



Barley (*Hordeum Vulgare*) as An Anti-Diabetic Agent: Fourier Transform Infrared Spectroscopy Analysis

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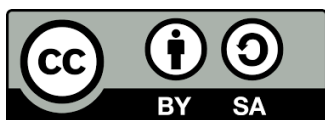
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Abstract

Barley (*Hordeum vulgare*) is a promising dietary resource for glycemic management; however, evidence regarding the chemical composition and physiological effects of cooked barley porridge remains limited. This study aimed to characterize barley porridge using Fourier transform infrared (FTIR) spectroscopy and phytochemical screening and to evaluate its effects on fasting blood glucose (FBG) levels. A randomized controlled animal experiment was conducted involving 36 male Wistar rats assigned to six groups: a normal control group, a diabetic control group, a metformin-treated control group, a group of nondiabetic rats receiving barley-mixed feed, a group of diabetic rats receiving barley-mixed feed, and a group of diabetic rats receiving barley-only feed. Diabetes was induced using alloxan, and FBG levels were measured weekly throughout the 28-day intervention. Data were analyzed using the Wilcoxon signed-rank test and the Mann–Whitney U test. FTIR spectra revealed absorption bands consistent with functional groups associated with carbohydrates, proteins, and lipids, while phytochemical screening indicated the presence of alkaloids, flavonoids, and steroids/triterpenoids. In diabetic rats receiving barley-mixed feed, median FBG levels decreased from 343 to 230 mg/dL, representing an approximately 33% reduction. However, the reductions in FBG levels observed in the barley-treated diabetic groups were not statistically significant. These findings suggested that the chemical constituents of barley porridge warranted further investigation, although their proposed mechanisms of action remained unverified. Overall, barley porridge did not demonstrate statistically significant antidiabetic efficacy under the experimental conditions. Further studies involving larger sample sizes, longer intervention periods, and standardized dietary comparisons are needed to establish its potential role in glycemic management.



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INTRODUCTION

Diabetes mellitus (DM) is a complex chronic metabolic disorder and a major global health concern characterized by persistent hyperglycemia resulting from impaired insulin secretion, insulin action, or both. Addressing this condition is a global health priority that requires sustained, comprehensive, and multifaceted management strategies to mitigate the increasing prevalence of diabetes and prevent severe complications (Ong et al., 2023). According to the International Diabetes Federation (IDF), approximately 589 million adults aged 20–79 years were living with diabetes worldwide in 2024, and this figure is projected to reach 853 million by 2050. Indonesia ranked fifth globally, with an estimated 20.4 million adults living with diabetes in 2024, a number projected to increase to 28.6 million by 2050 (IDF, 2025). Given these projections, developing accessible and sustainable dietary interventions is essential for long-term glycemic management. Dietary habits, particularly the quality and quantity of macronutrient intake, play a fundamental role in the development and management of DM (Sapra & Bhandari, 2023). Although carbohydrates are essential macronutrients, excessive consumption and frequent intake of high-glycemic-index (GI) foods may contribute to elevated blood glucose levels and impaired glycemic control. Consequently, identifying alternative staple foods with lower glycemic responses to replace highly refined grains, such as white rice and refined wheat products, has become an important focus of nutritional research (Hwalla et al., 2021).

Barley (*Hordeum vulgare*) is a widely cultivated cereal grain with considerable potential as a dietary option for diabetes management. As one of the world's major cereal crops, ranking fourth in global cereal production, barley provides a source of carbohydrates and dietary fiber that may help moderate postprandial glycemic responses. Its potential metabolic benefits are largely attributed to its high β -glucan content, a form of soluble dietary fiber. Previous studies have extensively examined the role of barley-derived β -glucan in reducing two-hour postprandial blood glucose responses (Celin et al., 2024). The proposed mechanism involves increased viscosity of gastrointestinal contents, which may delay gastric emptying, slow starch digestion, and reduce the rate of intestinal glucose absorption, thereby attenuating postprandial glycemic excursions (Ahmed et al., 2025; Kellogg et al., 2025).

Although the short-term effects of barley consumption on postprandial glycemic responses have been investigated, its effects on fasting blood glucose (FBG) require further examination because fasting and postprandial glucose regulation involve different physiological mechanisms. Studies specifically evaluating the effects of sustained barley consumption on FBG levels remain relatively limited (Ahmed et al., 2025; Kellogg et al., 2025; Kim et al., 2024). Furthermore, an important research gap concerns the physical form of barley used in experimental investigations. Understanding the potential antidiabetic properties of barley under realistic dietary conditions requires characterization of its chemical composition in commonly consumed preparations, including cooked porridge. Thermal processing and hydration during cooking can alter the physicochemical properties of barley by promoting starch gelatinization and

modifying β -glucan solubility and molecular weight, potentially influencing its physiological effects (Fan et al., 2024; Nicholls, 2022).

Fourier transform infrared (FTIR) spectroscopy and phytochemical screening are commonly employed as complementary analytical techniques for characterizing functional groups and detecting classes of phytochemical constituents in plant-derived materials. However, previous studies applying these techniques to barley have primarily examined raw grain powder or solvent-derived extracts (Khalil et al., 2025). Analyses limited to raw materials may not adequately represent the physicochemical characteristics of barley after cooking. FTIR characterization of prepared barley porridge may provide information about functional groups present in the processed food matrix and potential changes associated with thermal treatment. In particular, spectral features associated with hydroxyl groups, polysaccharides, and other organic constituents may contribute to understanding the chemical characteristics of cooked barley. Nevertheless, FTIR spectroscopy alone cannot establish the bioavailability or biological activity of specific compounds, and complementary phytochemical analyses are necessary to provide additional information about the constituents potentially associated with glycemic regulation (Maheshwaran et al., 2024; Martiniakova et al., 2025).

Given the increasing prevalence of DM, investigating dietary interventions in forms that reflect actual consumption practices is important for evaluating their potential physiological relevance. Previous research has primarily focused on the chemical composition of raw barley flour and isolated extracts (Khalil et al., 2025), as well as the short-term effects of barley consumption on postprandial blood glucose responses (Celin et al., 2024). However, relatively few studies have examined the effects of sustained barley consumption on FBG levels while simultaneously characterizing the chemical properties of cooked, ready-to-consume barley porridge. This gap highlights the need for an integrated investigation combining chemical characterization with physiological assessment. Accordingly, this study aimed to characterize the functional groups and phytochemical constituents of prepared barley porridge using FTIR spectroscopy and qualitative phytochemical screening and to evaluate its effects on FBG levels in an experimental animal model of diabetes.

This study hypothesized that barley porridge retained detectable chemical functional groups associated with potentially bioactive constituents following thermal processing and that its dietary administration would significantly reduce FBG levels in diabetic rats compared with a standard diet. The experimental intervention involved administering barley porridge to alloxan-induced diabetic Wistar rats, with FBG levels assessed as the primary physiological outcome. FTIR spectral characteristics and qualitative phytochemical profiles were examined separately to characterize the prepared porridge. Dietary conditions, environmental factors, and alloxan administration were controlled according to the experimental protocol. The study combined FTIR spectroscopy and phytochemical screening with a 28-day controlled dietary intervention to investigate the chemical characteristics of cooked barley porridge and its potential effects on glycemic regulation.

METHOD

A true experimental study employing a randomized pretest–posttest control group design was conducted at the Faculty of Pharmacy, Universitas Sumatera Utara. The research protocol was approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Prima Indonesia (Approval No. 005/KEPK/UNPRI/VIII/2025).



Figure 1. Barley Preparation Workflow for FTIR Analysis, Phytochemical Screening, and In Vivo Testing.

Barley porridge was prepared by boiling 100 g of rinsed barley grains in 700 mL of water until softened, followed by blending with an additional 300 mL of water to obtain a homogeneous mixture. The prepared sample was characterized using Fourier transform infrared (FTIR) spectroscopy (Shimadzu IRPrestige-21; spectral range: 4,500–500 cm^{-1} ; KBr pellet method) to identify chemical functional groups. Qualitative phytochemical screening was performed to assess the presence of flavonoids, tannins, saponins, alkaloids, glycosides, steroids, and triterpenoids.

The animal experiment involved 36 male Wistar rats randomly assigned to six groups ($n = 6$ per group): normal control, diabetic control, positive control (metformin-treated diabetic rats), barley 1 (nondiabetic rats receiving barley-mixed feed), barley 2 (diabetic rats receiving barley-mixed feed), and barley 3 (diabetic rats receiving barley-only feed). Diabetes was induced by a single intraperitoneal injection of alloxan at a dose of 125 mg/kg body weight, while the nondiabetic groups received physiological saline. Rats with fasting blood glucose (FBG) levels ≥ 126 mg/dL following induction were

classified as diabetic. During the 28-day intervention, FBG levels were measured weekly using tail blood samples and an EasyTouch glucometer. As the data were not normally distributed, results were expressed as medians. Within-group differences were assessed using the Wilcoxon signed-rank test, while between-group differences were analyzed using the Mann–Whitney U test.

RESULTS AND DISCUSSION

FTIR Analysis

FTIR analysis was performed on the barley porridge to identify and confirm the presence of nutritional and functional components (Figure 1, Table 1).

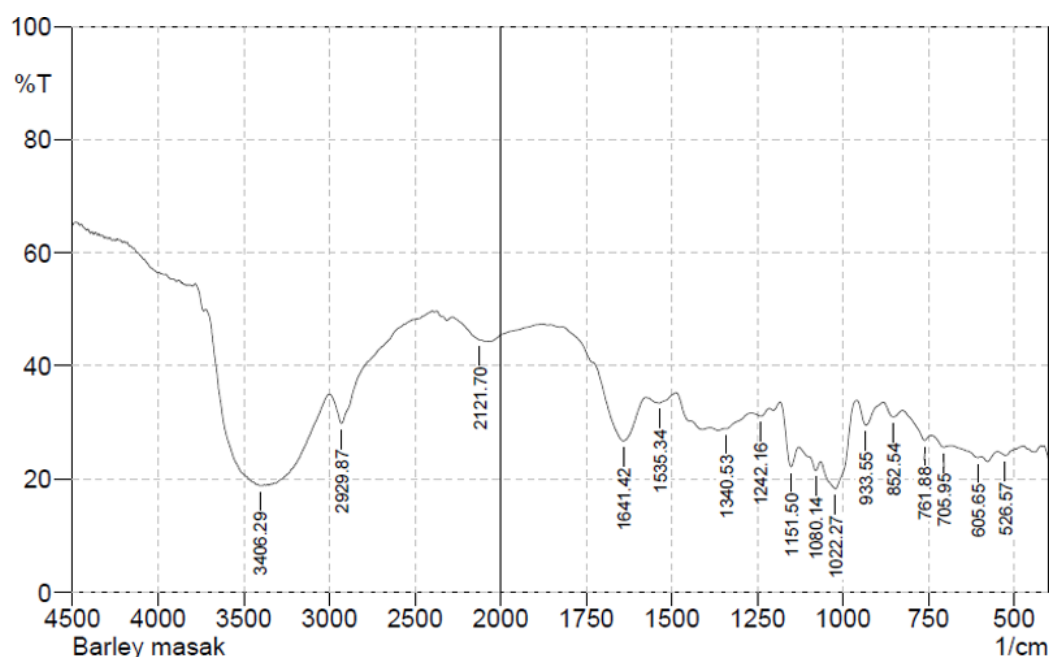


Figure 2. Fourier Transform Infrared (FTIR) Spectrum of Barley Porridge

Table 1. Interpretation of FTIR Analysis of Barley Porridge

Peak Positions (cm-1)	Corresponding chemical functional group	Conclusion
3406.29	Hydroxy (OH) stretch (H-bonded)	Water absorption. Indicative of starch gelatinization (Nagasaki et al., 2021).
2929.87	Asymmetric methylene (CH ₂) stretch	Strong contribution from the long aliphatic chains of fatty acids, confirming the presence of fat in barley, forms RS5 (Mekonnen, 2023; Photinam et al., 2024).
1641.42	Amide I group (C=O stretch)	Primary indicator of protein peptide bonds (Nandiyanto et al., 2019).
1151.5	C-O-C Asymmetric stretch	Glycosidic Linkages. Typical in starch and beta-glucan (Ma et al., 2018).
1535.34	Amide II group (N-H bend / C-N stretch)	Definitive indicator of protein peptide bonds (Nandiyanto et al., 2019).
1022.27	C-O stretch	Amorphous starch component, indicating loss of crystallinity (process of gelatinization) (Nagasaki et al., 2021).
933.55	C-O ring/Anomeric stretch	Alpha configuration detection (amylose & amylopectin) (Szaniawska et al., 2025).

The anti-diabetic potential observed in the animal model is likely a synergistic effect of the physical matrix and bioactive compounds. FTIR analysis provided information of how the preparation process altered the grain's structure. A prominent band identified at 1022.27 cm⁻¹ indicated the presence of amorphous starch, suggested that the cooking process successfully disrupted the crystalline structure of the starch granules (Nagasaki et al., 2021). This was further supported by the peak at 3406.29 cm⁻¹ (Xu et al., 2021), which reflected the OH stretch and water absorption characteristic of starch gelatinization. While gelatinization typically is a state that is easily digestible and usually increases glycemic index, the effect is countered by the simultaneous solubilization of β -glucan, indicative at 1151.5 cm⁻¹ (Ma et al., 2018).

This results in a highly viscous hydrocolloid matrix that acts as a physical barrier along the intestinal mucosa. The physical barrier slows down the movement of glucose molecules toward the absorption sites and also delays the activity of digestive enzymes. Therefore, while the gelatinization of starch is usually deemed more digestible due to its loss of crystallinity, its actual absorption into the bloodstream is significantly slowed by the viscous barrier created by the β -glucan (Ahmed et al., 2025).

Beyond the starch-fiber interaction, the presence of lipids in the barley porridge sample was confirmed by the methylene stretch at 2929.87 cm⁻¹ (Mekonnen, 2023). When starch gelatinizes in the presence of lipids, amylose-lipid complexes are formed. These complexes make up Type 5 resistant starch (RS5), which functions as dietary fiber. Given that barley is inherently high fiber, the formation of RS5 further increases the resistant starch content available for fermentation into short-chain fatty acids (SCFAs) by gut microbiota (Photinam et al., 2024).

SCFAs help regulate blood glucose through several mechanisms, they stimulate the release of incretin hormones like GLP-1, which enhances insulin secretion and suppresses glucagon, and they improve overall insulin sensitivity (Ahmed et al., 2025). Collectively, these processes effectively lower postprandial blood sugar levels.

Additionally, protein presence was confirmed by Amide I (1641.42 cm⁻¹) and Amide II (1535.34 cm⁻¹) peaks (Nandiyanto et al., 2019). These proteins are crucial not only for nutritional value but for their interaction with starch granules. The proteins in barley can coat starch granules, restricting the digestion of starch degraded by α -amylase, which reduces starch hydrolysis and the subsequent glucose release (Scott & Awika, 2023).

Phytochemical Analysis

Other than physical characterization, the phytochemical screening identified specific profile of secondary metabolites that provide a biological mechanism of action. The screening confirmed the presence of alkaloids, flavonoids, and steroids/triterpenoids in the porridge (Table 2). These compounds extend the food's function beyond simple nutrition. Flavonoids and triterpenoids, for example, are potent antioxidants capable of alleviating diabetes-related oxidative stress (Dias et al., 2021; Martiniakova et al., 2025; Randeni et al., 2025). Quercetin, a type of flavonoid found in barley, can inhibit the formation of reactive oxygen species (ROS) through chelation of iron, directly countering the oxidative damage (Martiniakova et al., 2025).

Table 2. Phytochemical Screening of Barley Porridge

Active Ingredients	Results
Alkoloid	Positive
Flavonoid	Positive
Tannins	Negative
Saponins	Negative
Steroid/Triterpenoid	Positive

Statistical Analysis of Barley Porridge in Alloxan-Induced Rat Model Between-Group Comparisons

The Metformin-treated PC group demonstrated a statistically significant reduction in FBG compared to the DC group at Day 28 ($p = 0.0495$). This confirmed the efficacy of Metformin and validates the diabetic model and the study's sensitivity to detect significant differences (Hilgard, 2021).

Within-Group Changes

Despite clear chemical and mechanical evidence, the barley-treated groups (B2 & B3) did not reach statistical significance ($p = 0.077$ & $p = 0.157$). Even though the B2 group exhibited a dramatic reduction in median FBG from 343 mg/dL to 230 mg/dL, which is approximately a 33% decrease, the lack of statistical significance is likely a result of a small sample size and short duration of the experiment (Shreffler & Huecker, 2023). This suggests that with proper sample sizing and longer duration of experiment done, the sample may show significant antidiabetic/hypoglycemic effect.

Table 3. Effects of Barley Porridge on FBG

Group	Median (IQR) (mg/dL)		Within-Group Change p value	Between-Group Comparison (D28 vs DC) p value
	FBG day 0	FBG day 28		
N	90.00	103.00	0.03*	(-)
PC	281.00	111.00	0.11	0.05*†
DC	320.00	342.00	0.11	(-)
B1	92.00	103.50	0.04*	0.02*
B2	343.00	230.00	0.07	0.08
B3	346.00	245.00	0.07	0.16

* Indicates statistical significance ($p < 0.05$).

† The p-value for this comparison was determined to be $p = 0.0495$.

CONCLUSION

This study characterized cooked barley (*Hordeum vulgare*) porridge and evaluated its effects on fasting blood glucose (FBG) levels in an alloxan-induced diabetic rat model. Fourier transform infrared (FTIR) spectra revealed absorption bands consistent with functional groups associated with carbohydrates, proteins, and lipids, while qualitative phytochemical screening indicated the presence of alkaloids, flavonoids, and steroids/triterpenoids. Following the 28-day intervention, diabetic rats receiving barley-mixed feed exhibited a reduction in median FBG levels from 343 to 230 mg/dL, representing an approximately 33% decrease. However, the reductions in FBG levels observed in the barley-treated diabetic groups were not statistically significant. These findings suggest that barley porridge warrants further investigation as a potential functional food for glycemic management but do not provide sufficient evidence to establish its antidiabetic efficacy. Proposed mechanisms involving β -glucan-induced increases in gastrointestinal viscosity, delayed intestinal glucose absorption, and antioxidant activity remain hypothetical and require direct experimental verification.

Future research should involve larger sample sizes determined through statistical power calculations, longer intervention periods, and standardized barley doses to establish the magnitude and consistency of glycemic responses. Dietary comparisons should account for total energy intake and nutrient composition to distinguish barley-specific effects from variations in food consumption. Quantitative analyses of β -glucan content, molecular weight, viscosity, resistant starch, and phytochemical concentrations would provide a more comprehensive understanding of the relationships between the physicochemical properties of barley porridge and its physiological effects. Additional assessments of postprandial blood glucose, longer-term glycemic indicators, insulin responses, oxidative stress biomarkers, and pancreatic histopathology could help elucidate the potential mechanisms underlying its effects on glucose regulation. Furthermore, comparisons of different preparation methods and investigations using experimental models that more closely reflect the pathophysiology of type 2 diabetes

would enhance the applicability of the findings and provide a stronger foundation for subsequent controlled clinical studies in humans.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest in the conduct of the research, the writing, or the publication of this article.

AUTHOR CONTRIBUTION

All authors contributed to the preparation of this article. They contributed to the conceptualization of the study, data collection and analysis, interpretation of the results, and drafting of the manuscript through to its final editing.

GENERATIVE ARTIFICIAL INTELLIGENCE USAGE STATEMENT

The authors declare that they did not use generative artificial intelligence in the preparation of this article.

REFERENCES

- Ahmed, H. G. M. D., Iqbal, R., Yang, X., Yang, J., Pu, X., Li, X., ... Zeng, Y. (2025). Bioactive compounds in barley modulating glycemic response: Implications for diabetes management. *Natural Product Communications*, 20(4). <https://doi.org/10.1177/1934578X251336985>
- Celin, Meldawati, & Halim, Y. (2024). Antidiabetic activity of barley porridge on postprandial blood glucose and histopathology of alloxan-induced diabetics rats. *Eduvest - Journal of Universal Studies*, 4(11). <https://doi.org/10.59188/eduvest.v4i11.39006>
- Dias, M. C., Pinto, D. C. G. A., & Silva, A. M. S. (2021). Plant flavonoids: Chemical characteristics and biological activity. *Molecules*, 26(17), Article 5377. <https://doi.org/10.3390/molecules26175377>
- Fan, C., Cheng, L., Hong, Y., Li, Z., Li, C., Ban, X., & Gu, Z. (2024). Study on the gelatinization and digestive characteristics of wheat starch and potato starch under low moisture conditions. *International Journal of Biological Macromolecules*, 269, Article 132192. <https://doi.org/10.1016/j.ijbiomac.2024.132192>
- Hilgard, J. (2021). Maximal positive controls: A method for estimating the largest plausible effect size. *Journal of Experimental Social Psychology*, 93, Article 104082. <https://doi.org/10.1016/j.jesp.2020.104082>
- Hwalla, N., Jaafar, Z., & Sawaya, S. (2021). Dietary management of type 2 diabetes in the MENA region: A review of the evidence. *Nutrients*, 13(4), Article 1060. <https://doi.org/10.3390/nu13041060>
- Kellogg, J. A., Monsivais, P., Murphy, K. M., & Perrigue, M. M. (2025). High β -glucan whole grain barley reduces postprandial glycemic response in healthy adults—Part

- one of a randomized controlled trial. *Nutrients*, 17(3), Article 430. <https://doi.org/10.3390/nu17030430>
- Khalil, I., Bashir, S., Saeed, K., Alsulami, T., Rafique, H., & Mukonzo, E. K. L. (2025). Phytochemical and structural portrayal of barley and pearl millet through FTIR and SEM. *Food Science & Nutrition*, 13(5), Article e70120. <https://doi.org/10.1002/fsn3.70120>
- Kim, I. S., Park, S. Y., Park, M. J., Kim, K. J., & Kim, J. Y. (2024). Effect of barley on postprandial blood glucose response and appetite in healthy individuals: A randomized, double-blind, placebo-controlled trial. *Nutrients*, 16(22), Article 3899. <https://doi.org/10.3390/nu16223899>
- Ma, Y., He, H., Wu, J., Wang, C., Chao, K., & Huang, Q. (2018). Assessment of polysaccharides from mycelia of genus *Ganoderma* by mid-infrared and near-infrared spectroscopy. *Scientific Reports*, 8(1), Article 10. <https://doi.org/10.1038/s41598-017-18422-7>
- Maheshwaran, L., Nadarajah, L., Senadeera, S. P. N. N., Ranaweera, C. B., Chandana, A. K., & Pathirana, R. N. (2024). Phytochemical testing methodologies and principles for preliminary screening/qualitative testing. *Asian Plant Research Journal*, 12(5), 11–38. <https://doi.org/10.9734/aprj/2024/v12i5267>
- Martiniakova, M., Sarocka, A., Penzes, N., Biro, R., Kovacova, V., Mondockova, V., ... Omelka, R. (2025). Protective role of dietary polyphenols in the management and treatment of type 2 diabetes mellitus. *Nutrients*, 17(2), Article 275. <https://doi.org/10.3390/nu17020275>
- Mekonnen, K. D. (2023). Fourier transform infrared spectroscopy as a tool for identifying the unique characteristic bands of lipid in oilseed components: Confirmed via Ethiopian indigenous desert date fruit. *Heliyon*, 9(4), Article e14699. <https://doi.org/10.1016/j.heliyon.2023.e14699>
- Nagasaki, A., Matsuba, G., Ikemoto, Y., Moriwaki, T., Ohta, N., & Osaka, K. (2021). Analysis of the sol and gel structures of potato starch over a wide spatial scale. *Food Science and Nutrition*, 9(9), 4916–4926. <https://doi.org/10.1002/fsn3.2441>
- Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R. (2019). How to read and interpret FTIR spectroscopy of organic material. *Indonesian Journal of Science and Technology*, 4(1), 97–118. <https://doi.org/10.17509/ijost.v4i1.15806>
- Nicholls, J. (2022). Perspective: The glycemic index falls short as a carbohydrate food quality indicator to improve diet quality. *Frontiers in Nutrition*, 9, Article 896333. <https://doi.org/10.3389/fnut.2022.896333>
- Ong, K. L., Stafford, L. K., McLaughlin, S. A., Boyko, E. J., Vollset, S. E., Smith, A. E., ... Vos, T. (2023). Global, regional, and national burden of diabetes from 1990 to 2021, with projections of prevalence to 2050: A systematic analysis for the Global Burden of Disease Study 2021. *The Lancet*, 402(10397), 203–234. [https://doi.org/10.1016/S0140-6736\(23\)01301-6](https://doi.org/10.1016/S0140-6736(23)01301-6)
- Photinam, R., Moongngarm, A., Detchewa, P., & Wang, Y. J. (2024). Improvement of amylose–lipid complex and starch digestibility profiles of corn starch added with rice bran oil or linoleic acid using ultrasonic and microwave treatment. *Journal of Food Science and Technology*, 61(12), 2287. <https://doi.org/10.1007/s13197-024-05993-3>
- Randeni, N., Luo, J., & Xu, B. (2025). Unveiling the molecular mechanisms of natural triterpenoids from mushrooms against type 2 diabetes: A critical review. *Phytotherapy Research*, 39(8), 3466–3485. <https://doi.org/10.1002/ptr.70030>

- Sapra, A., & Bhandari, P. (2023). *Diabetes*. In StatPearls. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK551501/>
- Scott, G., & Awika, J. M. (2023). Effect of protein–starch interactions on starch retrogradation and implications for food product quality. *Comprehensive Reviews in Food Science and Food Safety*, 22(3), 2081–2111. <https://doi.org/10.1111/1541-4337.13141>
- Shreffler, J., & Huecker, M. R. (2023). *Type I and type II errors and statistical power*. In StatPearls. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK557530/>
- Szaniawska, A., Grzeda, J., Binder, J., Kudelski, A., Malek, K., Wrobel, T. P., ... Roguz, K. (2025). Data-driven FTIR spectroscopy for the discrimination of nectars. *Molecules*, 30(20), Article 4083. <https://doi.org/10.3390/molecules30204083>
- Xu, F., Zhang, L., Liu, W., Liu, Q., Wang, F., Zhang, H., ... Blecker, C. (2021). Physicochemical and structural characterization of potato starch with different degrees of gelatinization. *Foods*, 10(5), Article 1104. <https://doi.org/10.3390/foods10051104>