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Unveiling The Distinctive Qualities of Malaysian and Thai Rice

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Abstract

This work compared the chemical and thermal properties of Malaysian and Thai rice cultivars. Malaysian rice was obtained from Terengganu, Malaysia, while Thai rice samples were Khao Hom Mali from Royal Umbrella Thailand. The paired-T statistic was employed to examine the chemical and thermal parameters. While there were no statistically significant differences in the amylose, moisture, and fat composition between the two samples ($p>0.05$), there were notable disparities in the protein, ash, carbohydrate, and fiber composition ($p<0.05$). Malaysian rice cultivars exhibited higher levels of protein (7.8%), ash (53%), and carbohydrate content (25.88%), whereas Thai rice possessed a fiber content that was five times greater. Regarding thermal characteristics, Malaysian rice exhibited higher values for onset (21.5%), conclusion (6.5%), and peak (8.7%), although Thai rice had a gelatinization range that was three times higher. These findings indicate that Malaysian rice yields firmer textures, rendering it appropriate for certain grain cuisines where separated grain is required. In contrast, Thai rice's softer, more adaptable texture might be suited to different culinary applications, improving consumer tastes and industrial utilization.

Keywords: Chemical and Thermal Properties, Malaysia, Rice, Thailand

1. Introduction

Rice has been one of the most essential crops in the world. Rice has been a staple food for billions of people globally [1]. It holds particular cultural and economic significance in Southeast Asia, especially Malaysia and Thailand. Rice is an important component of Malaysian daily consumption, with a yearly consumption of 82.3 kilograms per capita [2]. Malaysians consume rice daily as cooked rice or indirectly as a processed food. Thailand is also the world's sixth-largest rice producer, with 32,2 million tonnes produced annually [3]. Both countries heavily depend on rice as a primary source of carbohydrates, ensuring its status as a long-term staple food.

Malaysia is now in the process of targeting 100% of its rice supply [4]. This challenging objective encompasses several strategic initiatives, including enhancing domestic rice agriculture via advanced farming practices, investing in agricultural technologies, and promoting high-yielding rice cultivars [4]-[6]. These initiatives are components of a comprehensive national food security strategy.

Notwithstanding the significant importance of rice in Malaysia and Thailand, a notable gap exists in the comparative analysis of their rice varieties' distinct chemical and thermal characteristics [7], [8]. Although prior works have examined certain elements, including the physical attributes of glutinous rice and regional rice varieties (e.g., [9], [10]), these remain inadequate regarding the essential physicochemical properties that differentiate Malaysian and Thai white rice. Comprehending these distinctions is essential, as rice's chemical composition and thermal properties impact cooking characteristics, storage stability, and disintegration during processing, all of which affect consumer approval.

Thai Khao Hom Mali rice, also known as Jasmine rice, is celebrated for its distinctive aroma, superior cooking qualities, and lower gelatinization temperature, contributing to its desirable texture and fragrance when cooked [11], [12]. The higher presence of 2-acetyl-1-pyrroline (2AP), a compound responsible for its aroma, enhances its appeal in domestic and international markets [13]. Additionally, its higher amylose content produces a firmer texture upon cooking [14]. In contrast, though cultivated for quality, Malaysian rice varieties often lack the aromatic and textural appeal of Thai rice [15]. Predominantly non-aromatic, Malaysian rice focuses on improving local cultivars through breeding programs [16]. Malaysian rice's thermal properties and quality vary due to soil, cultivation practices, and environmental conditions, influencing consumer preferences and marketability [14].

The deficiency of thorough works on Malaysian and Thai rice's chemical and thermal properties is a significant concern, as these elements are crucial for rice quality and classification [17]-[20]. These attributes can directly influence the rice industry's capacity to innovate and enhance rice cultivars, rendering them more appropriate for home and international markets. This work seeks to address the work gap by examining and contrasting the chemical and thermal properties of Malaysian and Thai white rice types. The results will yield significant insights into the physicochemical distinctions between the two varieties, presenting prospective uses for rice categorization, processing, and further advancement in the rice industry.

2. Materials and Methods

2.1. Sample Preparation

For this work, five kilograms of Malaysian rice varieties (MR219, MR220CL, MR297, MR269, MR303, and MR309) were obtained from a rice mill in Terengganu, Malaysia. Five kilograms of Thai Khao Hom Mali from Royal Umbrella Thailand were used. Both are popular rice cultivars in each country. To preserve their qualities before the examination, the rice samples were stored in vacuum-sealed packages with silica gel and placed in sealed containers, thereby minimizing moisture absorption and environmental exposure. The rice grain was ground using laboratory mill 120, Perten, Sweden, for chemical and thermal properties analysis. Then, it sieved 2 mm size.

2.2. Determination of Chemical Properties

The chemical property determined was amylose [21]. The standard curve was used to determine the amylose content of the samples [22]. Moisture content was determined using gravimetric (method number 950.46), crude protein Kjedahl method conversion factor 6.25 (method number 928.08), fat content was determined using Soxhlet extraction (method number 963.15), ash content was determined using direct ashing (method number 920.153), and crude fiber content (method number 920.153) [23]. Equation (1) was used to compute carbohydrates:

$$\%\,\text{Carbohydrate} = 100\% - (\%\,\text{moisture} + \%\,\text{crude protein} + \%\,\text{fat} + \%\,\text{ash} + \%\,\text{crude fiber}) \quad (1)$$

2.3. Determination of Thermal Properties

A quantity of rice flour weighing 3.5 milligrams on a dry basis was measured and placed into an aluminum pan with a capacity of 40 milliliters (Mettler, ME-27331). Distilled water was then added using a Hamilton micro syringe to create a suspension of flour and water with a water content of 70% [24], [25]. Before being heated in the Differential Scanning Calorimeter (DSC), the samples were tightly sealed and left undisturbed for 1 hour at the ambient temperature. The sample pans were heated from 20 to 100 degrees Celsius at a constant rate of 10 degrees Celsius per minute. Temperatures at the start (To), peak (Tp), and end (Tc) were all computed automatically. The gelatinization range (R) was calculated as (Tc – To) because the peaks were symmetrical [26].

2.4. Statistical Analysis

Analysis of variance was utilized to determine statistically significant differences between the means of triplicate raw data of samples using the paired-T statistic. Using Minitab Software Version 17, significance was accepted at P 0.05. Minitab Software version 17 was used to calculate Pearson’s correlation.

3. Results

3.1. Chemical Properties From Different Rice Flour Varieties

Rice (Oryza sativa L.) is a hydrophilic plant typically cultivated in regions with low elevation. Rice cultivation currently spans around 137 million hectares in over 100 nations, primarily in the tropical and subtropical regions, with Asia being the predominant region. Several million hectares are cultivated in temperate zones, with a maximum limit of 53 degrees latitude. In Malaysia, the predominant location for rice cultivation is the granary, which uses an irrigation network and is commonly referred to as a lowland area. The origin of rice can influence its chemical qualities. The comparison of chemical properties between Malaysia and Thailand rice can be shown in Table 1.

Table 1. The Chemical Characteristics of White Rice From Malaysia and Thailand

Chemical properties	Malaysia mix varieties	Thailand Khao Hom Mali Thai Variety
Amylose content	17.49± 0.078 a	17.54± 0.11 a
Moisture content	10.05 ± 0.06 a	10.02± 0.08 a
Crude Protein	8.33± 0.11 a	7.73± 0.10 b
Crude fat	0.20± 0.08 a	0.08± 0.01 a
Crude ash	0.43± 0.01 a	0.28± 0.01 b
Crude Fiber	0.0033± 0.01 b	0.0165± 0.02 a

3.1.1. Amylose Content

The amylose level in rice grain is a crucial characteristic for accurately predicting the eating quality of rice grain. Amylose concentration is a crucial determinant of rice cooking and processing characteristics [27]. Amylose represents the long chain and unbranched part of the rice starch. The amylose content of different rice types is depicted by the results of the work, which show no significant variance ($p > 0.05$). The amylose concentration of different types varied greatly, ranging from 17.49±0.078 percent to 17.54±0.11 percent. The lowest amylose content was found in Malaysian rice, whereas the greatest amylose content was found in Thai rice. The data were expressed as mean ± SD; each value is a mean of duplicate readings. Means followed by a different letter within the same row are significantly different ($p < 0.05$)

3.1.2. Moisture Content

Rice cooking quality and palatability are linked to moisture content, which substantially impacts shelf life. Typically, rice intended for long-term storage should have no more than 12% moisture content to prevent spoilage and maintain its palatability over time [28]. However, in this work, the measured moisture content of Malaysian and Thai rice samples was lower than the limit. Moisture content percentages ranged from 10.02±0.08% to 10.05±0.06% (Table 1). Thai rice is projected to have a lower moisture percentage (10.02%), while Malaysian rice will have a high moisture content (10.05 percent).

Compared to previous work regarding the rice grain, all had a moisture content that was practically within the permissible limit (12 percent) for long-term storage of rice [29]. This discrepancy suggests that the rice samples in this work have a lower moisture content than expected for optimal long-term storage. However, this lower moisture content could still be beneficial, as it may contribute to extended shelf life by reducing the risk of microbial growth and spoilage. The statistical analysis revealed no significant variance in moisture content between the rice samples ($p > 0.05$), indicating consistency across the two varieties.

Further investigation may be necessary to explore whether such lower moisture levels affect cooking quality or consumer preferences, particularly as lower moisture content can influence the texture and palatability of cooked rice. Nonetheless, the findings suggest that Malaysian and Thai rice in this work are well-suited for long-term storage, even though their moisture content is below the commonly referenced 12% limit.

3.1.3. Crude Protein Content

Rice's nutritional quality is influenced by its protein concentration [30]. Rice has a small proportion of protein since it has an adequate carbohydrate percentage [22]. The protein network also affects rice's structure and gelling properties during cooking [31]. The protein content of the samples in this work is higher than that of Ali et al. [32], who found that the protein content in rice samples was around 4%. This investigation showed a significant difference in protein content ($p<0.05$). The protein content of several rice cultivars ranged from 7.73±0.10 to 8.33±0.11 percent, as shown in Table 1. The crude protein for Malaysian mixed white rice samples is higher than for Thailand varieties (7.8%).

3.1.4. Crude Fat Content

The crude fat content of rice grains was a significant characteristic. Prior authors have investigated the impact of lipid content in rice grains on the rheological characteristics of rice flour [33]. The lipid can make a complex with amylose by creating crystalline amylose lipid complexes that can increase rice's texture during storage [34]. Gu et al. [35] investigated the impact of lipid content and components on the cooking quality of rice grains and discovered similar investigations conducted by other authors. There is no significant variance in crude fat content in the results of both samples ($p > 0.05$). Two rice cultivars had fat content ranging from 0.08±0.01 to 0.20±0.08 percent. This lack of variance suggests that, while lipid content plays a role in rice texture and quality, it may not be a distinguishing factor between these specific rice varieties, which could be attributed to similar growing conditions or milling processes that reduce the overall lipid content in both samples.

3.1.5. Ash Content

Ash content represents the minerals in rice and is a key indicator of its nutritional value. Previous work investigated that rice is a good source of P, K, Mg, Na, Fe, and Zn, which are important for human health [36]. The amount of mineral varies depending on several factors, including the seasonal conditions during cultivation and the geographic location of the rice plantation [37]. Not only is it a good source of minerals, but the ash content also represents the toxic minerals such as Pb, Cu, and As that can be absorbed from the environment by the rice [38]. One of the main factors affecting the amount of minerals in foods is the degree of milling, with more heavily milled rice typically showing lower ash content due to removing the bran layers where minerals are concentrated [39]. Table 1 showed a significant difference ($p<0.05$) in ash content. Two rice types had ash content ranging from 0.43±0.01 to 0.28±0.01 percent. Malaysian mixed rice varieties have 53% more than Thai rice. This variation could be attributed to differences in rice variety and plantation conditions. Al- Daej [36] also mentioned that the mineral content in rice is affected by the variety and the plantation area. The higher ash content in Malaysian rice suggests it may retain more nutrients, possibly due to less intensive milling or more mineral-rich soil in the growing regions.

3.1.6. Crude Fiber

Most milled rice contains endosperm, which consists of starch. The fiber in the paddy was mostly found in the bran part. Fiber is a non-digestible polysaccharide. Wang et al. [39] mentioned that the fiber content depends on the degree of milling. They also found that rice's fiber content varies between 0.7 to 1.64 %. All of the rice examined had fiber levels < 1.0 percent. According to Table 1, the two rice types have crude fiber content ranging from 0.0033±0.01% to 0.0165±0.02%. Thai rice has 5 times higher fiber content than Malaysian mixed rice varieties ($p<0.05$). Due to the nutritional purpose, there has been an attempt to increase the amount of dietary fiber in rice by increasing resistant starch using processing [40].

3.1.7. Carbohydrate Content

The central part of milled rice is carbohydrate. The carbohydrate is mostly made up of amylose and amylopectin [41]. Around 80% of the carbohydrates consist of amylopectin. White rice is considered a high amylose starch. In glutinous rice, the amylose content is very low, around 2%. The ratio of amylose and amylopectin will affect the starch properties [42]. The carbohydrate is counted as a difference based on the other chemical components of the white rice. There is a significant difference in carbohydrate content between both samples ($p<0.05$). The amount of ash in two rice cultivars ranged from 64.33±0.01 percent to 80.98±0.01 percent. Malaysian mixed rice varieties have 25.88% higher carbohydrate content than Thai starch.

3.2. Thermal Properties

The thermal properties of the rice flour from Malaysian mix varieties and Thailand Khao Hom Mali varieties can be shown in Fig. 1. It can be explained that the onset temperature, conclusion temperature, peak temperature, and gelatinization range are significantly different from both varieties. Specifically, the Malaysian mixed varieties show higher onset, peak, and conclusion temperatures than the Thailand Khao Hom Mali variety, while the Thai variety has a broader gelatinization range.

Gelatinization is a key thermal property that affects rice's cooking quality and suitability for various culinary uses. The onset temperature (the point where gelatinization begins), peak temperature (where gelatinization is most rapid), and conclusion temperature (where gelatinization completes) are crucial indicators of how rice behaves when cooked. In this work, the Malaysian mixed varieties had a higher onset temperature (72.4°C), peak temperature (78.6°C), and conclusion temperature (84.1°C), indicating that they require more heat to gelatinize compared to the Thailand Khao Hom Mali variety, which had lower corresponding temperatures (onset 69.8°C, peak 74.5°C, and conclusion 79.0°C). The gelatinization range, which is the difference between the onset and conclusion temperatures, was broader for the Thai variety (9.2°C) than for the Malaysian variety (7.7°C), suggesting that the Thai rice gelatinizes over a wider temperature range, potentially affecting its texture and versatility in different cooking methods.

The high temperature of the gelatinization process for the Malaysia mix variety might be due to the structure of the starch. The chemical properties data support this: The Malaysia mix varieties have higher amylose, and the higher protein content would lead to higher crystallinity of the starch [43]. Also, the chemical properties indicate a higher crude protein. The formation of the amylose-protein complex might also lead the Malaysian mix varieties to have a higher gelatinization temperature than the Thailand Khao Hom Mali variety [44].

In terms of culinary applications, these thermal properties play a significant role. With its lower gelatinization temperatures and broader gelatinization range, the Thai Khao Hom Mali variety may be better suited for dishes that require softer or stickier textures, such as steamed rice or rice-based desserts. Conversely, with their higher gelatinization temperatures, the Malaysian mixed varieties may be more appropriate for dishes requiring firmer, non-sticky grains, such as fried rice or rice dishes that benefit from a more distinct grain separation [45]. By understanding these thermal properties, consumers and industry professionals can better select rice varieties for specific culinary uses, ensuring optimal texture and quality in the final dish.

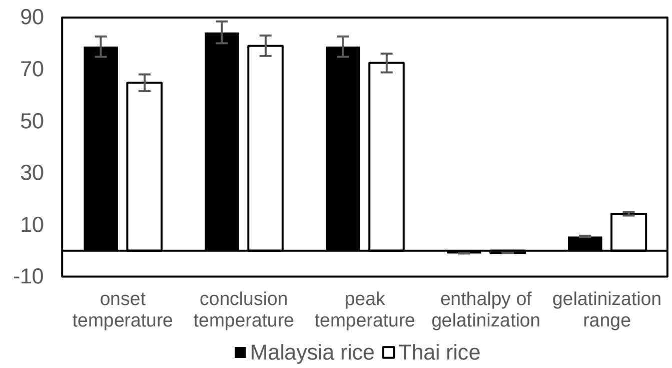

Figure 1. Comparison of Thermal Properties of Rice Between Mixed Varieties Malaysia and Thai

4. Conclusions

This work examined the chemical properties (amylose, moisture, crude protein, crude fat, crude ash, crude fiber, and carbohydrate) and thermal properties (onset temperature, conclusion temperature, peak temperature, enthalpy of gelatinization, gelatinization range) of rice from Malaysian mixed varieties and Thailand's Khao Hom Mali variety, revealing significant differences. The Malaysian rice had higher amylose (17.49%), moisture (10.05%), crude protein (8.33%), crude fat (0.20%), and ash (0.43%) content compared to the Thai variety, which showed a wider gelatinization range (14.29°C) and lower gelatinization temperatures. These chemical and thermal properties differences could influence consumer preferences, with Malaysian rice offering a firmer texture due to its higher amylose and protein. In contrast, Thai rice is softer and more aromatic. These findings can inform rice cultivation and processing practices in both countries. For example, breeders in Malaysia could focus on enhancing rice's amylose and protein content to meet consumer demand for firmer rice. At the same time, Thailand could optimize cultivation techniques to preserve the distinctive thermal properties of Khao Hom Mali, ensuring its soft texture and flavor. Additionally, rice processors could use this data to refine milling and storage processes to maintain desirable cooking traits, improving rice quality and marketability.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Rosnah Shamsudin and Jaturapatr Varith found the problem statement and developed the methodology.

Jhauharotul Muchlisyiyah analyzed the result and wrote and discussed the results.

Parichat Sathongpan performed the data collection.

Muhammad Hazwan Hamzah analyzed the result.

References

[1]. K. O. Falade and A. S. Christopher, "Physical, functional, pasting and thermal properties of flours and starches of six Nigerian rice cultivars," *Food Hydrocoll*, vol. 44, pp. 478–490, Feb. 2015, doi: https://doi.org/10.1016/J.FOODHYD.2014.10.005.

[2]. S. C. Omar and S. A. Tumin, "The Status of the Paddy and Rice Industry in Malaysia," 2010. [Online]. Available: https://www.researchgate.net/publication/351223058

[3]. S. C. Omar, N. S. Anis, and I. K. Y. Sze, "Paddy and Rice Statistics in East Malaysia," in *The Paddy and Rice Industry of Sabah and Sarawak,* Khazanah Research Institute, 2022, p. 20.

https://krinstitute.org/assets/contentMS/img/template/editor/EM%20Rice%20Report_website's%20copy_v5.pdf

[4]. N. N. Hawari and N. Z. Abidin, "Supply and demand of rice in Malaysia: A system dynamics approach," 2017. [Online]. Available: https://www.researchgate.net/publication/322447072

[5]. H. A. Rahman, M. H. M. Salleh, and N. M. Salim, "Effect of moisture content and microwave power on puffed yield and expansion volume of Malaysian paddy variety MR 297," *Malaysian Applied Biology*, vol. 48, no. 1, pp. 139-143, 2019. https://jms.mabjournal.com/index.php/mab/article/view/2304

[6]. D. Dorairaj and N. T. Govender, "Rice and paddy industry in Malaysia: governance and policies, research trends, technology adoption, and resilience," *Front Sustain Food Syst*, vol. 7, Jun. 2023, doi: https://doi.org/10.3389/fsufs.2023.1093605.

[7]. W. Zhang *et al.*, "Comparison of the structural and functional properties of starches in rice from main and ratoon crops," *J Cereal Sci*, vol. 99, p. 103233, May 2021, doi: https://doi.org/10.1016/J.JCS.2021.103233.

[8]. D. Zhu, C. Fang, Z. Qian, B. Guo, and Z. Huo, "Differences in starch structure, physicochemical properties, and texture characteristics in superior and inferior grains of rice varieties with different amylose contents," *Food Hydrocoll*, vol. 110, p. 106170, Jan. 2021, doi: https://doi.org/10.1016/J.FOODHYD.2020.106170.

[9]. N. Zainal and R. Shamsudin, "Physical Properties of Different Cultivar Local Glutinous rice (susu and siding) and Commercial Thai Cultivar," *Advances in Agricultural and Food Research Journal*, vol. .2, no. 1, Jan. 2021, doi: https://doi.org/10.36877/aafrj.a0000178.

[10]. P. Sathongpan, R. Shamsudin, J. Varith, and N. F. Abd Rahman, "Comparison of the physical properties between Malaysian and Thai Rice," *Advances in Agricultural and Food Research Journal*, vol.2, no. 1, Jan. 2021, doi: https://doi.org/10.36877/aafrj.a0000177.

[11]. K. Chinachanta, A. Shutsrirung, L. Herrmann, D. Lesueur, and W. Pathom-aree, "Enhancement of the Aroma Compound 2-Acetyl-1-pyrroline in Thai Jasmine Rice (Oryza sativa) by Rhizobacteria under Salt Stress," *Biology (Basel)*, vol. 10, no. 10, p. 1065, Oct. 2021, doi: https://doi.org/10.3390/biology10101065.

[12]. A. Vanavichit *et al.*, "Thai Hom Mali Rice: Origin and Breeding for Subsistence Rainfed Lowland Rice System," *Rice*, vol. 11, no. 1, p. 20, Dec. 2018, doi: https://doi.org/10.1186/s12284-018-0212-7.

[13]. S. Sansenya and K. Nanok, "α-glucosidase, α-amylase inhibitory potential and antioxidant activity of fragrant black rice (Thai coloured rice)," *Flavour Fragr J*, vol. 35, no. 4, pp. 376–386, Jul. 2020, doi: https://doi.org/10.1002/ffj.3572.

[14]. D. Oppong, W. Panpipat, and M. Chaijan, "Chemical, physical, and functional properties of Thai indigenous brown rice flours," *PLoS One*, vol. 16, no. 8, p. e0255694, Aug. 2021, doi: https://doi.org/10.1371/journal.pone.0255694.

[15]. S. Kongsri and C. Kukusamude, "A preliminary study on identification of Thai rice samples by INAA and statistical analysis," *J Phys Conf Ser*, vol. 901, p. 012047, Sep. 2017, doi: https://doi.org/10.1088/1742-6596/901/1/012047.

[16]. S. Bairagi, M. Demont, M. C. Custodio, and J. Ynion, "What drives consumer demand for rice fragrance? Evidence from South and Southeast Asia," *British Food Journal*, vol. 122, no. 11, pp. 3473–3498, Feb. 2020, doi: https://doi.org/10.1108/BFJ-01-2019-0025.

[17]. Y. Liu *et al.*, "Physicochemical and structural properties of pregelatinized starch prepared by improved extrusion cooking technology," *Carbohydr Polym*, vol. 175, pp. 265–272, 2017, doi: https://doi.org/10.1016/j.carbpol.2017.07.084.

[18]. F. Deng *et al.*, "Differences in starch structural and physicochemical properties and texture characteristics of cooked rice between the main crop and ratoon rice," *Food Hydrocoll*, vol. 116, p. 106643, Jul. 2021, doi: https://doi.org/10.1016/J.FOODHYD.2021.106643.

[19]. L. Pachuau, R. S. Dutta, P. K. Roy, P. Kalita, and H. Lalhlenmawia, "Physicochemical and disintegrant properties of glutinous rice starch of Mizoram, India," *Int J Biol Macromol*, vol. 95, pp. 1298–1304, Feb. 2017, doi: https://doi.org/10.1016/J.IJBIOMAC.2016.11.029.

[20]. J. Muchlisyiyah, R. Shamsudin, R. K. Basha, R. Shukri, S. How, and M. Rambli, "Kinetic Modelling During Soaking of Dried Long Grain Paddy MR297," *ASEAN Journal on Science and Technology for Development*, vol. 40, no. 2, Jan. 2024, doi: https://doi.org/10.61931/2224-9028.1537.

[21]. F. Vilaplana, J. Hasjim, and R. G. Gilbert, "Amylose content in starches: Toward optimal definition and validating experimental methods," *Carbohydr Polym*, vol. 88, no. 1, pp. 103–111, Mar. 2012, doi: https://doi.org/10.1016/J.CARBPOL.2011.11.072.

[22]. R. Thomas, W. A. Wan-Nadiah, and R. Bhat, "Physiochemical properties, proximate composition, and cooking qualities of locally grown and imported rice varieties marketed in Penang, Malaysia," *Int Food Res J*, vol. 20, no. 3, pp. 1345–1351, 2013.

[23]. G.W Latimer, Ed., "Official Methods of Analysis of AOAC International," 17th ed., Gaithersburg, MD: AOAC International, Jan. 2023, https://doi.org/10.1093/9780197610145.001.0001.

[24]. C. T. Rockembach, S. L. Mello El Halal, M. F. Mesko, L. C. Gutkoski, M. C. Elias, and M. de Oliveira, "Morphological and physicochemical properties of rice grains submitted to rapid parboiling by microwave irradiation," *LWT*, vol. 103, pp. 44–52, Apr. 2019, doi: https://doi.org/10.1016/j.lwt.2018.12.036.

[25]. S. Kumar and K. Prasad, "Effect of parboiling and puffing processes on the physicochemical, functional, optical, pasting, thermal, textural and structural properties of selected Indica rice," *Journal of Food Measurement and Characterization*, vol. 12, no. 3, pp. 1707–1722, Sep. 2018, doi: https://doi.org/10.1007/s11694-018-9786-4.

[26]. N. Singh, J. Singh, L. Kaur, N. S. Sodhi, and B. S. Gill, "Morphological, thermal and rheological properties of starches from different botanical sources," *Food Chem*, vol. 81, no. 2, pp. 219–231, May 2003, doi: https://doi.org/10.1016/S0308-8146(02)00416-8.

[27]. K. Tao, C. Li, W. Yu, R. G. Gilbert, and E. Li, "How amylose molecular fine structure of rice starch affects functional properties," *Carbohydr Polym*, vol. 204, pp. 24–31, Jan. 2019, doi: https://doi.org/10.1016/J.CARBPOL.2018.09.078.

[28]. H. M. I. U. Herath, J. A. Weliwita, S. M. V. P. D. Senanayake, and S. Witharana, “Effect of moisture content on cooking time of rice,” *2016 Manufacturing and Industrial Engineering Symposium: Innovative Applications for Industry, MIES 2016*, no. October, 2016, doi: https://doi.org/10.1109/MIES.2016.7780257.

[29]. A. N. Husain, “Quality parameters for Malaysian rice varieties,” *MARDI Res. Bull.*, vol. 12, no. 3, pp. 320–332, 1984. http://jtafs.mardi.gov.my/jtafs/12-3/QUALITY.pdf

[30]. R. Sompong, S. Siebenhandl-Ehn, G. Linsberger-Martin, and E. Berghofer, "Physicochemical and antioxidative properties of red and black rice varieties from Thailand, China, and Sri Lanka," *Food Chem*, vol. 124, no. 1, pp. 132–140, 2011, doi: https://doi.org/10.1016/j.foodchem.2010.05.115.

[31]. A. Barbiroli, F. Bonomi, M. C. Casiraghi, S. Iametti, M. A. Pagani, and A. Marti, “Process conditions affect starch structure and its interactions with proteins in rice pasta,” *Carbohydr Polym*, vol. 92, no. 2, pp. 1865–1872, Feb. 2013, doi: https://doi.org/10.1016/J.CARBPOL.2012.11.047.

[32]. A. Ali, T. A. Wani, I. A. Wani, and F. A. Masoodi, “Comparative study of the physico-chemical properties of rice and corn starches grown in Indian temperate climate,” *Journal of the Saudi Society of Agricultural Sciences*, vol. 15, no. 1, pp. 75–82, Jan. 2016, doi: https://doi.org/10.1016/J.JSSAS.2014.04.002.

[33]. F. J. Dautant, K. Simancas, A. J. Sandoval, and A. J. Müller, "Effect of temperature, moisture, and lipid content on the rheological properties of rice flour," *J Food Eng*, vol. 78, no. 4, pp. 1159–1166, Feb. 2007, doi: https://doi.org/10.1016/J.JFOODENG.2005.12.028.

[34]. Z. Zhou, K. Robards, S. Helliwell, and C. Blanchard, “Ageing of Stored Rice: Changes in Chemical and Physical Attributes,” *J Cereal Sci*, vol. 35, no. 1, pp. 65–78, Jan. 2002, doi: https://doi.org/10.1006/JCRS.2001.0418.

[35]. D. D. Gu *et al.*, “Effect of Lipid Content and Components on Cooking Quality and Their Responses to Nitrogen in Milled Japonica Rice,” *Acta Agronomica Sinica*, vol. 37, no. 11, pp. 2001–2010, Nov. 2011, doi: https://doi.org/10.1016/S1875-2780(11)60053-9.

[36]. M. I. Al-Daej, “Genetic studies for grain quality traits and correlation analysis of mineral element contents on Al-Ahsa rice and some different varieties (Oryza Sativa L.),” *Saudi J Biol Sci*, vol. 29, no. 3, pp. 1893–1899, Mar. 2022, doi: https://doi.org/10.1016/J.SJBS.2021.10.032.

[37]. S. Karunarathna, S. Somasiri, and R. Mahanama, “Seasonal variation on mineral profile in rice varieties of Sri Lanka,” *Journal of Food Composition and Analysis*, vol. 108, p. 104447, May 2022, doi: https://doi.org/10.1016/J.JFCA.2022.104447.

[38]. V. F. de Oliveira *et al.*, “Assessing mineral and toxic elements content in rice grains grown in southern Brazil,” *Journal of Food Composition and Analysis*, vol. 100, p. 103914, Jul. 2021, doi: https://doi.org/10.1016/J.JFCA.2021.103914.

[39]. Z. Wang *et al.*, “Effect of the degree of milling on the physicochemical properties, pasting properties and in vitro digestibility of Simiao rice,” *Grain & Oil Science and Technology*, vol. 4, no. 2, pp. 45–53, Jun. 2021, doi: https://doi.org/10.1016/J.GAOST.2021.04.002.

[40]. D. Yi, W. Maike, S. Yi, S. Xiaoli, W. Dianxing, and S. Wenjian, “Physiochemical Properties of Resistant Starch and Its Enhancement Approaches in Rice,” Rice Science, vol. 28, no. 1, pp. 31–42, Jan. 2021, doi: https://doi.org/10.1016/j.rsci.2020.11.005

[41]. H. Odi and V. R. Sinija, “Comparative Study on Functional Properties of Starch Extracted from Various Sources,” International Journal of Current Microbiology and Applied Sciences, vol. 10, no. 01, pp. 3612–3619, Jan. 2021, doi: https://doi.org/10.20546/ijcmas.2021.1001.426.

[42]. [42] B. Karakelle, N. Kian-Pour, O. S. Toker, and I. Palabiyik, “Effect of process conditions and amylose/amylopectin ratio on the pasting behavior of maize starch: A modeling approach,” Journal of Cereal Science, vol. 94, p. 102998, Jul. 2020, doi: https://doi.org/10.1016/j.jcs.2020.102998

[43]. Y. Zhao, X. Dai, E. Mackon, Y. Ma, and P. Liu, “Impacts of Protein from High-Protein Rice on Gelatinization and Retrogradation Properties in High- and Low-Amylose Reconstituted Rice Flour,” Agronomy, vol. 12, no. 6, p. 1431, Jun. 2022, doi: https://doi.org/10.3390/agronomy12061431.

[44]. Z. Wang *et al.*, “Effect of the degree of milling on the physicochemical properties, pasting properties and in vitro digestibility of Simiao rice,” *Grain & Oil Science and Technology*, vol. 4, no. 2, pp. 45–53, Jun. 2021, doi: https://doi.org/10.1016/J.GAOST.2021.04.002.

[45]. J. Muchlisyiyah, R. Shamsudin, R. Kadir Basha, R. Shukri, and S. How, “Correlation Among Physical Properties of Parboiled Milled Rice During Hydrothermal Pretreatment Processing,” *Pertanika J Trop Agric Sci*, vol. 47, no. 2, pp. 421–438, Apr. 2024, doi: https://doi.org/10.47836/pjtas.47.2.07.