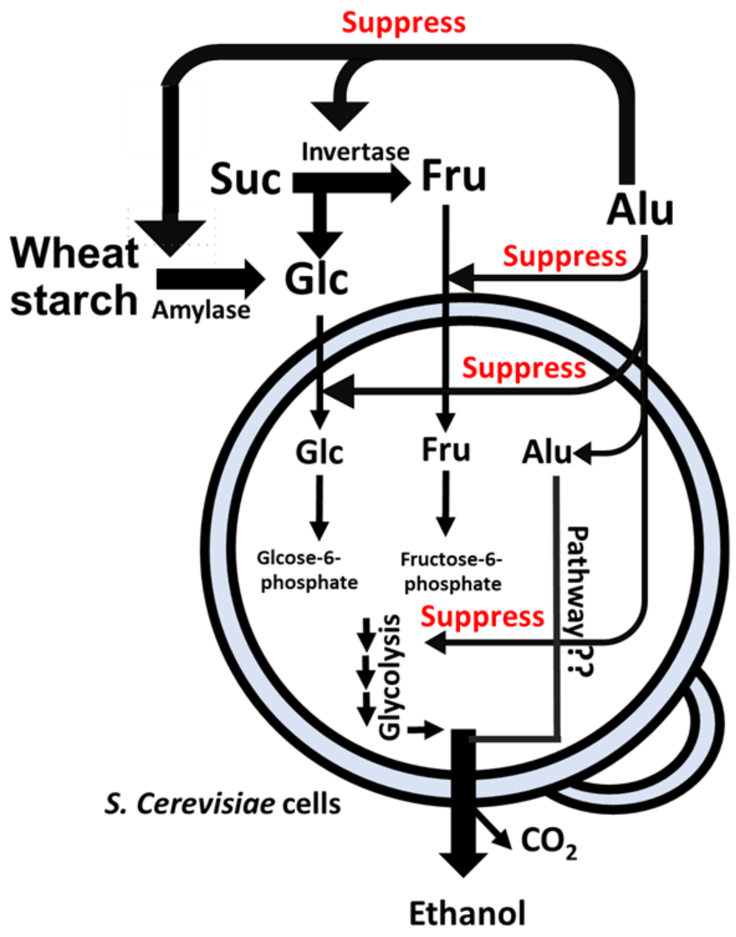

Figure 1 Hypothesis of inhibition mechanism of alcoholic fermentation of *S. cerevisiae* inhibited by Alu

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