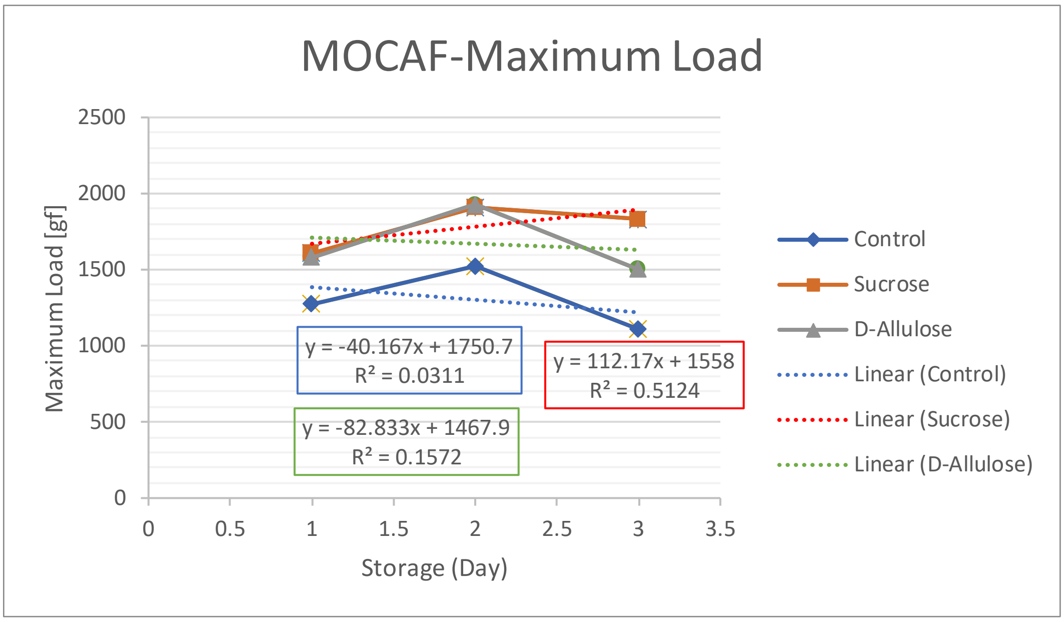
CHAPTER IV

RESULT AND DISCUSSION

4.1. Maximum Load of MOCAF

Maximum load obtained from creep meter analysis was used as an indicator of gel hardness and represents the maximum force required to deform the gel structure before failure (Kwakye et al., 2024). In starch gel systems, hardness reflects the strength and integrity of the gel network formed during gelatinization and subsequent storage (Ulbrich et al., 2022).



Ilustration 4. MOCAF Maximum Load

The regression results demonstrated decreasing maximum load in the control and D-allulose treatments but a slight increasing trend in the sucrose treatment, with D-allulose showing the strongest linear association ($R^2 = 0.52$). The maximum load of MOCAF gels exhibited a rise–then–fall pattern throughout storage. The control treatment (T0) increased from 1,274.3 ± 233.4 gf on the 1st day of storage to 1,523.7 ± 73.7 gf on the 2nd day of storage, before declining to 1,108.7 ± 364.6 gf on the 3rd day of storage. The relatively large standard deviations observed on the 1st and 3rd days indicate greater heterogeneity within the gel matrix during storage. Crystal nuclei do not form at the same time or density throughout a gel. Following nucleation, the growth and maturation of these crystals are also non-uniform (Berski et al., 2018; Chang et al., 2021).

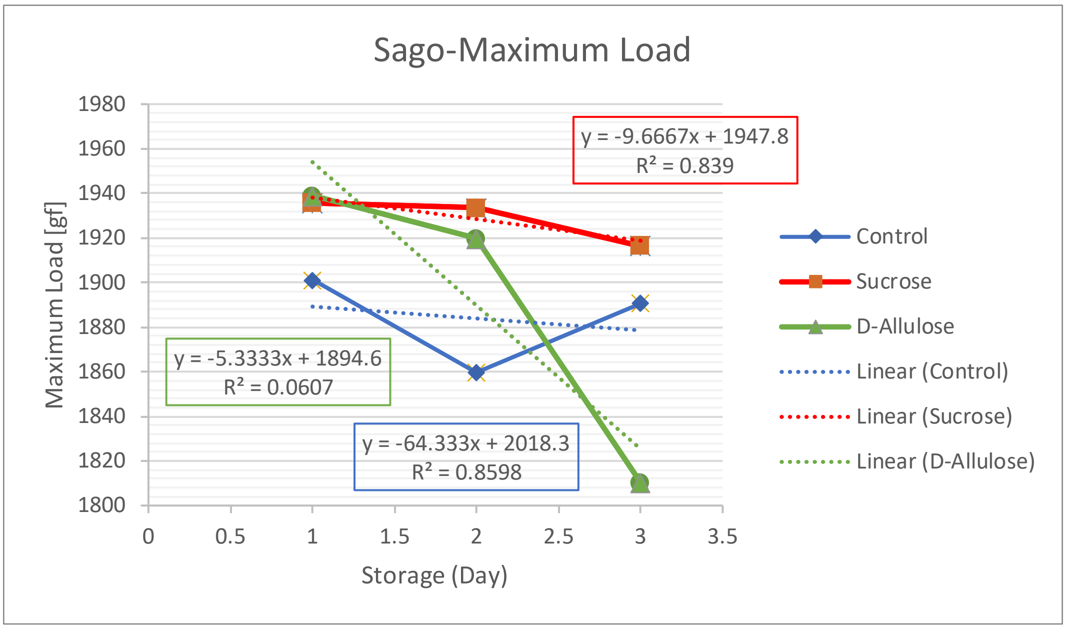
Sucrose addition markedly enhanced gel strength and improved its stability during storage. The maximum load increased from 1,607.0 ± 238.9 gf on the 1st day of storage to 1,908.7 ± 36.1 gf on the 2nd day of storage and remained relatively stable at 1,831.3 ± 41.0 gf on the 3rd day of storage. Compared with the control treatment, the sucrose treatment gels maintained higher hardness values and exhibited substantially lower variability during prolonged storage. The formation of hydrogen bonds between sucrose and starch chains has been reported to strengthen intermolecular interactions within the gel matrix, contributing to the development of a denser and more cohesive network structure (Z. Wang et al., 2024; Woodbury & Mauer, 2023). Consequently, sucrose treatment MOCAF gels demonstrated the highest and most stable maximum load values throughout storage.

D-allulose treatment also increased the hardness of MOCAF gels during the early stages of storage. Maximum load increased from 1,581.0 ± 233.5 gf on the 1st day of storage to 1,929.3 ± 11.9 gf on the 2nd day of storage, followed by a decline to 1,500.7 ± 423.1 gf on the 3rd day of storage. Although the 2nd day measurement exhibited excellent uniformity, the large standard deviation observed on the 3rd day suggests increased structural variability within the gel network. Compared with sucrose, D-allulose was less effective in maintaining gel strength during prolonged storage. Previous studies have reported that D-allulose modifies starch interactions differently from sucrose due to its distinct molecular configuration and smaller molecular size, resulting in different mechanical responses during storage (Renzetti et al., 2021; Woodbury & Mauer, 2023).

Overall, all MOCAF treatments displayed a similar rise then fall pattern in maximum load, indicating that initial strengthening was followed by structural weakening during extended storage. However, the magnitude of this decline differed among treatments, with reductions of approximately 27%, 22%, and 4% for the control, D-allulose, and sucrose treatments, respectively. These findings suggest that sugar addition primarily affected the preservation of gel strength rather than the initial development of the gel network. Among the tested sugars, sucrose provided the greatest stability, whereas D-allulose produced an intermediate response between the control and sucrose treatments.

4.2. Maximum Load of Sago

The maximum load of sago gels remained considerably more stable throughout storage than that of MOCAF gels. The regression results revealed decreasing maximum load in all treatments during storage, with the steepest decline observed in the D-allulose treatment, while the sucrose treatment showed the strongest linear relationship ($R^2 \approx 0.84$). In the control treatment, hardness decreased slightly from 1,909.5 ± 19.1 gf on the 1st day of storage to 1,859.7 ± 52.2 gf on the 2nd day of storage, before increasing to 1,890.7 ± 27.3 gf on the 3rd day of storage. The consistently low standard deviations indicate a homogeneous gel structure and stable mechanical performance throughout storage. This stability may be related to the relatively high amylose content of sago starch, which has been reported to exceed 20% and contributes to the formation of dense and mechanically robust gel structures (Jiamjariyatam et al., 2015; Z. Wang et al., 2024).



Ilustration 5. Sago Maximum Load

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Sucrose treatment of sago gels exhibited the highest overall hardness values, although only minor changes were observed throughout storage. Maximum load decreased slightly from 1,935.7 ± 34.1 gf on the 1st day of storage to 1,916.3 ± 11.9 gf on the 3rd day of storage. The consistently low variability indicates that sucrose effectively maintained the mechanical integrity of the gel network during storage. Similar to the MOCAF system, sucrose likely contributed to the formation of a more cohesive structure, allowing the gel to retain its resistance to deformation over time (Chang et al., 2021; Z. Wang et al., 2024).

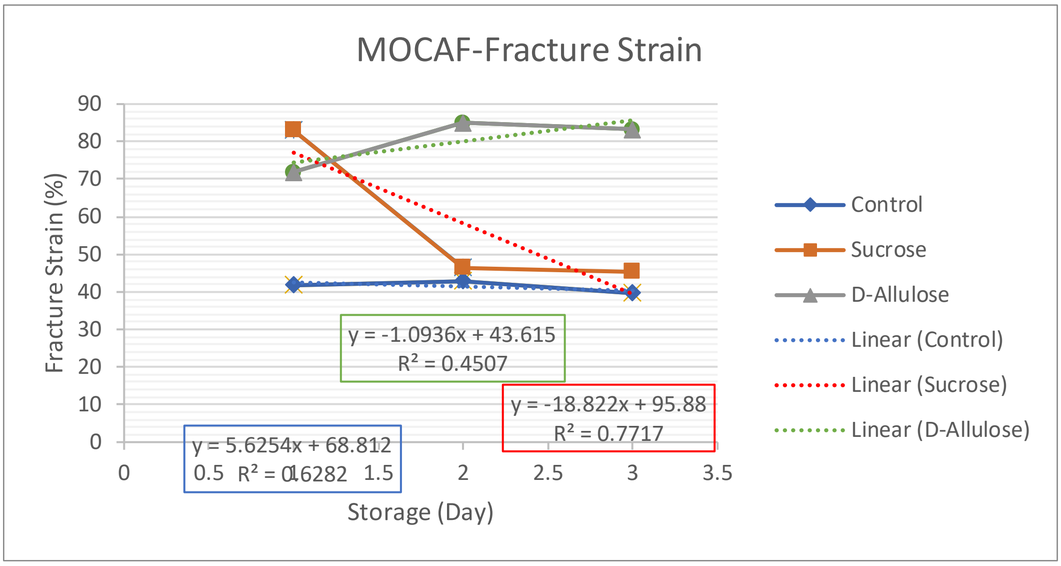
The incorporation of D-allulose resulted in a gradual reduction in hardness due to the looser hydrogen bonds (Kwakye et al., 2024), from 1,939.0 ± 3.5 gf on the 1st day of storage to 1,919.7 ± 13.6 gf on the 2nd day of storage, followed by a more pronounced decline to 1,810.3 ± 197.1 gf on the 3rd day of storage. Although the initial hardness was comparable to that of sucrose-treated gels, the larger variability observed at the end of storage suggests reduced structural uniformity within the gel matrix. A significant factor in reduced structural uniformity is that monosaccharides like D-allulose (and its epimer fructose) are more prone to phase separation at high concentrations than disaccharides like sucrose (Woodbury et al., 2023). Nevertheless, the average maximum load values remained comparable to those of the control treatment, indicating that D-allulose was still capable of maintaining substantial load bearing capacity throughout storage.

Compared with MOCAF, sago gels exhibited greater resistance to changes in maximum load regardless of sugar treatment. This observation suggests that the inherent structure of sago starch provided a more stable gel network during storage. While both sugars influenced gel strength, their effects were less pronounced in sago than in MOCAF. Overall, sucrose provided the greatest preservation of hardness, whereas D-allulose produced moderate stabilization with increased variability during prolonged storage.

4.3. Fracture Strain of MOCAF

Fracture strain represents the extent of deformation that a gel can undergo before failure and is commonly used as an indicator of gel deformability (X. Wang et al., 2022). Higher fracture strain values indicate that the gel can withstand greater deformation before rupture, reflecting a more flexible and less brittle structure (Lan et al., 2017). In starch-based gels, fracture strain is strongly influenced by molecular mobility, network organization, and the extent of retrogradation occurring during storage.

The linear regression indicates that fracture strain decreased during storage in the sucrose treatment, whereas slight increasing trends were observed in the control and D-allulose treatments, with sucrose showing the strongest linear relationship (R^2 = 0.77). The fracture strain of MOCAF gels showed distinct responses depending on the type of sugar added. The control treatment (T0) exhibited relatively stable fracture strain values throughout storage, ranging from 41.82 ± 6.22% on the 1st day of storage to 42.82 ± 1.54% on the 2nd day of storage before slightly decreasing to 39.64 ± 4.14% on the 3rd day of storage. The limited changes observed across storage suggest that the deformability of the control gel remained relatively constant. The slight decrease during storage may be attributed to the gradual reassociation of starch chains through hydrogen bonding, leading to the formation of a more compact network structure and reducing the ability of the gel to deform before fracture (Das et al., 2024). However, the overall stability indicates that major structural rearrangements had largely reached equilibrium within the storage period (X. Wang et al., 2022).



Ilustration 6. MOCAF Fracture Strain

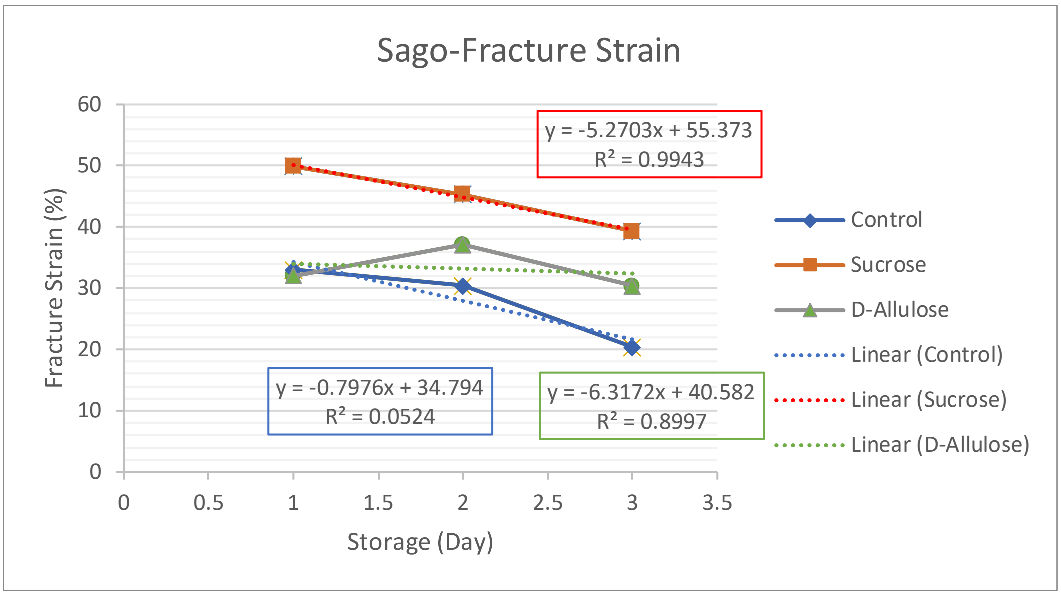
Sucrose addition resulted in the highest fracture strain on the 1st day of storage (82.97 ± 1.82%), indicating substantial initial deformability. However, fracture strain decreased markedly to 46.41 ± 29.36% on the 2nd day of storage and remained at 45.32 ± 37.74% on the 3rd day of storage. The pronounced reduction, accompanied by considerably larger standard deviations, suggests that the gel network became increasingly heterogeneous during storage. While sucrose initially enhanced flexibility, this effect was not maintained over time. The decrease in fracture strain may reflect the progressive development of a more rigid starch network as retrogradation proceeded, reducing the gel's ability to deform before failure (Chang et al., 2021; Gong et al., 2024). The high variability observed at later storage stages further suggests non-uniform structural development within the gel matrix, where localized starch-rich regions may have undergone greater contraction and recrystallization than others (Renzetti et al., 2021).

In contrast, D-allulose-treated MOCAF gels maintained high fracture strain values throughout storage. Fracture strain increased from 71.94 ± 17.61% on the 1st day of storage to 85.06 ± 10.57% on the 2nd day of storage and remained high at 83.19 ± 4.36% on the 3rd day of storage. Unlike sucrose, D-allulose not only preserved but slightly improved the deformability of the gel during storage. Higher fracture strain values indicate that the gel could undergo greater deformation before rupture, suggesting a more flexible and resilient network structure (Jiamjariyatam et al., 2015; Kwakye et al., 2024). Previous studies have reported that D-allulose promotes the formation of looser hydrogen-bonding interactions within starch systems, allowing molecular rearrangement without extensive structural failure (Kwakye et al., 2024). Furthermore, D-allulose has been shown to facilitate starch chain hydration and molecular expansion, resulting in increased flexibility and resistance to brittle fracture (Z. Wang et al., 2024). Its smaller molecular size may also allow greater penetration into amorphous regions of the starch matrix, enhancing molecular mobility and promoting a more deformable gel structure (Ellis et al., 2019; Renzetti et al., 2021).

Overall, MOCAF gels demonstrated strong sensitivity to sugar type. While sucrose produced high initial deformability, this characteristic declined substantially during storage. In contrast, D-allulose consistently maintained high fracture strain values, indicating superior preservation of gel deformability. These findings suggest that sucrose primarily contributed to initial flexibility, whereas D-allulose was more effective in maintaining flexibility throughout storage.

4.4. Fracture Strain of Sago

Compared with MOCAF, sago gels exhibited lower fracture strain values and smaller treatment effects, indicating a generally less deformable gel structure (Lan et al., 2017). This behavior is consistent with previous reports showing that starch systems with higher amylose content tend to exhibit lower fracture strain due to the formation of more rigid and tightly packed gel networks (Shahsavani Mojarrad & Rafe, 2018).



Ilustration 7. Sago Fracture Strain

The linear regression indicated a slight decrease in fracture strain for the control and sucrose treatments during storage, whereas D-allulose exhibited a relatively stable trend with a weak linear relationship ($R^2 = 0.05$). The control treatment showed a gradual decline in fracture strain from 33.05 ± 3.06% on the 1st day of storage to 30.38 ± 4.95% on the 2nd day of storage and further to 20.41 ± 2.45% on the 3rd day of storage. This reduction indicates a progressive loss of deformability during storage, likely associated with continued molecular reassociation and network consolidation within the gel matrix. During cooling and storage, amylose and amylopectin chains move together to form double helices, which then pack into crystalline regions known as junction zones, this occur the hardness in control treatment (Chang et al., 2021; Gong et al., 2024).

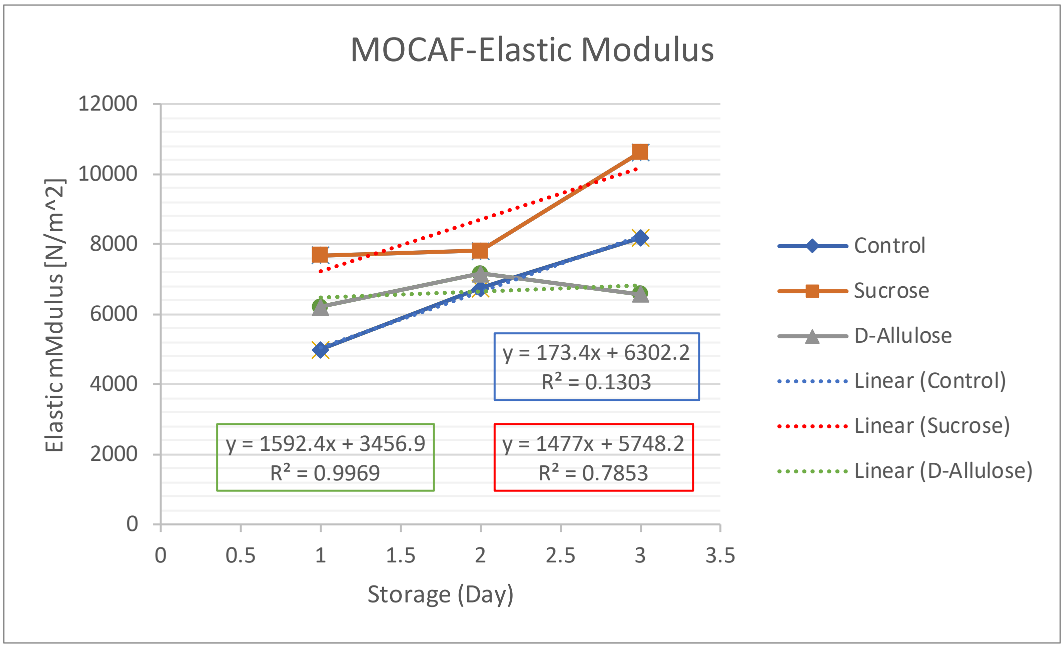
Sucrose-treated sago gels exhibited the highest fracture strain values among the sago treatments, decreasing from 49.87 ± 5.77% on the 1st day of storage to 45.29 ± 2.34% on the 2nd day of storage and 39.33 ± 1.80% on the 3rd day of storage. Despite the gradual decline, the relatively low standard deviations indicate a stable and homogeneous gel structure throughout storage (Woodbury & Mauer, 2023). These results suggest that sucrose partially preserved gel deformability while maintaining structural consistency. The ability of sucrose to interact with starch chains through hydrogen bonding may have contributed to a more uniform network structure and moderated the reduction in deformability during storage (Chang et al., 2021).

D-allulose-treated sago gels exhibited a fluctuating response. Fracture strain increased from 32.04 ± 6.34% on the 1st day of storage to 37.12 ± 9.97% on the 2nd day of storage before decreasing to 30.44 ± 11.66% on the 3rd day of storage. Although the average values remained comparable to the control treatment, the larger standard deviations indicate greater variability within the gel network. This suggests that the influence of D-allulose on deformability was less consistent in sago starch than in MOCAF starch. The inherently stronger and more crystalline structure of sago starch may have limited the ability of D-allulose to maintain molecular mobility to the same extent observed in the MOCAF system. This happened due to higher the amylose content of sago compared wtih MOCAF (Oyeyinka et al., 2020), amylose undergoes rapid short-term retrogradation, reassociating within hours of cooling, this occur a more rigid structure (Chang et al., 2021).

Overall, sago gels exhibited lower deformability than MOCAF gels regardless of sugar treatment. Sucrose provided the most stable preservation of fracture strain during storage, whereas D-allulose produced a more variable response. These results indicate that the effectiveness of sugar addition on gel deformability depended not only on sugar type but also on starch source and structural characteristics.

4.5. Elastic Modulus of MOCAF

Elastic modulus (Young's modulus) represents the resistance of a material to deformation and is commonly used to evaluate gel stiffness (Lyu et al., 2024). Higher elastic modulus values indicate a stiffer gel structure that resists deformation, whereas lower values reflect a softer and more deformable network, the lower number can be indicate as softer and more deformable (Ellis et al., 2019; Koekuyt et al., 2025; Lyu et al., 2024). In starch based gels, the development of stiffness is closely associated with retrogradation, during which leached starch molecules gradually reorganize into a more ordered three dimensional network (Allan & Mauer, 2022; Y. Yang et al., 2024). The leached starch reorganize form a three-dimensional network (Y. Yang et al., 2024). As this network becomes increasingly interconnected, the rigidity of the gel increases, resulting in higher elastic modulus values (Koekuyt et al., 2025).



Ilustration 8. MOCAF Elastic Modulus

The regression analysis showed increasing elastic modulus over storage in the control and sucrose treatments, while D-allulose exhibited a slight decreasing trend, with the control presenting the strongest linear relationship ($R^2 = 0.997$). In MOCAF gels, the control treatment (T0) exhibited a continuous increase in elastic modulus throughout storage, rising from 5,115.29 ± 162.56 N/m^2 on the 1^{st} day to 6,744.02 ± 490.67 N/m^2 on the 2^{nd} day and further to 8,183.01 ± 270.52 N/m^2 on the 3^{rd} day. This progressive increase indicates the gradual formation of a more rigid gel network as retrogradation proceeded during storage. Without the presence of added sugars, starch chains were free to reassociate and form microcrystalline regions, thereby increasing resistance to deformation over time (Lyu et al., 2024; Y. Yang et al., 2024).

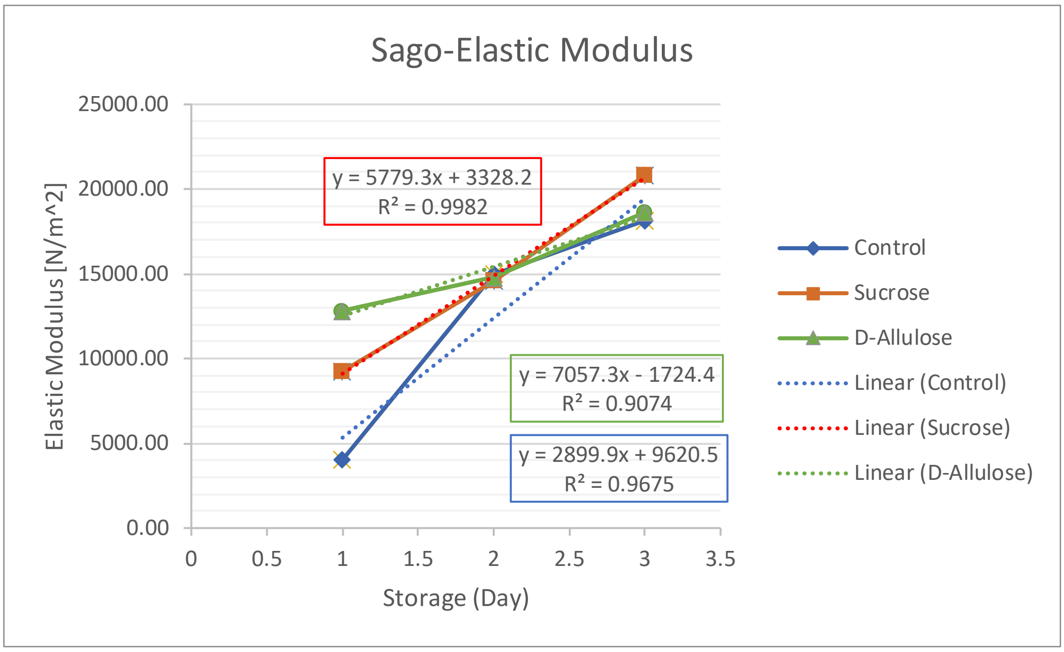
Sucrose-treated MOCAF gels exhibited the highest stiffness among all treatments, increasing from 7,676.19 ± 1,430.54 N/m^2 on the 1^{st} day to 7,810.56 ± 154.58 N/m^2 on the 2^{nd} day and reaching 10,625.11 ± 1,278.12 N/m^2 on the 3^{rd} day. The consistently high modulus values suggest that sucrose promoted the formation of a highly resistant gel network during storage. This behaviour can be attributed to the high density of equatorial hydroxyl (-OH) groups in sucrose, which facilitates extensive hydrogen bonding interactions with starch chains (Ellis et al., 2019). In addition, sucrose competes for available water and acts as an anti-plasticizer (Renzetti et al., 2021), reducing molecular mobility and reinforcing intermolecular associations within the gel matrix. As a result, the MOCAF gel developed a highly organized structure that offered greater resistance to deformation.

D-allulose-treated MOCAF gels exhibited a different behaviour. The elastic modulus increased from 5,281.66 ± 896.44 N/m² on the 1st day to 7,166.40 ± 1,372.20 N/m² on the 2nd day, but subsequently decreased to 6,563.79 ± 202.68 N/m² on the 3rd day. This trend suggests that D-allulose promoted early network development but was less effective in maintaining stiffness during prolonged storage. As a small ketose monosaccharide, D-allulose can influence water organization and facilitate the initial reassociation of starch chains (Allan & Mauer, 2022; Ellis et al., 2019; Renzetti et al., 2021). However, its smaller molecular size may also contribute to greater molecular mobility and localized structural heterogeneity during storage (Renzetti et al., 2021; Y. Yang et al., 2024). Consequently, the resulting gel network appeared less stable than that formed in the presence of sucrose.

The elastic modulus results generally corresponded with the hardness trends observed in the Maximum Load analysis, where sucrose-treated MOCAF gels also exhibited the highest resistance to mechanical force. However, the Fracture Strain results revealed that increased stiffness did not necessarily correspond to reduced deformability. Although D-allulose-treated gels exhibited lower final stiffness than sucrose-treated gels, they maintained substantially higher fracture strain values throughout storage. This indicates that D-allulose produced a gel network capable of sustaining deformation before fracture, whereas sucrose promoted a more rigid and deformation-resistant structure.

4.6. Elastic Modulus of Sago

Sago gels exhibited substantially higher elastic modulus values than MOCAF gels regardless of treatment, indicating a greater intrinsic resistance to deformation. The higher amylose content than MOCAF makes the sago less pronounced due to the sugar addition. Amylose is a linear polymer that reassociates much faster than amylopectin, forming a strong, interconnected three-dimensional network immediately upon cooling (Kwakye et al., 2024; Shoukat et al., 2025). The regression analysis showed increasing elastic modulus in all treatments throughout storage, with D-allulose exhibiting the steepest increase, although the strength of the linear relationships varied among treatments. The control treatment increased from 3,755.71 ± 2,585.16 N/m^2 on the 1st day to 14,993.62 ± 1,385.20 N/m^2 on the 2nd day and 18,145.69 ± 2,993.62 N/m^2 on the 3rd day. Similarly, sucrose-treated gels increased from 8,706.84 N/m^2 to 14,602.23 ± 3,611.57 N/m^2 and ultimately reached 20,808.42 ± 5,908.55 N/m^2, while D-allulose-treated gels increased from 12,827.19 ± 2,468.89 N/m^2 to 14,806.45 ± 2,871.59 N/m^2 and 18,626.90 ± 3,133.13 N/m^2 during the same period.



Ilustration 9. Sago Elastic Modulus

Unlike MOCAF gels, all sago treatments exhibited a similar increasing trend throughout storage, suggesting that the intrinsic retrogradation tendency of sago starch played a more dominant role in determining gel stiffness than the type of sugar added (Kwakye et al., 2024). The naturally higher amylose content and greater structural integrity of sago starch favor the formation of a rigid and highly interconnected network during storage (Chang et al., 2021), leading to substantial increases in elastic modulus regardless of treatment. While sucrose and D-allulose influenced the initial stiffness values, neither sugar fundamentally altered the overall progression of stiffness development.

The relatively similar stiffness trajectories observed among sago treatments suggest that the effect of sugar addition was less pronounced than in MOCAF gels (Kwakye et al., 2024). This observation may be related to the relatively low sugar concentration used in the present study. Previous studies reported that higher sugar concentrations can substantially alter the rheological behaviour of sago starch systems by reducing storage modulus (G′) and loss modulus (G″) (Udomrati et al., 2024). Under the conditions of the present study, however, the inherent retrogradation behaviour of sago starch appeared to remain the primary factor governing stiffness development during storage.

4.7. Overall Effect of D-Allulose and Sucrose

The overall results demonstrated that the addition of sucrose and D-allulose altered the mechanical behaviour of both MOCAF and sago starch gels throughout storage. Compared with the control treatment, sugar addition generally increased the maximum load, maximum stress, and elastic modulus of the gels, indicating the formation of stronger and more rigid gel networks. These findings suggest that the presence of sugars modified the structural evolution of starch gels during storage (X. Zhang et al., 2017)and influenced the extent to which the gel network resisted external forces (Allan & Mauer, 2022).

Although both sugars enhanced the mechanical performance of the gels, their effects were not identical. Sucrose generally produced more consistent mechanical responses throughout storage (Renzetti et al., 2021), as reflected by the relatively stable values observed across several parameters . In contrast, D-allulose often generated greater variability among replicates, particularly in MOCAF gels at later storage stages. This observation indicates that D-allulose may induce a more dynamic restructuring of the starch network during storage, resulting in a less uniform mechanical response.

The combined interpretation of maximum load, elastic modulus, and fracture strain further suggests that sugar addition influenced not only gel strength but also the balance between rigidity and deformability. While both sugars increased the resistance of the gels to mechanical deformation (Su et al., 2024), fracture strain data revealed that the ability of the gels to deform before fracture differed among treatments. In particular, D-allulose-treated MOCAF gels maintained relatively high fracture strain values during storage, whereas the control gels generally exhibited lower deformability.

This finding indicates that increased gel strength did not necessarily correspond to a reduction in deformability. The different responses observed between sucrose and D-allulose may be associated with differences in molecular structure, molecular size, and interactions with starch and water molecules (Chang et al., 2021; Kwakye et al., 2024; Z. Wang et al., 2024). These factors influence water mobility (Ilhan et al., 2020), starch chain reassociation (Kwakye et al., 2024), and the development of retrograded structures during storage. Consequently, the mechanical properties of the gels evolved differently depending on the sugar type and starch source (Woodbury & Mauer, 2023).

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study demonstrated that D-allulose and sucrose exerted different effects on the stability and mechanical properties of sago and MOCAF starch gels during cold storage, with the magnitude of these effects depending on the starch source. Compared with sucrose, which generally maintained more stable mechanical properties throughout storage, D-allulose promoted a different balance between gel strength, stiffness, and deformability. Therefore, D-allulose cannot be regarded as a direct functional substitute for sucrose in starch gel systems, but rather as an alternative sweetener that modifies gel mechanical behaviour through a distinct mechanism.

5.2. Recommendations

Future studies should investigate the microstructural changes and retrogradation behaviour of starch gels during storage using techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), differential scanning calorimetry (DSC), low-field nuclear magnetic resonance (LF-NMR), and syneresis analysis. In addition, evaluating different sugar concentrations would provide further insight into their effects on the mechanical properties and storage stability of starch gels.

REFERENCES

Allan, M. C., & Mauer, L. J. (2022). Variable Effects of Twenty Sugars and Sugar Alcohols on the Retrogradation of Wheat Starch Gels. *Foods*, *11*(19). https://doi.org/10.3390/foods11193008

Anggraeni, A. A., Triwitono, P., Lestari, L. A., & Harmayani, E. (2024). Evaluation of glucomannan as a fat replacer in the dough and cookies made from fermented cassava flour and soy protein concentrate. Food Chemistry, 434(August 2023). https://doi.org/10.1016/j.foodchem.2023.137452

Berski, W., Ziobro, R., Witczak, M., & Gambuś, H. (2018). The retrogradation kinetics of starches of different botanical origin in the presence of glucose syrup. International Journal of Biological Macromolecules, 114, 1288–1294. https://doi.org/10.1016/j.ijbiomac.2018.04.019

Bintoro, M. H., Nurulhaq, M. I., Pratama, A. J., Ahmad, F., & Ayulia, L. (2018). Growing area of sago palm and its environment. In Sago Palm: Multiple Contributions to Food Security and Sustainable Livelihoods (pp. 17–29). https://doi.org/10.1007/978-981-10-5269-9_2

Bintuni, T., Baru, Y., Dimara, P. A., Heatubun, C. D., Program, M., Magister, S., Papua, P. U., Kehutanan, J., Kehutanan, F., & Papua, U. (2026). Keragaman varietas lokal dan produksi pati sagu di Distrik Aranday , Kabupaten Teluk Bintuni. 9(1), 44–54.

Bolger, A. M., Rastall, R. A., Oruna-concha, M. J., & Rodriguez-garcia, J. (2021). Effect of D -allulose , in comparison to sucrose and D -fructose , on the physical properties of cupcakes. 150(March).

Chang, Q., Zheng, B., Zhang, Y., & Zeng, H. (2021). A comprehensive review of the factors influencing the formation of retrograded starch. International Journal of Biological Macromolecules, 186(July), 163–173. https://doi.org/10.1016/j.ijbiomac.2021.07.050

Compart, J., Singh, A., Fettke, J., & Apriyanto, A. (2023). Customizing Starch Properties : A Review of Starch Modifications and Their Applications. Polymers, 15(16), 16. https://doi.org/https://doi.org/10.3390/polym15163491

Das, S., Das, M. K., Jamatia, T., Bhattacharya, B., Mazumder, R., Yadav, P. K., Ghose Bishwas, N. R., Deka, T., Roy, D., Sinha, B., Das, B., Daule, I., Paul, K., Roy, A., Choudhury, A., Sadhukhan, P., Sarmah, D., Bhargab, D., Jana, B.

K., … Mandal, S. (2024). Advances of cassava starch-based composites in novel and conventional drug delivery systems: a state-of-the-art review. RSC Pharmaceutics, 1(2), 182–203. https://doi.org/10.1039/d3pm00008g

Defri, I. D., Nurhamzah, L. Y., Natasyari, D. D. S., Lestari, I. P. C., & Putra, A. Y. T. (2022). Potensi Tiwul dalam Upaya Diversifikasi Pangan serta Perkembangan Inovasinya Sebagai Pangan Fungsional. Muhammadiyah Journal of Nutrition and Food Science (MJNF), 3(1), 17. https://doi.org/10.24853/mjnf.3.1.17-26

Dimara, P. A., Purwanto, R. H., Sunarta, S., & Wardhana, W. (2021). The spatial distribution of sago palm landscape sentani watershed in jayapura district, papua province, indonesia. Biodiversitas, 22(9), 3811–3820. https://doi.org/10.13057/biodiv/d220926

Du, C., Jiang, F., Jiang, W., Ge, W., & Du, S. kui. (2020). Physicochemical and structural properties of sago starch. International Journal of Biological Macromolecules, 164, 1785–1793. https://doi.org/10.1016/j.ijbiomac.2020.07.310

Ehara, H., Toyoda, Y., & Johnson, D. V. (2018). Sago palm: Multiple contributions to food security and sustainable livelihoods. In Sago Palm: Multiple ContrEhara, H., Toyoda, Y., & Johnson, D. V. (2018). Sago palm: Multiple contributions to food security and sustainable livelihoods. In Sago Palm: Multiple Contributions to Food Security and Sustainable Livelihoods. https://doi.org/10. https://doi.org/10.1007/978-981-10-5269-9

Ellis, A. L., Mills, T. B., Norton, I. T., & Norton-Welch, A. B. (2019). The effect of sugars on agar fluid gels and the stabilisation of their foams. Food Hydrocolloids, 87(February 2018), 371–381. https://doi.org/10.1016/j.foodhyd.2018.08.027

Gao, M., Ma, C., Xu, Y., Wang, B., Zhang, G., Wang, Y., Liu, Y., Yang, Y., & Zhang, N. (2025). Effect of different retrogradation conditions on the physicochemical and sensory properties of rice. International Journal of Biological Macromolecules, 330(September). https://doi.org/10.1016/j.ijbiomac.2025.148137

Gong, Y., Xiao, S., Yao, Z., Deng, H., Chen, X., & Yang, T. (2024). Factors and modification techniques enhancing starch gel structure and their applications in foods:A review. Food Chemistry: X, 24(June). https://doi.org/10.1016/j.fochx.2024.102045

Ilhan, E., Pocan, P., Ogawa, M., & Oztop, M. H. (2020). Role of ‘ D-allulose ’ in a starch based composite gel matrix. 228(August 2019).

Ji, T., Cui, J., Wei, Y., Yu, S., Zhang, M., Gao, B., Jia, F., Zhang, X., & Fang, Y. (2026). Enzymatic conversion of α-1,4 to α-1,3 linkages by glyco transferase for tailoring cassava starch structure and digestibility. In Carbohydrate Polymers (Vol. 381). https://doi.org/10.1016/j.carbpol.2026.125194

Jiamjariyatam, R., Kongpensook, V., & Pradipasena, P. (2015). Effects of amylose content, cooling rate and aging time on properties and characteristics of rice starch gels and puffed products. Journal of Cereal Science, 61, 16–25. https://doi.org/10.1016/j.jcs.2014.10.001

Khasanah, Y., Indrianingsih, A. W., Triwitono, P., & Murdiati, A. (2024). Production, biological activities and functional food of modified cassava flour (mocaf). Canrea Journal: Food Technology, Nutritions, and Culinary Journal, 7(2), 213–229. https://doi.org/10.20956/canrea.v7i2.1280

Kitagawa, N., Hamaker, B. R., & Mauer, L. J. (2025). Exploring oligosaccharide effects on wheat starch gelatinization: Mechanisms and oligosaccharide structural perspectives. Food Hydrocolloids, 159(August 2024). https://doi.org/10.1016/j.foodhyd.2024.110614

Koekuyt, H. A., Dobson, S., & Marangoni, A. G. (2025). Lipid complexation improves the mechanical properties and functionality of legume starch gels. Food Hydrocolloids, 167(January). https://doi.org/10.1016/j.foodhyd.2025.111401

Kwakye, A. O., Fukada, K., Ishii, T., & Ogawa, M. (2024). Impact of Rare Sugar D-Allulose on Hardening of Starch Gels during Refrigerated Storage. Foods, 13(14). https://doi.org/10.3390/foods13142183

Lan, X., Liu, X., Yang, Y., Wu, J., & Wang, Z. (2017). The effect of lamellar structure ordering on the retrogradation properties of canna starch subjected to thermal and enzymatic degradation. Food Hydrocolloids, 69, 185–192. https://doi.org/http://dx.doi.org/10.1016/j.foodhyd.2017.02.004

Li, C. (2022). Recent progress in understanding starch gelatinization - An important property determining food quality. Carbohydrate Polymers, 293(May). https://doi.org/10.1016/j.carbpol.2022.119735

Li, C. (2024). Unraveling the Complexities of Starch Retrogradation: Insights from

Kinetics, Molecular Interactions, and Influences of Food Ingredients. Food Reviews International, 40(9), 3159–3182. https://doi.org/10.1080/87559129.2024.2347467

Li, J., Sun, J., Wang, W., Jiang, C., & Hao, J. (2025). International Journal of Biological Macromolecules Purification , immobilization , evolution , and characterization of D-allulose 3-epimerase from Antarctic Microbacterium. 310(April).

Li, S., Wang, Z., Feng, D., Pan, Y., Li, E., Wang, J., & Li, C. (2024). The important role of starch fine molecular structures in starch gelatinization property with addition of sugars/sugar alcohols. Carbohydrate Polymers, 330(April 2023), 1–11. https://doi.org/10.1016/j.carbpol.2024.121785

Lyu, Z., Sala, G., & Scholten, E. (2022). Water distribution in maize starch-pea protein gels as determined by a novel confocal laser scanning microscopy image analysis method and its effect on structural and mechanical properties of composite gels. Food Hydrocolloids, 133(December 2021). https://doi.org/10.1016/j.foodhyd.2022.107942

Lyu, Z., Sala, G., & Scholten, E. (2024). Texture of emulsion-filled pea protein-potato starch gels: Effect of processing conditions and composition. International Journal of Biological Macromolecules, 277(December 2023). https://doi.org/10.1016/j.ijbiomac.2024.133889

Martínez, R. M., Cruz, M., Loredo-Treviño, A., Martínez, J. L., Ruiz, H. A., Rodríguez-Jasso, R. M., & Belmares, R. (2024). Evaluation of the addition of cassava flour fermented with lactic acid bacteria on the sensorial and nutritional properties of a baked product. Food and Humanity, 3(March). https://doi.org/10.1016/j.foohum.2024.100329

Moshawih, S., Kong, J. P. T., Goh, B. H., Renganathan, E., Goh, H. P., Goh, K. W., & Ming, L. C. (2025). Exploring the nutritional, cultural, and industrial significance of Metroxylon sagu. Discover Food, 5(1). https://doi.org/10.1007/s44187-025-00638-6

Natalia, R., Muliani, R., Ujianti, D., Umiyati, R., & Muflihati, I. (2022). Fisikokimia Bakso Ikan Patin (Pangasius hypophthalmus) Effect Of Starch Type And Carrageenan Concentration On Physicochemical Characteristics Of Catfish Meatballs (Pangasius hypophthalmus). Jurnal Kelautan Dan Perikanan Terapan, 5(1), 11–16.

Okazaki, M. (2018). The Structure and Characteristics of Sago Starch. In Sago palm: Multiple contributions to food security and sustainable livelihoods (pp. 247–259). https://doi.org/https://doi.org/10.1007/978-981-10-5269-9_18

Oyeyinka, S. A., Adeloye, A. A., Olaomo, O. O., & Kayitesi, E. (2020). Effect of fermentation time on physicochemical properties of starch extracted from cassava root. Food Bioscience, 33(December 2018), 1–8. https://doi.org/10.1016/j.fbio.2019.100485

Paksi, A. K., Aris Pujiyanto, M., Rohmatika, F. A., & Budiargo, N. F. (2025). Exploring the Export Potential of Mocaf Flour to International Markets: Opportunities and Institutional Challenges. IOP Conference Series: Earth and Environmental Science, 1566(1), 012025. https://doi.org/10.1088/1755-1315/1566/1/012025

Park, J., Oh, S. K., Chung, H. J., & Park, H. J. (2020). Structural and physicochemical properties of native starches and non-digestible starch residues from Korean rice cultivars with different amylose contents. Food Hydrocolloids, 102(August 2019). https://doi.org/10.1016/j.foodhyd.2019.105544

Putri, N. A., Subagio, A., & Diniyah, N. (2022). Pasting Properties of Mocaf (Modified Cassava Flour) Using Rapid Visco Analyzer With Variations of pH Solution. Food ScienTech Journal, 4(1), 18. https://doi.org/10.33512/fsj.v4i1.14441

Renzetti, S., Hoek, I. A. F. Van Den, & Sman, R. G. M. Van Der. (2021). Food Hydrocolloids Mechanisms controlling wheat starch gelatinization and pasting behaviour in presence of sugars and sugar replacers : Role of hydrogen bonding and plasticizer molar volume. 119(April).

Rong, L., Mao, W., & Xie, J. (2026). Comparative study on rheological behaviors, gel and digestive properties of corn starch/Mesona chinensis polysaccharide gels under manual and mechanical gelatinization methods. International Journal of Biological Macromolecules, 359(235). https://doi.org/10.1016/j.ijbiomac.2026.151908

Saputra, F. F., & Setyowati, E. (2024). ANALISIS FAKTOR-FAKTOR YANG MEMPENGARUHI IMPOR GANDUM INDONESIA DARI AUSTRALIA TAHUN1997-2022. Jurnal Kajian Pendidikan Ekonomi Dan Ilmu Ekonom, 09, 1–11.

Shahsavani Mojarrad, L., & Rafe, A. (2018). Rheological characteristics of binary composite gels of wheat flour and high amylose corn starch. In Journal of Texture Studies (Vol. 49, Number 3). https://doi.org/10.1111/jtxs.12302

Shoukat, R., Cappai, M., Pilia, L., & Pia, G. (2025). Rice Starch Chemistry, Functional Properties, and Industrial Applications: A Review. Polymers, 17(1), 21. https://doi.org/10.3390/polym17010110

Su, Y. Bin, Zhang, J., Huang, K., & Xie, N. (2024). Small molecular sugars effect on the pasting and retrogradation of Mesona chinensis polysaccharide/starch complexes. International Journal of Food Science and Technology, 59(3), 1935–1944. https://doi.org/10.1111/ijfs.16950

Syahbanu, F., Napitupulu, F. I., Septiana, S., & Aliyah, N. F. (2023). Struktur pati beras (Oryza sativa L.) dan mekanisme perubahannya pada fenomena gelatinisasi dan retrogradasi. Agrointek : Jurnal Teknologi Industri Pertanian, 17(4), 755–767. https://doi.org/10.21107/agrointek.v17i4.15315

Ulbrich, M., Scholz, F., & Flöter, E. (2022). High Amylose Corn Starch Gels – A Molecular Investigation of the Network Constituting Polymers. Starch/Staerke, 74(5–6), 1–10. https://doi.org/10.1002/star.202200032

Wang, L., Xu, J., Fan, X., Wang, Q., Wang, P., Zhang, Y., Cui, L., Yuan, J., & Yu, Y. (2016). Effect of disaccharides of different composition and linkage on corn and waxy corn starch retrogradation. Food Hydrocolloids, 61, 531–536. https://doi.org/10.1016/j.foodhyd.2016.06.010

Wang, X., Liu, S., & Ai, Y. (2022). Gelation mechanisms of granular and non-granular starches with variations in molecular structures. Food Hydrocolloids, 129(March). https://doi.org/10.1016/j.foodhyd.2022.107658

Wang, Z., Lv, J., Xie, D., Li, X., Liu, X., Li, N., & Liu, J. (2024). The effects of D-allulose on the gelatinization and gelling properties of wheat starch. International Journal of Biological Macromolecules, 282(October). https://doi.org/10.1016/j.ijbiomac.2024.137326

Widowati, S., Misgiyarta, Setyawan, N., Herawati, H., Widaningrum, Suhirman, S., Noerwijati, K., Budiono, R., Astuti, S. D., Tjahjohutomo, R., Unadi, A., & Budiharti, U. (2025). Physicochemical and functional properties of cassava flour produced by controlled fermentation using mixed culture from various bacteria and yeast. Journal of Agriculture and Food Research, 19(September 2024), 0–7. https://doi.org/10.1016/j.jafr.2025.101684

Woodbury, T. J., & Mauer, L. J. (2023). Oligosaccharide, sucrose, and allulose effects on the pasting and retrogradation behaviors of wheat starch. Food Research International, 171(February). https://doi.org/10.1016/j.foodres.2023.113002

Woodbury, T. J., Pitts, S. L., Pilch, A. M., Smith, P., & Mauer, L. J. (2023). Mechanisms of the different effects of sucrose, glucose, fructose, and a glucose–fructose mixture on wheat starch gelatinization, pasting, and retrogradation. Journal of Food Science, 88(1), 293–314. https://doi.org/10.1111/1750-3841.16414

Yang, S., Dhital, S., Shan, C. S., Zhang, M. N., & Chen, Z. G. (2021). Ordered structural changes of retrograded starch gel over long-term storage in wet starch noodles. Carbohydrate Polymers, 270(June), 118367. https://doi.org/10.1016/j.carbpol.2021.118367

Yang, Y., Fu, J., Duan, Q., Xie, H., Dong, X., & Yu, L. (2024). Strategies and Methodologies for Improving Toughness of Starch Films. Foods, 13(24). https://doi.org/10.3390/foods13244036

Zhang, H., Gao, F., Li, X., Li, X., Liu, Z., Zou, X., Jin, L., Li, Z., & Wang, L. (2023). Analysis of changes in gel properties during retrogradation of four kinds of sorghum starch. International Journal of Food Science and Technology, 58(6), 3109–3120. https://doi.org/10.1111/ijfs.16438

Zhang, L., Zhao, J., Li, F., Jiao, X., Zhang, Y., Yang, B., & Li, Q. (2024). Insight to starch retrogradation through fine structure models: A review. International Journal of Biological Macromolecules, 273(17). https://doi.org/10.1016/j.ijbiomac.2024.132765

Zhang, W., Chen, D., Chen, J., Xu, W., Chen, Q., Wu, H., Guang, C., & Mu, W. (2023). D-allulose, a versatile rare sugar: recent biotechnological advances and challenges. Critical Reviews in Food Science and Nutrition, 63(22), 5661–5679. https://doi.org/10.1080/10408398.2021.2023091

Zhang, X., Li, R., Kang, H., Luo, D., Fan, J., Zhu, W., Liu, X., & Tong, Q. (2017). Effects of low molecular sugars on the retrogradation of tapioca starch gels during storage. PLoS ONE, 12(12). https://doi.org/10.1371/journal.pone.0190180

Zhao, Y., Duan, X., Zhang, J., Ding, Y., & Liu, Q. (2025). Advances in the bioproduction of D-allulose: A comprehensive review of current status and future prospects. Food Research International, 202(October 2024). https://doi.org/10.1016/j.foodres.2025.115767

Zhu, J., Fan, L., Chen, J., Xu, W., Sitanggang, A. B., Laksmi, F. A., Ding, J., & Mu, W. (2026). Research progress in microbial synthesis of D-allulose using metabolically engineered microbes. Trends in Food Science and Technology, 169(January). https://doi.org/10.1016/j.tifs.2026.105551