ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2026, 11 (3): 15-27 doi: 10.28978/nesciences.263002

Influence of Parboiling on Physicochemical and Morphological Characteristics of Indigenous Iraqi Rice (Oryza sativa L.) Varieties

Mustafa Falah Jaafar Witwit[1*], Muna N. Khalaf[2], Ali Joodi Shuna Alfatlawi[3]

[1]Department of Food Health and Nutrition, College of Food Sciences, Al-Qasim Green University, Babylon, Iraq. E-mail: mustafajaafar@fosci.uoqasim.edu.iq

[2]Department of Food Health and Nutrition, College of Food Sciences, Al-Qasim Green University, Babylon, Iraq. E-mail: munanajmkhalaf@fosci.uoqasim.edu.iq

[3]Department of Food Sciences - College of Agriculture - University of Kufa, Iraq. E-mail: alij.alfatlawi@uokufa.edu.iq

Abstract

The present study aimed to evaluate the effect of parboiling on the nutritional value of three Iraqi rice varieties grown in Iraq: Iraqi Amber 300, Iraq 179, and Iraq Basmati 201.The results indicated that the parboiling process does not affect grain length, but significantly influences grain width and elongation capacity. The width of brown rice grains was recorded at 3.18, 2.06, and 2.05 mm, respectively. It was found that processing techniques and rice variety play a crucial role in altering the chemical composition. Furthermore, the gelatinization capacity and water retention increased depending on the preparation method. The data showed that the crude protein content decreased slightly during parboiling. Conversely, the results revealed that parboiling increases the ash content, reaching 0.86% in Iraq Basmati 201, while carbohydrate percentages ranged between 90.14% and 91.40%.The findings also indicated that the level of phenolic compounds in white rice samples was significantly higher than in parboiled rice. Regarding antioxidant activity, the DPPH free radical scavenging activity was comparable in both parboiled and white rice; the highest scavenging activity was recorded at 37.10% and 33.20% in white Iraq Basmati and white Iraqi Amber 300, respectively. Finally, the results demonstrated that parboiled rice achieved high overall acceptability in sensory evaluation indices. These findings highlight the characteristics of new Iraqi Amber rice varieties and the impact of parboiling on their properties.

Keywords:
Iraqi rice, Iraqi Ambar, parboiling, physical, morphological, and chemical properties

Available Online: 01/09/2026

Introduction

The second significant grain crop of Iraq is rice. Rice is an unexplainable aspect of the entire sustainable food and an important component of the nutritional foundation of the globe which supplies the globe with nearly 4.5 million tons annually in 2020 season produced on about 1.074 million fedds annually (FAOSTAT, 2020). Thus, this implies the need to determine whether minimalism or maximalism is more efficient to convey a message:(Bashir and Aggarwal 2019 and Bandumula et al., 2018). This is probably because rice requires much more water to grow compared to other crops, and thus, much research was

Corresponding Author: Mustafa Falah jaafar Witwit, E-mail: mustafajaafar@fosci.uoqasim.edu.iq

conducted on the creation of drought-resistant types of rice (Fukagawa and Ziska, 2019). In addition to its usefulness as a food crop in the agricultural sector, rice contains lots of protein, fat, carbohydrates, minerals, vitamins and dietary fiber which are consumed by the people of the world in a wide variety of ways: in bread, noodles, parboiled grains, etc. Huang et al. (2016) also found in one study that the benefits of rice are not simply due to its macronutrient content because the grain contains bioactive, non-nutrient compounds, containment of which includes phenolic antioxidants. Avoiding platelet aggregation is one of the ways in which these chemicals were linked to a reduced risk of some disorders (Ghasemzadeh et al., 2018; Ma et al., 2022). Rice undergoes a number of processes which are undertaken after it is harvested to ensure that it is fit to be eaten. These include dry cleaning, milling, and packaging. In the course of the first milling, the paddy rice is deprived of its husk to get brown rice. This is to keep the brown color and the outer covering of the rice which bran has. To make white or polished rice, the second process entails the elimination of the layer of bran that encompasses pericarp, aleurone subaleurone layer and the germ (nutrient-rich and bioactive phytochemicals). —(Kaur et al., 2016; Saleh et al., 2019). The nutritional content, milling yield, appearance of the grain, cooking quality and sensory quality as well as head rice recovery rate are some of the factors that determine the market value of rice. This is what defines the quality of rice and the demand of rice among the different consumers. This is proved by the fact that some employers, including Prom-u-thai and Reraise (2020), hire the same people, but use different names. Postharvest activities have significantly added value to the uncooked rice in terms of physicochemical and nutritional characteristics which undergoes parboiling prior to dehulling and refining per Zohoun et al. (2018). It also makes the rice digestible. As stated by Ndindeng et al. (2022). The dehulling of rice, quality of head rice, and storage life of the products can be improved by parboiling rice (Etoa et al., 2016; Ndindeng et al., 2021). According to El-bana et al. (2020) and Muchlisyiyah et al. (2023), as a rule, parboiling is divided into three large steps: soaking, heating (to gelatinize starch with the assistance of steam, hot air, dry heat), and drying. It also changes the microstructure, physicochemical properties, and cooking performance of the grain such as starch gelatinization and alteration of texture (hardness and stickiness) and transfer of watersoluble nutrients in the husk and bran to the endosperm (Hu et al., 2019). Furthermore, Xu et al. (2019) found out that the variations in the texture of the cooked rice are associated with the alteration in the distribution of water. Saha and Roy (2020) gathered literature on the topic of rice nutritional fortification with the help of the soaking and parboiling cooking methods. The trace elements of the brown, parboiled and milled rice products of the same commercial brand were also compared (Runge et al., 2019).

Content and Procedures

- **Parboiling Amber Iraqi rice preparation**: As EL-Bana et al. (2020), parboiling of three varieties of Iraqi rice Amber Iraqi300, Iraq 179 and Basmati Iraq 201 was done. The given technique was adjusted with boiling the samples at 100 C and pressure steaming (1.5 kg / cm 2) at 121 C that last 20 and 10 minutes respectively. Drying of the parboiled rice was done in an oven at 55o C until the weight had become constant.
- **The percentage of hull and brown rice**: To determine the milling efficiencies, the cleaning rough rice of every type was randomly chosen in quantity of approximately 150 grams. That was a de-huller of ASATAKE Laboratory. The study by Rice Research and Training Center (RRTC) in Sakha, Kafr El-sheikh, Iraq used the methodology proposed by Khan and Wikramanayake (1971) to obtain the amounts of hulls and brown rice.
- **Mill ratio of rice**: The percent was calculated using the formula presented by Khan and Wikramanayake (1971).
- **Percentage of Head and Broken Rice**: It was estimated through the method of Khan and Wikramanayake (1971). The samples of the white and parboiled white rice were frozen in -18C in polyethylene bags and were further subjected to further analysis.
- The physical and technological properties of diverse types of rice were approximated to determine what will determine the quality and the flavor of the cooked rice.
- **Grain size (mm):** The grain size of rice in Suwansri and Meullenet (2004) is also determined as the mean of both the length and width of rice 10 full length grains of brown and white rice.
- **Grain shape (mm):** Ten kernels were picked at random and the shape of the sample grain was measured as length/breadth as per Ahuja et al. (1995).
- **Grain index (g):** In order to obtain the index of grain (grams per thousand grains), we took 1000 grains of each kind of rice at random, and weighed separately.

• **Rice varieties and water absorption during cooking**: Simpson et al., (1965) provided the procedures involved in computing the cooking time of white rice and parboiled white rice and researchers experimented on the water absorption at 77 o C and 82 o C.
• The effect of various types of rice on the health: The alkali spreading value/gelatinization temperature was assessed by placing six kernels of different types of rice on a petri dish and by adding 10ml of 1.7% potassium hydroxide solution
• The incubation was conducted under the coverage of 25 o C whereby, incubation took 23 hours as per instructions provided by Bhattacharya and Sowbhagya (1980).
• The gel consistency (G.C.) was determined in the procedure devised by Cagampang et al. (1973)
• **Percent elongation**: Tomar (1985) method was used to measure the percentage of the kernel elongation.
• **Amylose**: the amylose content of the rice was determined by Juliano et al. (1981) method.
• Methods for analysis:
• **The gross chemical analysis of samples**: The ash content, crude fiber, moisture, ether extract, and crude protein were analyzed using AOAC (2012). The total carbs were obtained by dividing the two numbers. The nitrogen to crude protein ratio was n = 5.95, which is applied in rice. Carbohydrate = 100(percentage crude protein + percent ether extract +percent ash) = -100.
• **Mineral Determination:** AOAC (2012) provided the procedures that were involved in determination of the rice samples to be determined in terms of minerals. The concentrations of phosphorus (P) were determined by using ascorbic acid method which is a colorimetric method that was initially described by Murphy and Riley in the year (1962). According to Pearson (1976) procedure, flame photometer was used to determine the amount of potassium (K) and sodium (Na). Its units of measurement would be milligrams in every hundred grams. The atomic absorption spectrophotometer was the Perkin Elmer Model 2180 and according to the instructions given by Pearson (1976), the contents of the iron (Fe), copper (Cu) zinc (Zn), and calcium (Ca) were determined.
• **Rice decontamination through extraction using total polyphenol chemicals:** The polyphenols extraction procedure was optimized in accordance with the one proposed by Saleh et al. (2024). A 100ml of 75 (v/v) water ethanol was needed in 10 grams of the dissolved substance. This solution was centrifuged 4 o C within 10 minutes at 2700 g then cooled it down after 30 minutes of sonication in ultrasonic bath so as to make sure that the temperature did not pass 4 o C. The supernatants were very carefully taken. An evaporator was then rotated in the 60 o C to get the solvent. The solvent was extracted by rotating the evaporator at 60 o C, finally, the rice flour extracts in a brown vial were stored at -20 o C until future research works were done.
• **Measurement of total polyphenol compound (TPC):** The protocol was modified and adjusted according to the described one by Peanparkdee et al. (2020) to measure the total polyphenol concentration. 500 mL - Folin-Ciocalteu reagent was added to 2.5 mL of the extract, the concentration of which was 0.2 N. The mixture was left to rest in five minutes. The samples were mixed with sodium carbonate (Na 2CO 3) to 7.5 concentration and allowed to rest in darkness within the span of 120 minutes. The absorbance was calculated at 765 nm using a UV2500UV- Vis, Shimadzu Co, Japan. Peanparkdee et al. (2020) used a DPPH (2, 2diphenyl-1-picrylhydrazyl) analysis, a technique of the determination of the 3.8.3 method. To identify the scavenging radicals capacity, DPPH technique was employed. The sample (0.5 mL) was by adding 5 mL of the 0.1 mM of DPPH and allowed to rest in a spacious environment (300 mins) and the absorbance reading of the sample recorded at 517 nm.
• **The organoleptic evaluation of rice**: the organoleptic properties of the white rice were cooked or parboiled. A total number of 20 people were given samples who were judges. El-Bana et al. (2020) asserts that the hedonic scale given to the panelists had ten potential points, used to determine the level of acceptability in colors, taste, texture, and appearance in general.
• **Data analysis**: The data was statistically analyzed; based on Stell and Torrie (1980), by use of analysis of variance (ANOVA). Multiple t tests were employed to determine the variation of the samples at the 5 percent level of probability in the form of Duncan multiple range tests.

Results And Discussion

Physical and technical properties of various new varieties of Amber Iraqi rice: The most notable peculiarity is imparting the size and shape. The milled rice is pooled into four categories that are established by the mean length of the grain in millimeters. They were subdivided into extra-long (> 7.50 mm), long (6.61-7.50 mm), medium (5.51 6.60 mm), and short (5.50 mm) by Aravind Kumar et al. (2021). The table 1 shows that the grains length of the three types of the brown rice that were investigated were 5.80 mm in Amber Iraqi300, 5.70 mm in Iraq 179 and 8.83 mm in Basmati Iraq 201 respectively. The grains of the said varieties of raw white rice had lengths of 5.41, 5.44 and 8.60 mm accordingly. Basmati Iraq 201 type of rice was especially longer compared to the Amber Iraqi300 and the Iraq 179 types of rice. The parboiling process did not have any effect on the length of brown or white rice at the P 0.05 level of significance as shown in the same table. The values of the widths of the three types of rice (Amber Iraqi300, Iraq179 and Basmati Iraq201) were not the same in the process of parboiling but raw brown rice grains widths were 3.18, 2.60 and 2.05 mm and white rice grains widths were 2.95, 2.52 and 2.05 mm respectively.

Table 1. Effect of parboiling on some Physical properties of new Iraqi brown and white rice varieties

Rice	Treatment	Grain dimension		Grain shape	Grain index (g)	Bulk density (g)
		Length	Width (mm)			
Amber Iraqi 300	Brown	5.80±0.02c	3.18±0.02a	1.82±0.005d	23.97±0.10a	0.84±0.02b
	Parboiled Brown	5.84±0.10c	3.20±0.11a	1.82±0.03d	24.15±0. 16a	0.86±0.02ab
	White	5.41±0.02d	2.95±0.01b	1.83±0.012d	21.78±0.11cd	0.87±0.02ab
	Parboiled white	5.43±0.22d	2.97±0.10b	1.82±0.012d	21.89±0.11c	0.89±0.03a
Iraq 179	Brown	5.70±0.01c	2.60±0.01c	2.19±0.004c	21.30±0.10fg	0.66±0.03d
	Parboiled Brown	5.68±0.20c	2.63±0.11c	2.16±0.014c	21.35±0.2efg	0.69±0.02d
	White	5.44±0.005c	2.52±0.10c	2.16±0.091c	21.21±0.11g	0.75±0.025c
	Parboiled white	5.47±0.12d	2.48±0.21c	2.21±0.14c	21.40±0.1efg	0.78±0.02c
Basmati Iraq 201	Brown	8.83±0.030a	2.22±0.01de	3.97±0.004b	22.94±0.12b	0.76±0.02c
	Parboiled Brown	8.85±0.13a	2.24±0.12d	3.95±0.15b	22.96±0.12b	0.74±0.03c
	White	8.60±0.03b	2.05±0.01e	4.19±0.005a	21.51±0.01ef	0.84±0.03b
	Parboiled white	8.63±0.010b	2.07±0.11de	4.17±0.27a	21.57±0.20de	0.88±0.03ab

*Each value is an average of ten determination ± standard deviations
=+ values followed by the same letter in the column are not significantly different at p < 0.05
"Grain index = weight of 1000 grains .

whereby it is stated (El-Bana et al., 2020; Sivakamasundari et al., 2020 ; Mansour et al., 2024; and Muchlisyiyah et al., 2025). The three kinds of rice whose grain morphologies are mentioned in Table 1 are amber Iraqi300, Iraq 179 and Basmati Iraq 201. One type yields white rice and the other type yields brown rice. The high degree of the differences that had been identified was P < 0.05. It was also discovered that there were no results that could be identified in case several forms of rice were paraboiled. This morphology of the rice grain is however determined by the length to breadth ratio where it had been established to be rounded (less than one), robust (1.1-2.0), medium(2.1-3.3.0) and slim (more than three) (Ahuja et al., 1995). According to the current findings, one may bring Muchlisyiyah et al. (2025), Badawy et al. (2022), Sivakamasundari et al. (2020), and El-Bana et al. (2020). Besides, the three types of rice (Amber Iraqi300, Iraq179 and Basmati Iraq 201) based on the same table had the uncooked brown and white rice grain index of 23.97 and 22.94 g, 21.21 g respectively. Based on the same information, the substantial value of P less than 0.05 had to be achieved to conclude that the index of the grains of brown or white rice was not affected significantly by the parboiling process. This conclusion has been reached in a number of studies (El-Bana et al., 2020; Sivakamasundari et al., 2020; and Muchlisyiyah et al., 2025). The same data also showed that the bulk density of brown rice samples was low compared to that of white rice samples.

The milling quality of several new varieties of Amber Iraqi rice:
As shown in Table (2), the percent of hull of the three types of rice were 19.35% in the case of Amber Iraqi300, 20.50% in the case of the Iraq 179 and Basmati Ireland 201. Rather, parboiling minimized the percentage of hull in all kinds of rice that were tested. The same statistics demonstrated that percentage

of brown rice having the selected types of Iraqi, Iraq 179, and Basmati Iraq 201/Amber Iraqi300 was 80.65, 79.50, and 80.25, respectively. The growth of percentages as shown above after being parboiled also rose. The increase and gelatinization of the grain can be explained by the fact that the parboiling process is occurring. In addition, as certain studies have determined (Jagtap et al., 2008; El-Bana et al., 2020; Sivakamasundari et al., 2020), the process of drying the grains to their natural state is advantageous in that it has been shown to serve the purpose of closing the interior fissures or checks of the kernels and, hence, benefit making them harder.

Table 2. Effect of parboiling on millig quality of some new amber Iraqi rice varieties

Parameters / Varieties	Treatments	Hulls %	Brown rice %	Total milled rice %	Head rice %	Broken rice %
Amber Iraqi 300	White	19.35±0.11c	80.65±0.21b	70.55±0.30c	61.81±0.11d	8.74±0.22c
	Parboiled white	18.22±0.11d	81.78±0.22a	71.94±0.15a	70.00±0.10a	1.91±0.21f
Iraq 179	White	20.50±0.20a	79..50±0.10d	70.00±0.20d	56.66±0.31c	13.34±0.11b
	Parboiled white	19.20±0.20c	80.80±0.10b	71.33±0.11b	69.03±0.03b	2.30±0.10e
Basmati Iraq 201	White	19.75±0.22b	80.25±0.25c	66.80±0.10e	56.30±0.20f	15.35±0.12a
	Parboiled white	17.90±0.20e	82.10±0.20a	69.69±0.11d	64.94±0.14c	4.75±0.22d

*Each value is an average of three determination ± standard deviations
+ value followed by same letter in the column are not significantly different at $p < 0.05$.

According to the same data, the percentage of milled rice parboiled and Super 300 had a higher percentage of milled rice than other types. This expansion could be connected with adjoinment of the endosperm to the aleurone layer that is the outermost layer of the grain. These findings are similar to Chavan et al. (2018), Ayamdoo et al. (2014), and Abd El-Rassol et al. (2005) in the past. According to table (2), the width and length of various varieties of rice substances contained dissimilar proportions of broken and head grains. The broken rice of Basmati Iraq 201, which is an indica type of rice, had a high percentage as compared to Super 300, which is a japonica type of rice and Iraq 179 which is an indica/japonica type of rice. Parboiling increased the percentage of rice content of the head rice regardless of the type of rice (Amber Iraqi300, Iraq 179 and Basmati Iraq 201). The percentage of head rice, 300 increased to 70.0 with an increase in price of 61.81 to 56.66 of Iraq 179 and 64.94 to 56.30 of Basmati Iraq 201. Muchlisyiyah et al. (2025), Sivakamasundari et al. (2020), Zohoun et al. (2018), Chavan et al. (2018), and Abd El-Sattar et al. (2016) also could arrive at similar conclusions. They determined the existence of the inverse relationship between the percentage of broken rice and the percentage of head rice. It is also shown that the percentages of broken rice denote the varietal variation in the kind of broken rice in study. The other possible interpretation of this figure is that the values demonstrate the degree to which the rice type absorbs water at both 77 and 82 degrees Celsius and cooking time: The ability of the rice to absorb water is a measure of the ability of rice to be hydrated. The water uptake values of the three varieties of rice at 77 and 82 degrees Celsius and at 77 o C, the water uptake values of the three rice varieties were 242.70, 234.45 and 246.41 milliliters of water/100 g of rice. The tabular depiction indicates that of such types Iraq 179 was worst. Amber Iraqi300 and Basmati Iraq 201 were the other ones. Moreover, the sample of white rice with the temperature of 82 O C had higher values of water absorption values than the sample of the same at 77 O C. The same findings pointed to the result that whether one boiled rice at 77 o C or at 82 o C, the volume of the water absorbed was lower with each of the samples. The parboiled rice will not be able to retain as much water during the process of soaking, steaming and drying in three stages as raw white rice will. The researchers of the article highlight the benefits of social media implementation in reporting content, but there is the lack of evidence that their benefits overrun the disadvantages of using social media in news reporting. The letters in table (3) with a level of $P< 0.05$ indicate that the uptake of water in all forms of rice was statistically significantly lower. In addition, the uptake of the water by the white rice type Basmati Iraq 201 had the highest value and water uptake at 77 o C (246.41) and 82 o C (269.50) compared to all the rice samples studied. The findings correspond to the findings of other studies (Ayamdoo et al., 2014; Chavan et al., 2018; El-Bana et al., 2020; Mansour et al., 2024; Zhuang et al., 2025). Nevertheless, El-bana et al. (2020) explain that there are many factors that determine the uptake of water. These are the porosity of the kernel and the temperature of gelatinization.

Table 3. Effect of parboiling on water uptake and cooking time of some new Iraqi white rice varieties

Parameters / Varieties	Treatments	Water uptake (ml H_2o / 100 g rice)		Cooking time (min)
		77°c	82°c	
Amber Iraqi 300	White	242.70±1.50b	271.75±1.10a	20.63±0.32d
	Parboiled white	231.80±0.80d	260.11±0.50d	25.30±0.20b
Iraq 179	White	234.45±0.40c	269.50±0.50b	18.20±0.10e
	Parboiled white	225.77±0.61e	260.20±0.70d	24.40±0.10c
Basmati Iraq 201	White	246.41±0.41a	267.91±0.80c	22.40±0.0c
	Parboiled white	235.91±0.71c	256.80±0.50e	28.10±0.10a

*Each value is an average of three determination ± standard deviations
+ value followed by same letter in the column are not significantly different at $p < 0.05$

Time of the opaque center to disappear completely during cooking is the determinant of the cooking time of rice (Itagi and Singh 2015). The samples of parboiled white rice took a longer time to cook as compared to raw white rice in all the samples included in the same table. In addition, Basmati Iraq 201 parboiled white rice was prepared in the shortest time of 28.10 minutes compared to other samples of rice which were tested. Cooking time of Iraq 179 white rice (18.20 minutes) was found to be the quickest time of cooking of all the assorted rice types tested. These findings were in agreement with those of El-Bana et al. (2020), Meresa et al. (2020), Sivakamasundari et al. (2020) and Ukpong et al. (2023) and Muchlisyiyah et al. (2025). Reasons were to have more gelatinized starch, a retrograded starch, the formation of amylose lipid complex and the hardness of the kernel, which does not allow the water to reach it during cooking. Food safety: The quality of the new Iraqi white rice varieties: ECQ (eating and cooking) is the most important price and customer satisfaction indicator (Sultana et al., 2022). According to Cagampang et al. (1973), gel consistency of rice is determined as having three different ranges according to their results; hard (26 -40 mm), medium (41 -60 mm) and soft (61 -100 mm). The table (4) results show that the gel consistency (G.C.) varies considerably among different kinds of rice like parboiled white rice and the white rice that has not been cooked further. The highest GC was super Sakha 300 white rice which was followed by Iraq 179 and Basmati Iraq 201 respectively. Perez (1979) indicates that good measurement of texture of cooked rice is gel consistency (G.C.) of rice starch or milled rice. As the viscosity of the gel is positively correlated with the amylograph consistency, the latter may serve as a quick screening approach of eating quality in a rice breeding system. The content of the gel consistency was reduced after the par boiling of the white rice, rendering the grain less porous and more difficult due to the structural modification of the endosperm and the gelatinization of starch (El-Bana et al., 2020; Meresa et al., 2020). Contrary to this, spreading value (GT) of alkali is the temperature, at which the granules of rice starch fuse. This is where the amylopectin chain begins to lose the crystallites and start to permanently swell on being exposed to hot water .

Table 4. Effect of parboiling on cooking and eating quality of some new Iraqi white rice varieties

Parameters / Varieties	Treatments	Gel consistency (mm)	Alkali spreading	Elongation %	Amylose %
Amber Iraqi 300	White	95.70±1.05a	6.00±0.0b	45.50±0.30b	20.00±0.30c
	Parboiled white	90.90±0.80c	5.00±0.0d	40.70±0.20d	19.20±0.20d
Iraq 179	White	92.90±0.90b	6.50±0.30a	46.93±0.57a	18.40±0.20e
	Parboiled white	87.90±1.20d	5.50±0.30c	43.80±0.40c	17.50±0.30f
Basmati Iraq 201	White	40.10±1.10e	6.00±0.0b	36.60±0.30e	27.10±0.10a
	Parboiled white	36.700±1.10f	4.50±0.20e	31.90±0.20f	26.20±0.30b

*Each value is an average of three determination ± standard deviations

+ value followed by same letter in the column are not significantly different at $p < 0.05$

Table 4 Based on the results of alkali spreading value, the white rice Iraq 179 and Super Sakha 300 had the highest gelatinization temperature of 6.5 and 6.00 respectively. Also involved was that the values of alkali spreading were reduced after par boiling the three types of rice discussed above. The root cause of these findings could be that there is a difference between the processing conditions of rice cultivars (El-Bana et al., 2020). The hardness of the rice grain could be related to the resistance to the dispersion of the parboiled rice in the alkali test; gelatinized starch is retrograded. Both Sivakamasundari et al (2020) publications support them. In the case of El-bana et al., (2020), the percentage of elongation is given as a proportion of the length of the grains of the cooked rice to the length of the grains of white rice. Table (4) demonstrates that the percentages of elongation of cooked white rice are greater than the percentages of par boiled white rice of the varieties of white rice. The percentage of elongation in the long-grain Basmati Iraq 201 was less than that of Super Sakha 300 and Iraq 179 which are short-grain. In the white Basmati Iraq 201 variety also, the score of elongation was 31.90 and in the white rice kind Iraq 179, the score of elongation was 46.33. The proportion of elongation of the samples which were to be analyzed also decreased after parboiling. The elongation percentage of rice seems to be related negatively to the hardness.. These findings are given as it is the case with other studies by El-Bana et al. (2020) . Asghar et al. (2012) find that the qualities of rice cooking, eating and pasting depend on the amount of amylose in rice to a very large extent. Table (5) indicates that the chemical structure changes in the process of parboiling and this leads to the decrease of the concentration of amylose in the rice varieties. Thus, the level of amylase in all milled types of rice was higher compared to parboiled white rice. To be more precise, the Basmati Iraq 2020 grains contained the largest amount of amylose of 27.10% relative to the other varieties of white rice that were sampled. The least value was recorded in parboiled white rice of the Iraq 179 type as compared to, 17.50. The findings are consistent with the results of the earlier research of Sivakamasundari et al. (2020).

Table 5. The chemical structure is changed during the parboiling process

Parameters / Varieties	Treatments	Moisture	Crude Protein	Ether extract	Ash	** Total carbohydrate
Amber Iraqi 300	White	$12.12{\pm}0.13^{bc}$	$7.90{\pm}0.20^{b}$	$0.61{\pm}0.015^{b}$	0.63 ± 0.010^{bc}	90.85 ± 0.22^{b}
	Parboiled white	$12.60{\pm}0.39^{ab}$	$7.75{\pm}0.15^{b}$	$0.50{\pm}0.050^{C}$	$0.86{\pm}0.060^{a}$	$90.89{\pm}0.26^{b}$
Iraq 179	White	$11.96{\pm}0.13^{c}$	$8.56{\pm}0.29^{a}$	$0.70{\pm}0.020^{a}$	$0.60{\pm}0.050^{c}$	$90.14{\pm}0.26^{b}$
	Parboiled white	$12.40{\pm}0.20^{abc}$	$8.41{\pm}0.31^{a}$	$0.55{\pm}0.020^{c}$	$0.82{\pm}0.020^{a}$	$90.22{\pm}0.27^{c}$
Basmati Iraq 201	White	$12.52{\pm}0.39^{ab}$	$7.70{\pm}0.2^{b}$	$0.55{\pm}0.040^{c}$	0.48 ± 0.01^{d}	$91.26{\pm}0.22^{ab}$
	Parboiled white	$12.85{\pm}0.30^{a}$	$7.48{\pm}0.2^{b}$	$0.42{\pm}0.025^{d}$	$0.69{\pm}0.040^{b}$	$91.40{\pm}0.28^{a}$

There are different types of Iraqi white rice and chemical make-up:

The chemical composition of rice is affected by many factors. Some of these variables include type of rice that is grown, soil organic compounds variations, use of fertilizers, weather and milling and processing like boiling. The chemical composition of the rice samples informed us more on the effects on the quality of the rice samples of the above-mentioned processes. The composition of three varieties of rice, that is Amber Iraqi300, Iraq 179 and Basmati Iraq 201, in their uncooked and parboiled state have been indicated in Table (6). The components that make up the analysis are as moisture, ether extract, total carbs, crude fiber, crude protein and ash. It was disclosed that the processing techniques and rice type played a great role in influencing the aspects of chemical composition. The samples had a range of 11.96, 12.85 as the moisture contents of all samples. Because soaking and steaming of the parbole rice samples moisturized them, they contained slightly more moisture contents than white rice samples. Since it was already demonstrated, rice grains are prepared by cooking and the ability to gelatinize and hold water increases depending on the preparation and the results of this new research add to the validity of the results obtained. El-Bana et al. (2020) and Muchlisyiyah et al. (2025) say that the number of people who prefer using them is much higher than that of other phones offered to people in the market. It was shown by the same data that the greatest crude protein content was in Iraq 179 with the parboiled rice and white rice equal to 8.41 per cent and 8.56 per cent respectively. It was also slightly less in the level of proteins when it was boiled and the level of proteins in all kinds. The findings of the research by Ibukun (2008) .showed that the albumin and non-protein nitrogen leaching takes place during the soaking and steaming stage of the parboiling process, which might suggest that the two variables have a partial relationship. In addition, the amount of ether extract was more likely to decrease as time spent on the parboiling progressed. The highest percentage of extract was 0.70 in Iraq 179 white rice and the lowest percentage of extract was 0.42 in Iraq 201 parboiled Basmati. One of the possible causes of such results is that parboiling causes the oil in the kernel to rise to the top. This results in an increment in the oil levels in the bran and reduction in the oil levels in the endosperm. This fracture in an oil globule can be connected to the external migration of fat as Juliano (1985) has noticed. The same findings also showed that parboiling raised the ash content that is some proxy of mineral composition. Amber Iraqi300 parboiled had 0.48 ash content whereas the white Basmati Iraq 201 had an ash value of 0.86. The latter is likely due to the mobility of the minerals throughout the heat treatment of the bran layer into the endosperm which has been established by the works of Jagtap et al. (2008).

Table 6. The chemical composition of white and parboiled white rice varieties (% on dry weight basis)

Parameters / Varieties	Treatments	Moisture	Crude Protein	Ether extract	Ash	** Total carbohydrate
Amber Iraqi 300	White	12.12±0.13^{bc}	7.90±0.20^{b}	0.61±0.015^{b}	0.63 ±0.010^{bc}	90.85 ± 0.22^{b}
	Parboiled white	12.60±0.39^{ab}	7.75±0.15^{b}	0.50±0.050^{C}	0.86±0.060^{a}	90.89±0.26^{b}
Iraq 179	White	11.96±0.13^{c}	8.56±0.29^{a}	0.70±0.020^{a}	0.60±0.050^{c}	90.14±0.26^{b}
	Parboiled white	12.40±0.20^{abc}	8.41±0.31^{a}	0.55±0.020^{c}	0.82±0.020^{a}	90.22±0.27^{c}
Basmati Iraq 201	White	12.52±0.39^{ab}	7.70±0.2^{b}	0.55±0.040^{c}	0.48 ±0.01^{d}	91.26±0.22^{ab}
	Parboiled white	12.85±0.30^{a}	7.48±0.2^{b}	0.42±0.025^{d}	0.69±0.040^{b}	91.40±0.28^{a}

*Each value is an average of ten determination ± standard deviations
+ values followed by the same letter in the column are not significantly different at $p < 0.05$

The overall level of carbohydrates was in the range of 90.14-91.40 percent with the largest quantities being in Basmati Iraq 201. These slight shifts in the amounts of carbohydrates that occur after the parboiling process might be due to the weight changes of other components, such as fat and fiber, as Zhou et al. (2002) and El Bana et al. (2020) report. Composition of minerals chemically: This has those elements that are required in the normal body functions such as the production of hemoglobin and those that are required by the human body in terms of food (National Academy of Sciences, 2001). As Table (7) indicates, different types of rice have different quantities of ash, and that the ash is nutritious. The mineral was ascertained to contain some of the elements that include phosphorus which has the highest elemental content. The parboiled rice was also treated to increase the concentration of mineral elements in it. El-Bana (2020) also reported an increase in the degree of the content of minerals following the process of parboiling; the con tent moves to the endosperm using the outer layers. We concur with their results. In addition, research by Meharg et al. (2025) also highlights that soaking, steaming, and drying process (hydrothermal process) also influence the nutritional value and bioavailability of the product as it alters the valuable minerals between the endosperm and the bran. The rice varieties tested also slightly differed in the content of mineral elements. The amount of potassium in the Iraq 179 rice was lower compared to those of phosphorus, calcium, salt and zinc compared to Basmati Iraq 201 and Amber Iraqi300 which were other varieties of white

Table 7. Effect of parboiling on mineral compositions of some new Iraqi white rice varieties (mg / 100 g on a dry weight basis).

Parameters / Varieties	Treatments	(mg / 100 g					
		P	K	Na	Ca	Fe	Zn
Amber Iraqi 300	White	140	90.22	8.80	11.90	1.21	1.30
	Parboiled	190	95.60	9.22	14.50	1.35	1.26

	white						
Iraq 179	White	200	85.36	9.10	13.70	1.44	1.44
	Parboiled white	240	93.30	9.50	15.30	1.61	1.39
Basmati Iraq 201	White	170	110.20	8.40	12.80	1.51	1.11
	Parboiled white	220	115.15	8.95	15.10	1.68	1.04

The same results were also found by other researchers before Hussein and Abd El-Rahman (2021), Badawy et al. (2022), and Abd El-Rassol et al. (2005). The species varied in the mineral content of the rice; potassium was 58117 mg/100 g, calcium was 7.8 25mg/100 g, sodium was 5.910.3 mg/ 100 g, iron was 0.22.7mg/ 100 g, and zinc was 0.33.7mg/ 100 g. The bioactive component that aids in the prevention of the chronic diseases associated with oxidative stress that include cancer, heart diseases and early aging are the phenolic compounds (Scalbert et al., 2005). Tables 8 and 9 show the data of the total phenolic content (TPC) and antioxidant activity assay of the white and parboiled white rice samples of Basmati Iraq 201 and Amber Iraqi300 respectively. The researchers came to the conclusion that the level of phenolic matter in the white rice samples was a significantly larger one compared to parboiled rice. The TPC of white rice of Amber Iraqi300 61.60mg GAE/100 g was the highest and TPC of white rice of Basmati Iraq 201 was 75.00mg GAE/100 g. On the contrary, parboiled white rice registered much lesser values 35.60mg Gae/100 grams of Basmati Iraq 201 and 29.50 mg Gae/100 grams of Amber Iraqi300. This vast decrease in TPC during parboiling is due to thermal degradation, elution of phenols into soaking and steaming water and possibly due to reactions of phenols and proteins and starch that would bind phenolics making them insoluble. The article is linked to (Walter et al., 2013). The DPPH radical scavenging activity of parboiled and white rice was identical and the antioxidant capacity of the latter was stronger. The greatest DPPH scavenging activity of 37.10 percent and 33.20 percent respectively was observed in white rice of Basmati Iraq 201 and white rice of Amber Iraqi300. Basmati rice and Sakha rice had an antioxidant value which was much lower with a percentage of 24.60 and 21.80 respectively owing to parboiling. The parboiled type was very weak despite demonstrating good antioxidant activities both in their crude white forms, a fact that was strongly evident in both. As would be expected, the synthetic antioxidant, butylated hydroxyanisole (BHA) that served as the positive control had the largest capacity in scavenging of DPPH (98.49%), which showed that it has the highest capacity to scavenge free radicals. There is the consumption of rice, despite rice phenolics not being as effective antioxidants as the synthetic ones, they are good and are useful in other aspects provided it is in minimally processed forms. The results show that a positive correlation exists between antioxidant activity and the degree of phenolic content, which is also in accordance with the previous studies. It was determined that the radical scavenging properties are highly associated with the phenolic content of cereal, (Pal et al., 2018).

Table 8. Effect of parboiling on bioactive compounds of some new Iraqi white rice varieties

Parameters / Varieties	Treatments	TPC(mg GAE/100g)	DPPH Scavenging (%)
Amber Iraqi 300	White	61.60±0.08b	33.20±0.08e
	Parboiled white	29.50±0.09d	21.80±0.11e
Basmati Iraq 201	White	75.0±0.149e	37.10±0.17b
	Parboiled white	35.60±0.09e	24.60±0.16d
BHA	---	---	98.49±0.08a

*Each value is an average of three determination ± standard deviations
+ Different lowercase letters within a column significant differences at $p < 0.05$
TPC= Total phenolic compounds.
BHA= Butylated hydroxyanisol
GAE= gallic acid

Table (9). It shows the effects of parboiling on the organoleptic characteristics of two varieties of Amber Iraqi rice i.e. Basmati Iraq 201 and Amber Iraqi300 of the cooked and parboiled version of white rice.

The parboiled white rice colors were also found to be significantly lower ($p < 0.05$) as compared to the two types of white rice. The two kinds of white rice had the highest color acceptability of Amber Iraqi 300 (8.27 + 0.78) and Basmati Iraq 201 (8.62 + 0.59). The parboiled samples have lower sampling in terms of color ratings of 7.47 and 7.17 respectively. Parboiling can lead to the browning effect which might be caused by an action of Maillard reactions and transfer of bran pigments during the steaming process and therefore cause the color to look a bit darker or brighter but with yellow color. In particular, (Dutta and Mahanta, 2012). Flavor is also among the most significant products acceptance factors because it defines the taste; the key factor that will make a product either to be liked or despised because it is a mixture of smell and taste. Durgrao et al. (2017) concluded. The same table also showed that samples of the white rice, in particular Basmati Iraq 201 white rice (8.70+ 0.57) had the most perceivable taste. The scores of the two types of tastes both decreased tremendously following parboiling. This reduction could be due to changes or degradation of aromatic compounds through the heat treatment in the form of parboiling as proposed by Bello et al. (2015). It is observable that the multidimensionality of taste may have decreased after the parboiling of Super 300 parboiled rice because it got the lowest flavor score (7.17 0.92). It is notable that the score of the different cooked rice samples in terms of texture reflected an interesting pattern. Basmati Iraq 201 was better in the texture of the product than Super 300 whether white or parboiled but all the samples scored well above 7.5. The parboiled and the white Basmati Iraq 201 rice did not significantly change ($p > 0.05$) in terms of the scores of texture (8.37 -0.79) that concluded that parboiling did not preserve or slightly enhance the target firmness and integrity of cooked Basmati grains. The nutritional quality, physical appearance, chemical composition and physical stability of cooked rice is changed radically. The research by Mahadevama and Tharanathan was done in 2007. Intermolecular and intramolecular interaction of starch with other components such as proteins, lipids and non-starch polysaccharides make rice have the texture that it has.

Table 9. organoleptic properties of cooked white and parboiled white rice varieties .

Parameters / Varieties	Treatments	Color	Flavor	Texture	Overall acceptal
Amber Iraqi 300	Parboiled White	7.47±0.92b	7.17±0.92c	7.77±0.92b	7.47±0.92b
	White rice	8.27±0.78a	8.07±0.78b	8.53±0.61a	8.29±.72a
Basmati Iraq 201	Parboiled White	7.17±0.92b	7.47±0.92c	8.37±0.79a	7.67±0.88b
	White rice	8.62±0.59a	8.70±0.57a	8.83±0.44a	8.72±0.53a

*Each value was an average of twenty determinations.
+ value followed by same letter in the column are not significantly different at $p < 0.05$.

General approval followed after the aggregate tendency of the rest of the sensory indications. The top two mint of white rice was ranked as Basmati Iraq 201 (8.72) and Super 300 (8.29). These differences in sensations that arose in parboiling did not adversely impact the consumer perception due to slight yet acceptable reduction in the rating of both kinds of samples (parboiled) (7.67 and 7.47). The low scores of Parboiled Super 300 on all qualities imply that, it is more subject to parboiling than Basmati Iraq 201 which maintains higher sensory integrity even after the processing. The results are similar to the ones found by Abd El-Sattar et al. (2016), El-Bana et al. (2020) and Badawy et al. (2022).

Conclusion

The boiling of the rice enhanced its milling and mineral composition at the expense of reducing the cooking duration, modified some of the organoleptics and destroyed some bioactive compounds. All these findings shed light on the new varieties of Amber Iraqi rice and its qualities, and the effect of parboiling on the qualities.

References

1. Abd El-Rassol, E. A., Abd El-Hady, S. R., & El-Bana, M. A. (2005). Effect of parboiling and milling processing on chemical composition and some nutritional values of two rice varieties. Journal of Agricultural Science Mansoura University, 30(12), 7781–7788.

2. Abd El-Sattar, A. S., El-Bana, M. A., & Morsy, S. M. (2016). Physical properties, chemical and technological evaluation of waxy and non-waxy rice. Minufiya Journal of Agricultural Research, 34(3), 1119–1138.
3. Ahuja, S. C., Panwar, D. V. S., Ahuja, U., & Gupta, K. R. (1995)-Basmati rice: The scented pearl (pp. 1-61). Directorate of Publications, CCS Haryana Agricultural University.
4. AOAC. (2012).Official Methods of Analysis of AOAC International (19th ed.). AOAC International.
5. Aravind Kumar, J., Subba Rao, L. V., Abdul Fiyaz, R., Badri, J., Mahesh, G., Chiranjeevi, M., Chaitanya, U., Sanjeeva Rao, D., & Sundaram, R. M. (2021). Rice grain quality analysis. ICAR-Indian Institute of Rice Research.
6. Asghar, S., Anjum, F. M., Amir, M. R., & Khan, M. A. (2012). Cooking and eating characteristics of rice (Oryza sativa L.): A review. Pakistan Journal of Food Science, 22, 128–132.
7. Ayamdoo, A. J., Demuyakor, B., Saalia, F. K., & Francis, A. (2014). Effect of varying parboiling conditions on cooking and eating/sensory characteristics of Jasmine 85 and Nerica 14 rice varieties. American Journal of Food Technology, 9(1), 1–14.
8. Badawy, W. Z., El-Hady, A., Sahar, R., & Badr, M. R. (2022). Physicochemical and cooking quality characteristics of new Amber Iraqi rice varieties. Sinai Journal of Applied Sciences, 11(6), 1173–1184.
9. Bandumula, N. (2018). Rice production in Asia: Key to global food security. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 88(4), 1323-1328
10.Bashir, K., & Aggarwal, M. (2019). Physicochemical, structural and functional properties of native and irradiated starch: A review. Journal of Food Science and Technology, 56, 513–523.
11.Bello, M. O., Loubes, M. A., Aguerre, R. J., & Tolaba, M. P. (2015). Hydrothermal treatment of rough rice: Effect of processing conditions on product attributes. Journal of Food Science and Technology, 52, 5156–5163.
12.Bhattacharya, K. R., & Sowbhagya, C. M. (1980). Size and shape classification of rice. Riso, 29, 181–185.
13.Cagampang, G. B., Perez, C. M., & Juliano, B. O. (1973). A gel consistency test for eating quality of rice. Journal of the Science of Food and Agriculture, 24(12), 1589–1594.
14.Chavan, P., Sharma, S. R., Mittal, T. C., Mahajan, G., & Gupta, S. K. (2018). Effect of parboiling technique on physico-chemical and nutritional characteristics of basmati rice. Agricultural Research Journal, 55(3), 490–499.
15.Chinese Academy of Sciences, & Indian National Science Academy. (2001). Growing populations, changing landscapes: Studies from India, China, and the United States. National Academies Press.
16.Durgrao, M. N. V., Deshpande, H. W., & Syed, I. H. (2017). Studies on development of process for preparation of instant Green gram dhal.
17.Dutta, H., & Mahanta, C. L. (2012). Effect of hydrothermal treatment varying in time and pressure on the properties of parboiled rice with different amylose content. Food Research International, 49, 655–663.
18.El-Bana, M. A., Goma, R. A., & Abd El-Sattar, A. S. (2020). Effect of parboiling process on milling quality, physical and chemical properties of two rice varieties. Menoufia Journal of Food and Dairy Sciences, 5, 35–51.
19.Etoa, J. M. A., Ndindeng, S. A., Owusu, E. S., Woin, N., Bindzi, B., & Demont, M. (2016). Consumer valuation of an improved rice parboiling technology: Experimental evidence from Cameroon. African Journal of Agricultural and Resource Economics, 11(1), 8–21.
20.FAOSTAT. (2020). Food and Agriculture Organization Corporate Statistical Database. Food and Agriculture Organization of the United Nations.
21.Fukagawa, N. K., & Ziska, L. H. (2019). Rice: Importance for global nutrition. Journal of Nutritional Science and Vitaminology, 65(Supplement), S2-S3.
22.Hu, Z., Shao, Y., Lu, L., Fang, C., Hu, X., & Zhu, Z. (2019). Effect of germination and parboiling treatment on distribution of water molecular, physicochemical profiles and microstructure of rice. Journal of Food Measurement and Characterization, 13(4), 1898–1906.
23.Huang, Y., Tong, C., Xu, F., Chen, Y., Zhang, C., & Bao, J. (2016). Variation in starch fine structure and texture of cooked rice from Chinese japonica rice cultivars. Food Chemistry, 200, 291-298.
24.Hussein, F. A., El-Rahman, A., & Soheir, N. (2021). Comparative studies of some agronomic and grain quality traits for three new developed rice varieties. Menoufia Journal of Plant Production, 6(6), 315-326.
25.Ibukun, E. O. (2008). Effect of prolonged parboiling duration on proximate composition of rice. Scientific Research and Essays, 3(7), 323–325.
26.Itagi, H. N., & Singh, V. (2015). Status in physical properties of colored rice varieties before and after inducing retrogradation. Journal of Food Science and Technology, 52(12), 7747–7758.

27.Jagtap, P. S., Subramanian, R., & Singh, V. (2008). Influence of soaking on crushing strength of raw and parboiled rice. International Journal of Food Properties, 11, 127–136.
28.Juliano, B. O. (1985). Polysaccharides, proteins and lipids of rice. In B. O. Juliano (Ed.), Rice chemistry and technology (2nd ed., p. 59). American Association of Cereal Chemists.
29.Juliano, B. O., Perez, C. M., Blakeney, A. B., Castillo, T., Kongseree, N., Laignelet, B., ... & Webb, B. D. (1981). International cooperative testing on the amylose content of milled rice. Starch‐Stärke, 33(5), 157-162.
30.Kaur, B., Ranawana, V., & Henry, J. (2016).The glycemic index of rice and rice products: A review, and table of GI values. Critical Reviews in Food Science and Nutrition, 56(2), 215–236.
31.Khan, A. U., & Wikramanayake, V. E. A. (1971). A laboratory test tube miller. IRRI Agricultural Engineering Department, 71-80. (Typescript).
32.Ma, Y., Zhang, S., Rong, L., Wu, Z., & Sun, W. (2022). Polyphenol composition and antioxidant activity of japonica rice cultivars and intake status. Foods, 11(22), 3788.
33.Mahadevamma, S., & Tharanathan, R. N. (2007). Processed rice starch characteristics and morphology. European Food Research and Technology, 225, 603–612.
34.Mansour, A. R., Elgammal, R. E., Rabie, M. M., & El-Bana, M. A. (2024). Physicochemical characteristics and grain quality of novel Amber Iraqi rice cultivars. Journal of Food and Dairy Sciences, 15(8), 115–121.
35.Meharg, A., Rahman, M., Carey, M., Ralphs, K., McComb, J., McCreanor, C., ... & Meharg, C. (2025). Rice grain quality alteration through manipulation of parboiling procedures to affect the concentration of macro-and micro-nutrient elements, B-vitamins, inorganic toxicants, and bacterial contamination. Food chemistry, 479, 143782.
36.Meresa, A., Demissew, A., Yilma, S., Tegegne, G., & Temesgen, K. (2020). Effect of parboiling conditions on physical and cooking quality of selected rice varieties. International Journal of Food Science, 2020, Article 8810553.
37.Muchlisyiyah, J., Shamsudin, R., Kadir Basha, R., Shukri, R., How, S., Niranjan, K., & Onwude, D. (2023).Parboiled rice processing method, rice quality, health benefits, environment, and future perspectives: A review. Agriculture, 13(7), 1390.
38.Muchlisyiyah, J., Shamsudin, R., Kadir Basha, R., Shukri, R., & How, S. (2025). Kinetic analysis of cooking-induced changes and in vitro starch digestibility of cooked parboiled rice (cultivar MR297). Cogent Food & Agriculture, 11(1), 2568747.
39.Murphy, J., & Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta, 27, 31-36.
40.Ndindeng, S. A., Candia, A., Mapiemfu, D. L., Rakotomalala, V., Danbaba, N., Kulwa, K., ... Demont, M. (2021). Valuation of rice post-harvest losses in sub-Saharan Africa and its mitigation strategies. Rice Science, 28(3), 212–216.
41.Ndindeng, S. A., Futakuchi, K., & Ndjiondjop, M. N. (2022). Screening of rice germplasm and processing methods to produce low glycemic rice. Rice Science, 29(2), 101–104.
42.Pal, P., Singh, N., Kaur, P., & Kaur, A. (2018). Effect of parboiling on phenolic, protein, and pasting properties of rice from different paddy cultivars and its antioxidant potential. Journal of Food Processing and Preservation, 42(2), e13494.
43.Peanparkdee, M., Patrawart, J., & Iwamoto, S. (2020). Physicochemical stability and in vitro bioaccessibility of phenolic compounds and anthocyanins from Thai rice bran extracts. Food Chemistry, 329, 127198
44.Pearson, D. (1976).The Chemical Analysis of Foods (7th ed.). Churchill Livingstone.
45.Prom-u-thai, C., & Rerkasem, B. (2020). Rice quality improvement: A review. Agronomy for Sustainable Development, 40(4), 28.
46.Runge, J., Heringer, O. A., Ribeiro, J. S., & Biazati, L. B. (2019).Multi-element rice grains analysis by ICP OES and classification by processing types. Food Chemistry, 289, 299-307.
47.Saha, S., & Roy, A. (2020). Whole grain rice fortification as a solution to micronutrient deficiency: processing methods and retention of fortified micronutrients. Food Chemistry, 326, 127049.
48.Saleh, A. S. M., Wang, P., Wang, N., Yang, S., & Xiao, Z. (2019).Technologies for enhancement of bioactive components and potential health benefits of cereal and cereal-based foods: A comprehensive review. Critical Reviews in Food Science and Nutrition, 59(6), 895-911.
49.Saleh, M. N., El-Bana, M. A., Khalifa, T. H., & Mospah, W. M. (2024). Enhancing Protein Digestibility, Bioaccessibility, and Nutrient Retention in Faba Beans Using Nano-Zinc Oxide and Thermal Treatments. Journal of Food and Dairy Sciences, 15(10), 133-142.
50.Scalbert, A., Johnson, I. T., & Saltmarsh, M. (2005). Polyphenols: Antioxidants and beyond. American Journal of Clinical Nutrition, 81(1 Suppl), 215S–217S.

51.Simpson, J. E., Adair, C. R., Kohler, G. O., Dawson, E. H., Deobald, H. J., Kester, E. B., ... & Halick, J. V. (1965). Quality evaluation studies of foreign and domestic rices. USDA Technical Bulletin, 1331, 1-187.
52.Sivakamasundari, P., Moses, S. J., & Natarajan, S. (2020). Effect of parboiling methods on the physicochemical characteristics of rice varieties. Journal of Food Science and Technology, 57, 1348–1356.
53.Steel, R. G. D., & Torrie, J. H. (1980). Principles and Procedures of Statistics: A Biometrical Approach (2nd ed.). McGraw-Hill.
54.Sultana, H., Hasan, M. S., Islam, M. S., Akter, N., & Islam, M. N. (2022). Grain eating and cooking quality evaluation of some rice varieties in Bangladesh. Cereal Research Communications, 50(4), 669–679.
55.Suwansri, S., & Meullenet, J. F. (2004). Physicochemical characterization and consumer acceptance by Asian consumers of aromatic jasmine rice. Journal of Food Science, 69(1), SNQ30-SNQ37.
56.Tomar, J.B. (1985). Studies on the inheritance of kernel size and its association with physical and chemical quality characters in rice, Z. Pflanzenzucht, 95: 361-366.
57.Ukpong, J. J., Udenigwe, C. C., & Aluko, R. E. (2023). Effect of steaming on physicochemical properties of parboiled rice. Food Science & Nutrition, 11, 3948–3958.
58.Walter, M., Silva, L. P., & Costa, H. (2013). Rice phenolics and antioxidant activity after cooking: Effects of parboiled and raw rice preparations. Food Research International, 54(2), 778–786.
59.Xu, F., Wang, S., Li, Y., Wang, W., & Yu, X. (2019).Effects of different water content and heating rate on gelatinization characteristics of rice starch. LWT, 111, 334-341.
60.Zhou, Z., Robards, K., Helliwell, S., & Blanchard, C. (2020). The distribution of phenolic acids in rice. Food Chemistry, 87(3), 401-406.
61.Zhuang, Y., Yan, R., & Sun, W. (2025). Investigation of the physicochemical factors affecting the in vitro digestibility and water uptake of rice. Scientific Reports, 15, 85660.
62.Zohoun, E. V., Akissoé, N., Faloye, O. T., & Hounhouigan, D. J. (2018). Effect of storage conditions on the quality of local rice (Oryza glaberrima) parboiled with improved techniques in Benin. Food Science & Nutrition, 6(5), 1166-1176.