Pertanika J. Trop. Agric. Sci. 49 (S3): 95 - 107 (2026)

PERTANIKA JOURNALS

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Comparison of Steamed and Non-Steamed Parboiled Rice Dried at Different Superheated Steam Drying Temperatures

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ABSTRACT

Parboiled rice is produced by soaking, steaming and drying the rice grain. This process can enhance the dietary advantages of rice due to changes in the structure of starch and retention of nutrients. However, the conventional parboiling procedure is challenging and time-consuming, as it involves multiple steps, including soaking and steaming, thereby increasing processing time and energy consumption. Hence, there is a need to explore alternative processing technologies that could reduce or eliminate the steaming stage, thereby simplifying the process while maintaining rice quality. In this study, rice soaked, steamed and dried by superheated steam drying (SSD) at different temperatures was compared with rice dried at the same temperatures without the steaming step. The samples were measured for the amylose content, head rice yield, starch crystallinity and antioxidant properties. Samples of rice that were steamed before SSD drying demonstrated better starch structure, thermal behaviour, and milling quality than samples that were dried without steaming. Among the treatments, the rice sample dried at 100°C showed desirable characteristics such as lower amylose concentration, higher head rice yield and moderate crystallinity. Overall, SSD effectively modifies rice starch structure while preserving good milling quality and antioxidant properties, with steamed samples having better overall quality than those treated without steaming.

Keywords: Amylose content, antioxidant activity, head rice yield, parboiled rice, starch crystallinity, superheated steam drying

ARTICLE INFO

Article history:
Received: 26 May 2026
Accepted: 25 September 2026
Published: 20 November 2026

DOI: https://doi.org/10.47836/pjtas.49.S3.05

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INTRODUCTION

Rice is a major source of carbohydrates for the world's population, especially in Asian

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countries where rice consumption is highest. There are wide varieties of rice with different processing techniques such as white rice, brown rice, glutinous rice, and parboiled rice (Bana et al., 2020), with white rice being the most consumed. Due to growing health awareness among consumers, the demand for healthier rice varieties such as parboiled rice is increasing.

Parboiled rice is rich in nutrients and has a delayed digestion rate, which makes it a better option for consumer (Li et al., 2021). The soaking and steaming process transfers nutrients from the bran to the endosperm, hence retaining nutrients (Taleon et al., 2022). Usually, parboiling treatment is carried out as a sequential process of soaking, steam treatment and drying before milling. Soaking allows water uptake, steaming gelatinises starch and plugs fissures, and drying restores hardness, enhancing grain structure and stability in storage. However, traditional methods frequently do these processes independently, which are time and energy-consuming and lead to variable rice quality (Muchlisyiyah et al., 2023; Yousaf et al., 2017).

Superheated steam drying (SSD) is a technique that is more efficient alternative, combining steaming and drying into a single operation (Muchlisyiyah et al., 2023). Indeed, SSD is a process of soaking raw paddy for uniform moisture, followed by steam and then drying at an optimum temperature. It provides uniform heat in a short time and saves energy (Jittanit & Angkaew, 2021). Steam acts like other hot gases and can efficiently dry high-moisture paddy by releasing sensible and latent heat (Muchlisyiyah et al., 2023). This technique leads to a development of the target product quality with a reduction in processing time (Fang et al., 2023). SSD also controls oxidation of food by preventing lipid oxidation and formation of hazardous chemicals using a low-oxygen atmosphere, keeping flavour, and extending shelf life (Fang et al., 2023; Yodkaew et al., 2017).

Although SSD has several advantages, the effects of SSD temperature on parboiled rice quality have not been well studied. Conventional parboiling is inefficient, with distinct soaking, steaming, and drying procedures that need significant energy and long processing periods. High-temperature soaking and steaming can induce unwanted colour changes and reduced consumer approval (Muchlisyiyah et al., 2023; Yousaf et al., 2017). The drying process is typically the most time-consuming, and solar drying might take as long as five days depending on the weather (Chen et al., 2025). Soybean drying using SSD showed a faster and more reliable alternative drying method. Compared with hot air drying, SSD can save energy consumption and enhance heating efficiency (Prachayawarakorn et al., 2006).

Consequently, this study aim to assess how different SSD conditions influence parboiled rice quality, focusing on temperature effects and a comparison of steam- and non-steamed samples. The study seeks to optimize SSD processing parameters based on rice quality attributes, including starch gelatinisation, water reduction, and textural properties of cooked parboiled rice.

MATERIALS AND METHODS

Sample Collection

MR 315 paddy was collected from a local field in Kodiang, Kedah, Malaysia, on 10 February 2025. The grains were vacuum-packed and stored in a chiller at 10 °C until further use.

Parboiled Rice Preparation

Paddy samples were weighed (200 g) and added to 700 mL of water in a beaker. The beaker was then placed in a water bath set at 70 °C for 3 hours. For the steamed rice sample, the rice sample was steamed for 15 minutes after being soaked (Onmankhong et al., 2021). In addition, a non-steamed sample was also prepared under the same soaking conditions to serve as a comparison without steaming.

Superheated Steam Drying Process

After being soaked, the paddy samples were spread evenly on baking paper, placed on a stainless-steel tray and loaded into the dryer (Sharp Healsio Superheated Steam Oven-AX1600VMR). The soaked samples were dried using superheated steam at 100 °C, 120 °C, and 140 °C until 12% moisture content was achieved. This was done to observe the overall quality attributes of paddy rice under different temperature conditions.

Dehusking Process

The dehusking process was done by removing the outer husk of the paddy using an Electrical Vertical Rice Husking Machine (JLGJ-45), allowing for subsequent quality analysis.

Determination of Head Rice Yield

Head rice yield (HRY) is the mass percentage of rough rice remaining as head rice, which is an indicator of rice quality. A 20 g sample of rice kernel was sieved to separate the broken rice kernels from full-length rice kernels. All rice samples were carried out in triplicate. The full-length rice kernels were weighed and calculated with the following Equation 1 (Meresa et al., 2020)

$$Head\ Rice\ Yield\ (\%) = \frac{Weight\ of\ head\ rice\ (g)}{Weight\ of\ total\ rice\ sample\ (g)} \times 100 \qquad [1]$$

Amylose Content (%)

The iodine colorimetric method was used to determine the amylose content of the rice samples. About 100 mg of finely ground rice flour was mixed with ethanol and an alkaline solution, heated to gelatinise the starch, and then reacted with a standard iodine- potassium iodide solution to form the distinctive amylose- iodine complex. The resulting blue colour was measured spectrophotometrically at 620 nm using a UV-Vis spectrophotometer (Lambda 365+, PerkinElmer, USA) and compared to a calibration curve made from certified amylose concentrations (Martins et al., 2021).

Crystalline Structure Analysis

An XRD (PANalytical, X'Pert3 Powder, Netherlands) operating at 40 mA and 40 kV was used to get the X-ray patterns of parboiled rice. At room temperature (25 °C), the diffraction angle (2θ) ranged from 5°θ to 65°θ at a rate of 0.05°θ/min. The sample holder was firmly filled with the rice powder. The Savitzky-Golay method was used to smooth the diffractogram curves. The diffractogram was convoluted using the Gaussian response function to expose the amorphous region (Almeida et al., 2019).

Cooked Parboiled Rice Preparation

The optimal drying temperature of the selected dryer was determined by cooking in an electric rice cooker (Milux, model MRC-510SE, Malaysia) at a rice-to-water ratio of 1:3, by volume. After cooking, the parboiled rice is collected by removing the strainer and cooled until it reaches room temperature (approximately 25 °C). The cooked rice was freeze-dried using a freeze dryer (Memmert, Model UF110) for 24 hours before further analysis.

Rice Samples Extraction

Prior to analysis, 10 mL of distilled water and 1 g of rice powder were combined, and the mixture was left for five minutes. The combination was centrifuged for 15 minutes at 5000 rpm, and the supernatant was collected for further analysis of total phenolic content (TPC) and antioxidant analysis (Priyanthi & Sivakanesan, 2021). The total phenolic content (TPC) and antioxidant activity (DPPH) of the selected rice samples, both 100 °C steam-treated and non-steam-treated, and commercial parboiled rice were evaluated. Based on the evaluation of physicochemical and structural characteristics of samples, treatment at 100 °C was selected for further comparison.

Total Phenolic Content Determination

The total phenolic content was assessed using the Folin-Ciocalteu technique. Initially, 1000 ppm gallic acid stock solution was prepared by dissolving 100 mg in 100 mL of distilled

water, and standard solutions (0, 20, 40, 60, 80, 100, 150, and 200 ppm) were prepared by dilution. For the standard curve, 1 mL of each solution was combined with 5 mL of Folin-Ciocalteu reagent, vortexed, allowed to stand for 3 to 5 minutes, followed by the addition of 4 mL of 7.5% (w/v) Na_2CO_3, and incubated at room temperature (25 °C) for 2 hours prior to measuring absorbance at 765 nm. A reagent blank was prepared using 1 mL of distilled water, 5 mL of Folin-Ciocalteu reagent, and 4 mL of Na_2CO_3. Samples were analysed in triplicate to ensure validation of the experiment.

Antioxidant Activity Determination

A newly prepared DPPH working solution (2850 µL) was mixed with 150 µL of sample and allowed to react in the dark cabinet for 30 minutes. The absorbance of the mixture was measured at 515 nm using a ultraviolet-visible (UV-Vis) spectrophotometer (LAMBDA 365+, PerkinElmer, USA). Methanol served as a blank, whereas the control sample consisted only of methanol with a diluted DPPH stock solution (Abd. Razak et al., 2021). The following Equation 2 was used to determine the proportion of scavenging activity.

$$DPPH\ Radical\ Scavenging\ Activity(\%) = \frac{A\ blank - A\ sample}{A\ blank} \times 100 \quad [2]$$

Statistical Analysis

The data from each treatment group were subjected to two-way Analysis of Variance (ANOVA) to assess the impact of SSD temperature and duration on the evaluated quality parameters. Upon identifying significant differences using ANOVA, Tukey's Honestly Significant Difference (HSD) test was utilised to compare the treatment means. All results were presented as mean ± standard deviation, and differences were considered significant at $p<0.05$ (Tao et al., 2020) using Microsoft Excel and GraphPad Prism.

RESULTS AND DISCUSSION

Head Rice Yield of Parboiled Rice

The present study evaluated the quality of parboiled rice samples dried using superheated steam drying (SSD) at different drying temperatures, and head rice yield (HRY) is a key indicator to assess the overall quality of rice grains. Table 1 shows that the steamed sample at 100 °C produced a high HRY (90.61%) compared to the non-steamed sample (77.26%). This could be due to the starches being gelatinised to minimise fissuring and reduce the susceptibility to milling breakage in the parboiled end-product (Wang et al., 2018). The data suggest that fissures formed during soaking were not sealed due to incomplete

Table 1
Percentage of head rice yield for steam and non-steam parboiled rice

	100 °C	120 °C	140 °C
Steam	90.61 ± 3.3^{Aa}	91.86 ± 2.4^{Aa}	87.21 ± 0.7^{Aa}
Non-steam	77.26 ± 0.3^{Ba}	66.76 ± 1.3^{Bb}	73.66 ± 1.0^{Ba}

Note. $^{A, B}$ Within a column means that values without a common superscript differ ($P<0.05$)
^{a,b} Within a row means that values without a common superscript differ ($P<0.05$)

gelatinisation while steaming (Buggenhout et al., 2014), highlighting a significant difference ($p<0.05$) between the two processing procedures. There was no significant difference ($p >0.05$) across temperatures in the same treatment, indicating that the processing method did not influence the HRY more than temperature. For the non-steam treatment, HRY was significantly decreased at 120 °C (66.76%) as compared to 100 °C (77.26%) and 140 °C (73.66%) ($p < 0.05$). This reduction could be attributed to the increased susceptibility of the rice kernels to fissure and breakage under the 120 °C drying condition. However, the HRY at 140 °C increased to 73.66%, and no significant difference was observed from 100 °C ($p > 0.05$). In contrast, the steamed samples showed no significant difference in HRY across the three drying temperatures ($p > 0.05$), indicating that the steaming treatment may have reduced the susceptibility of the kernels to temperature-related milling damage.

Amylose Content Percentage

Table 2 shows that the highest percentage of amylose content was obtained at 100 °C for the drying of the non-steamed rice sample (59.84%), whereas the steamed rice sample dried at 100 °C exhibited the lowest amylose content (46.80%). The unexpectedly lower amylose value in the steam-treated rice might be due to the combined effects of heat and moisture (Gong et al., 2024) that disrupted starch crystallinity (Yang et al., 2019), allowing amylose to leach out from the granules and redistribute throughout the endosperm matrix (Huang et al., 2012). Consequently, less amylose remained available within the rice granules obtained from the analysis. Thus, steamed-rice samples with lower amylose content have softer grains, which leads to fewer fissures during milling and thus higher head rice yield (Kalpanadevi et al., 2019). However, the non-steam treatment created less moisture penetration, retained more amylose inside the granule matrix, resulting in greater identified amylose content during analysis (Park et al., 2017). This study also observed that the relationship of amylose content was negatively correlated with head rice yield. The amylose content of the steamed samples numerically increased to 59.43% and 58.81% at 120°C and 140°C, respectively. The non-steamed samples decreased to 47.25% and 48.49%, respectively. However, these changes across temperature levels were not statistically significant within the respective treatments ($p > 0.05$). In contrast, significant

differences were observed between the steam and non-steam treatments at both 120 °C and 140 °C ($p < 0.05$). Therefore, within the range studied, the treatment condition had a greater effect on the measured amylose content than did drying temperature. The lack of a significant effect of temperature may be due to the small changes in amylose leaching within the temperature range studied, as partial gelatinisation may not have shown distinct differences at the different temperatures (Chumsri et al., 2022). The results therefore suggest that the effect of moisture availability and changes in the structure of the starch induced by steaming were more influential on amylose leaching than the drying temperature itself.

Table 2
Amylose content (%) for rice samples at temperatures 100 °C, 120 °C, and 140 °C

	100 °C	**120 °C**	**140 °C**
Steam	46.80 ± 8.7^{Aa}	59.43 ± 2.0^{Aa}	58.81 ± 0.8^{Aa}
Non-steam	59.84 ± 5.6^{Aa}	47.25 ± 1.0^{Ba}	48.49 ± 0.9^{Ba}

Note. $^{A, B}$ Within a column means that values without a common superscript differ ($P<0.05$)
^{a,b} Within a row means that values without a common superscript differ ($P<0.05$)

Comparison of Optimum SST Temperature and Commercial Parboiled Rice

The rice sample treated with steam at 100 °C was chosen as the rice sample that obtained the optimum temperature for further comparison because the treatment displayed the lowest amylose content, which is beneficial for producing a lower glycaemic index. This sample had a higher head rice yield (90.61%) and lower amylose content (46.80%) than the non-steam sample at 100 °C. The XRD analysis showed that the crystallinity index of the steam-treated sample was 54.25% compared to 72.00% and 19.90% of the non-steam sample and commercial parboiled rice, respectively, as presented in Table 3. The decrease in crystallinity index of the steam-treated sample as compared to the non-steam sample indicated that the combined effect of heat and moisture during steaming disturbed the ordered structure of starch.

The XRD results should be interpreted separately from the DSC results, as the two techniques give different information on starch structure. XRD measures the relative crystalline order of starch. DSC measures the thermal energy associated with the disruption of thermally detectable ordered structures during gelatinisation. Thus, the gelatinisation enthalpy (ΔH) should not be used as a direct measure of the crystallinity index obtained from XRD. The ΔH of the steam-treated sample in this study was 254.4

Table 3
Crystallinity index (%) for steam and non-steam rice samples at 100 °C and commercial parboiled rice

	100 °C
Steam	54.25%
Non-steam	72.00%
Commercial Parboiled Rice	19.90%

J/g, and the non-steam sample was 110.5 J/g, much lower. Commercial parboiled rice had the highest ΔH (263.2 J/g) and the lowest XRD crystallinity index (19.90%). The results showed that the trend of XRD crystallinity index and DSC gelatinisation enthalpy was not the same in the samples. Thus, the two analyses provide complementary information for understanding the structural and thermal characteristics of parboiled rice.

X-ray Diffraction (XRD) is a conventional method employed to characterise changes in the crystallinity of starch. This investigation identified specific diffraction peaks at around 15°, 17°, 18°, and 23° (2θ), signifying a characteristic A-type crystalline structure often associated with rice starch (Zhang & Zhang, 2019). The crystallinity index of rice was 54.25% after steam treatment, whereas the sample without steam treatment had a higher index of 72.00%. The lower crystallinity index of the steam-treated sample could be due to the synergistic effect of heat and moisture that can break the ordered regions of starch during processing (Guo et al., 2023). In contrast, the non-steam sample has a higher crystallinity index and a better retention of detectable crystalline order. Commercial parboiled rice showed the lowest crystallinity index (19.90%), indicating that the crystalline structure of starch was significantly affected by the industrial parboiling process (Cheng et al., 2019). These extreme conditions caused extensive starch gelatinisation, which disrupted more A-type crystalline regions and resulted in a reduced crystallinity index (Kwofie & Ngadi, 2017).

Characteristics of Parboiled Rice

Rice starch's thermal characteristics were evaluated using DSC, measuring the onset temperature (T_o), peak temperature (T_P), and gelatinisation enthalpy (ΔH), as shown in Figure 1, which provide information about starch crystallinity, molecular order, and thermal stability. The corresponding thermal parameters are presented in Table 4. The T_o values of the steam, non-steam and commercial parboiled rice samples were similar and ranged from 31.00 °C to 31.51 °C. The T_P values were similarly in the range of 39.57-41.47 °C. The transition temperatures are relatively close, indicating the samples had similar thermal transition ranges under the conditions of the DSC analysis.

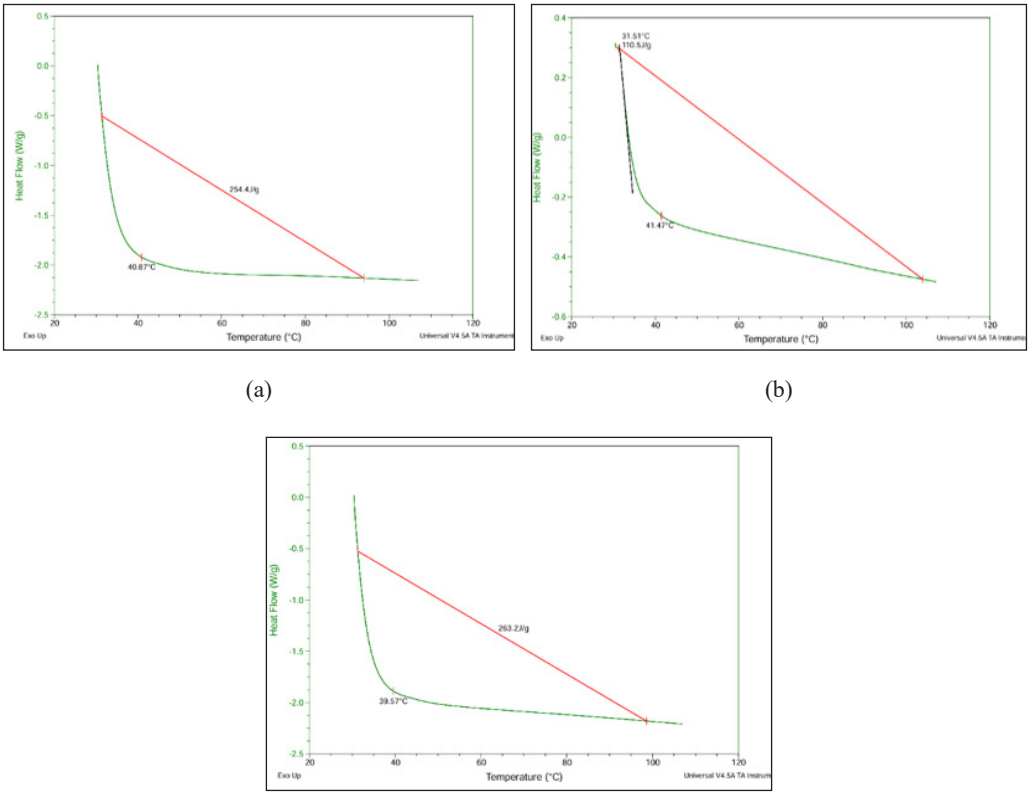
However, gelatinisation enthalpy (ΔH) varied considerably between samples. The ΔH of the steam-treated sample at 100 °C was determined to be 254.4 J/g, while that of the non-steam sample was significantly lower at 110.5 J/g. The commercial parboiled rice had the highest ΔH at 263.2 J/g. The ΔH

Table 4
Onset Temperature (T_O), Peak Temperature (T_P), and Gelatinisation enthalpy (ΔH) of steam and non-steam rice samples at 100 °C and commercial parboiled rice

	Steam	**Non-steam**	**Control**
	100 °C	**100 °C**	**Commercial Parboiled Rice**
T_o	31.00 °C	31.51 °C	31.00 °C
T_P	40.87 °C	41.47 °C	39.57 °C
ΔH	254.4	110.5	263.2

values did not follow the same trend as the crystallinity index calculated from the XRD. The non-steam sample had the highest XRD crystallinity index (72.00%) but the lowest ΔH (110.5 J/g). Commercial parboiled rice had the lowest XRD crystallinity index (19.90%) but the highest ΔH (263.2 J/g).

The present results thus indicate that XRD crystallinity index and DSC gelatinisation enthalpy should not be considered as equivalent measures of starch crystallinity. XRD provides information on the relative crystalline order that is detectable by X-ray diffraction, whereas DSC measures the thermal energy associated with the disruption of thermally detectable starch structures during gelatinisation. The observed differences between the two techniques may be indicative of differences in the structural organization and thermal behaviour of starch after the different processing treatments. The XRD and DSC results thus complement each other to describe the structural and thermal characteristics of the rice samples.



(a) (b)

(c)

Figure 1. Thermogram showing the Onset Temperature (T_o), Peak Temperature (T_P), and Gelatinisation Enthalpy (ΔH): (a) Steam sample at 100°C (b) Non-steam sample at 100°C (c) Commercial parboiled rice

Total Phenolic Content (TPC) and Antioxidant Activity of Parboiled Rice

In this study, rice samples were used for TPC and antioxidant activities to represent rice as commonly consumed. The evaluation of bioactive compounds in cooked rice is important since cooking can change the structure of starch and impact the nutritional quality.

The total phenolic content (TPC) of the selected 100 °C steam-treated and non-steam-treated rice samples and commercial parboiled rice is presented in Figure 2. No significant difference in TPC was observed among the evaluated samples ($p > 0.05$). The results indicate that the steam treatment at 100 °C did not significantly affect the TPC compared with the non-steam treatment at the same drying temperature. The sample treated with superheated steam at 100 °C showed a relatively high phenolic content, similar to the commercial parboiled rice, indicating that steam treatment could enhance the release or preservation of phenolic chemicals in the rice matrix. The presence of moisture during steam treatment increases hydrolytic reactions, leading to the weakening of phenolic-cell wall connections (Gupta & De, 2017; Wu et al., 2018). There was also no significant difference between the steam and non-steam treatments at 100 °C, indicating that this temperature was sufficient to disturb the rice matrix and release bound phenolics but not high enough to cause major breakdown.

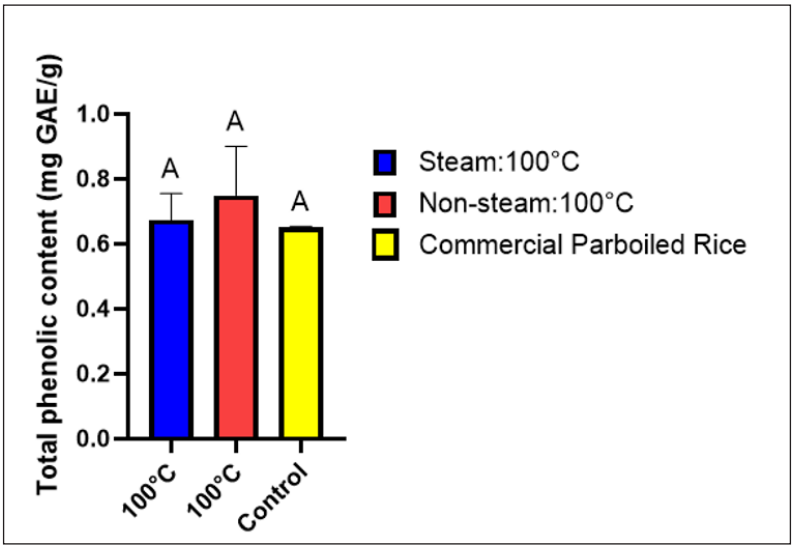


Figure 2. Total phenolic content and antioxidant activity of steam and non-steam rice samples at 100 °C and commercial parboiled rice

In fact, total phenolic content was generally associated with antioxidant activity. No significant difference in antioxidant activity was observed between the steam-treated and non-steam-treated samples at 100 °C ($p > 0.05$). This result was consistent with the TPC

findings, where no significant difference was observed between the two treatments. The relatively similar antioxidant activity may indicate that the 100 °C steam treatment did not significantly alter the antioxidant compounds detectable by the DPPH assay. Phenolic compounds can contribute to antioxidant activity through their ability to scavenge free radicals (Mathew et al., 2015). However, DPPH activity represents the overall radical-scavenging capacity of the extract and may not necessarily correspond directly to the measured TPC.

CONCLUSION

The results concluded that SSD at 100 °C was successful in maintaining rice quality with HRY (90.61%) and starch characteristics (amylose content, 46.80%; crystallinity, 54.25%; gelatinisation enthalpy, $\Delta H = 254.4$ J/g). The bioactive substances, such as TPC (0.67 mg GAE/g) and antioxidant activity (75.7%), had minimal nutritional degradation.

Results also demonstrated a positive correlation between gentle SSD treatment (100 °C) and the preservation of kernel structure, starch crystallinity, and antioxidant activity. At the higher drying temperature of 120 °C, the HRY and amylose content were still relatively high, indicating that the SSD process kept these quality characteristics within the investigated temperature range. The present findings contribute to the current knowledge of superheated steam processing of parboiled rice and provide a basis for further optimisation of SSD conditions to achieve desirable nutritional and textural properties.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support from the Ministry of Higher Education (MOHE), Malaysia, through the Fundamental Research Grant Scheme (FRGS) under Grant No. FRGS/1/2024/STG04/UNIMAP/03/2. The authors also thank Universiti Malaysia Perlis (UniMAP) for providing research facilities and support.

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