

# Optimizing Postharvest Drying for Improved Rice Quality in Hadejia Region, Nigeria

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## Abstract

**Background:** Rice milling and cooking quality is crucial for consumer satisfaction and market value, heavenly dependable on postharvest handling, particularly drying and Hadejia region of Nigeria, known for its extensive rice cultivation, experiencing varied climatic conditions, resulting in challenges for optimizing postharvest processes. This study investigates the impact of various postharvest drying methods on rice quality, focusing on milling and cooking constraints across three common rice varieties (FARO-44, FARO-52, and FARO-60) growing in the Hadejia region. **Method:** Three common rice varieties grown in the Hadejia region—FARO 44, FARO 52, and FARO 60—were selected for this study due to their widespread cultivation in the area, as responded by the farmer and Three major rice-growing areas within the Hadejia axis were identified: Guri, Hadejia and Auyo. Mechanical, shade, and sun drying techniques were evaluated to determine their effects on head rice yield (HRY), broken rice percentage (BRP), milling recovery (MR), cooking time, elongation ratio, and gel consistency. **Results:** Mechanical drying significantly improved HRY, with FARO 44 yielding 92.92%, while sun drying resulted in the highest BRP (49.95% for FARO-60). Shade drying outperformed sun drying in terms of HRY and reduced BRP, demonstrating its efficacy as an intermediary method. Cooking quality assessments revealed that mechanical drying minimized cooking time (15-25 minutes) and enhanced elongation ratios (1.8-3.5), leading to superior gel consistency. The overall quality index (OQI) for FARO-44 reached 3770.62 under mechanical drying, while FARO 60 showed the most significant quality losses. Additionally, the drying efficiency index (DEI) followed a similar trend, with FARO-44 achieving the highest DEI of 0.1422. The correlation analysis indicated a negative relationship between BRP and key quality indicators, such as MR and gel consistency, while higher MR positively correlated with improved cooking parameters. The study established that mechanical drying consistently yields the best overall quality indices and drying efficiency, especially for FARO-44. Hence, underscores the importance of optimizing drying methods to enhance rice quality and provide actionable insights for rice production and the need for variety-specific recommendations in postharvest handling practices in Nigeria.

**Keywords:** Drying Methods, Hadejia, Optimization, Postharvest, Rice Quality.

## 1. Introduction

Rice is a staple food for millions of people around the world and plays a crucial role in the economy of many African countries, including Nigeria (Fukagawa & Ziska, 2019; Zakari et.al., 2022). Rice quality is crucial for both consumer satisfaction and market value, heavenly reliable on postharvest handling, particularly drying; as determining factor for the final quality (Müller et al. 2022). Rice production is a significant agricultural activity in the Hadejia axis of Jigawa State, Nigeria. The region is characterized by its extensive floodplain

and irrigation systems and is part of the Hadejia-Nguru Wetlands, which is a critical area for agriculture providing favorable conditions for rice cultivation (Orifah et al. 2021). The wetlands are fed by the Hadejia River, which provides a reliable water source for irrigation. Several rice varieties are cultivated in the Hadejia axis, with the choice of variety often influenced by factors such as yield potential, resistance to pests and diseases, and market preferences (Abdulumuni, et al. 2021; Hadiza et al. 2022). The Hadejia axis, known for its extensive rice cultivation and experiences varied climatic conditions, resulting in challenges for optimizing postharvest processes to enhance rice quality, thus, affect the postharvest drying process.

Aggregate paddy yield in rice does not directly translate to augmenting food security because significant decrease in grain yield occurs during postharvest processing of the paddy rice (Tong et al. 2019). In parallel with improving paddy yield, enhancing the milling and cooking quality of rice is indispensable in ensuring food security by mitigating the impact of significant losses during the postharvest processing of rice grains. After harvesting, wet paddy needs to be dried to reduce grain moisture content to a safe level for storage. Implying that postharvest treatment is one of the important factors determining the final yield and quality of rice (Inprasit and Noomhorm, 2001; Wongpornchai et. al., 2004). Additionally, proper postharvest handling, especially drying, ensures that the rice maintains its nutritional value, taste, and marketability (Li, Yi, and Jin 2024). Effective postharvest management can significantly reduce losses, improve food security, and enhance the income of rice farmers. Rice harvesting in the Hadejia axis typically depend on the variety and planting time. Harvesting is done manually or using mechanical harvesters while timely harvesting is essential to prevent grain shattering and loss (Müller et al. 2022) and harvesting at the right moisture content (20-25%) ensures better grain quality and reduces postharvest losses. Many farmers in the Hadejia axis lack access to adequate drying facilities (Orifah et al. 2021), henceforth, heavenly relies on traditional sun and shade drying methods. Meas et al. (2011) reported that these methods are weather-dependent and can result in uneven drying, grain discoloration, and quality deterioration and the methods typically involve sun drying, where rice is spread on open ground or mats. While sun drying is cost-effective, it exposes the rice to environmental contaminants, uneven drying, and potential rewetting from unexpected rain (Meas et al. 2011). These inadequacies are resulting in inconsistent grain quality, and increased postharvest losses. Consequently, the use of inadequate drying practices in the Hadejia region might leads to several adverse outcomes such as high moisture content, poorly dried rice with a shorter shelf life, affecting its storage and transportability, adulterated rice posing health risks to consumers, affecting overall food safety in the region and lower quality, resulting to higher losses that translate to reduced income for farmers and higher prices for consumers.

The poor quality of the locally produced rice available in Hadejia axis markets is a combination of the types of rice varieties grown, pedestrian postharvest management and processing methods (Meas et al. 2011; Shuaibu, Muhammad, and Abu-Safyan 2022). The study of Sahu et al. 2017, reported that to meet the consumer preference and market demands, improvement of milling and cooking quality is the most important objective next to yield improvement. Therefore, breeding rice varieties that encompass desirable milling and appearance quality becomes a prime objective for rice breeders around the world (Wang et al. 2002; Li et al. 2024)). Several line of studies such as Zaidi et al. (2019); Sahu et al. (2017), and Fatema et al. (2011) have studied various genetic variability parameters and correlations on rice grain quality. However, to date, the genetic variability for milling and cooking quality of common rice in Nigeria has not been thoroughly studied. Rice breeders require information on the genetic variability in milling heritability and germplasm of target cooking traits to predict gain from selection. Optimizing postharvest drying methods will reduce postharvest losses, enhance rice quality, and increase farmers' income. Sustainable drying practices can reduce the reliance on traditional methods that may harm the environment, such as sun drying. Currently, there is a lack of access to advanced drying technologies for rice in Hadejia axis in addition to challenges posed by the region's weather patterns, such as high humidity and unexpected rainfall. Hence, there is a clear need for improved drying techniques that are suitable for the Hadejia region's specific climatic conditions and resource constraints. By addressing these gaps and implementing optimized drying methods, the Hadejia region can significantly improve its rice production and postharvest management practices, contributing to overall agricultural sustainability and economic development. This study aims to evaluate the effects of different postharvest drying conditions on the milling and cooking qualities of common rice varieties grown in the Hadejia axis.

## 2. Materials and Methods

### 2.1 Selection of Rice Varieties

Three common rice varieties grown in the Hadejia region—FARO 44, FARO 52, and FARO 60—were selected for this study due to their widespread cultivation in the area, as responded by the farmer in the axis (Table 1).

**Table 1:** Characteristics of Three common rice varieties grown in Hadejia Axis

S/No	Variety	Reason for Selection
1	FARO 44 (SIPI)	a. Widespread cultivation in rainfed lowland areas. b. Drought tolerance. c. High yield potential and good grain quality.
2	FARO 52 (WITA 4)	a. High-yielding variety b. Resistant to common rice diseases like blast and brown spot
3	FARO 60 (Gajera)	a. Robust performance under various environmental stresses such as salinity and flooding b. Early maturity c. Performs well in harsh conditions and suitable for climate variability studies
4	General Reasons	a. Widespread cultivation and adaptation in Hadejia axis b. Significant differences in yield potential. c. Converge on post-harvest quality and response to drying methods d. Importance for both domestic consumption and export markets e. Valuable for optimizing rice production and quality improvements.

**Source:** Field Survey 2024

### 2.2 Sampling Procedure

Three major rice-growing areas within the Hadejia axis were identified: Guri, Hadejia and Auyo. In each identified area, three fields (one for each variety) were selected randomly and replicated three times. Rice from each plot was harvested at physiological maturity, ensuring uniformity in grain development and approximately 5 kg of paddy rice was collected from each plot to provide a sufficient sample size for postharvest drying and quality assessment. The harvested rice was transported to the laboratory for immediate processing. Samples were handled carefully to prevent physical damage and contamination during transportation. The rice samples from each plot were mixed thoroughly and a subsample of 1 kg was taken from the mixed sample for each drying method (sun drying, shade drying, and mechanical drying). This process was repeated for all three rice varieties, resulting in a total of 27 subsamples (3 varieties × 3 drying methods × 3 replicates).

### 2.3 Drying Conditions

Three drying conditions were employed: Sun drying (most common method by the farmers), Shade drying (employed by many farmers, particularly during rainy season) and Mechanical drying (Morden drying technology).

- A. Sun Drying: rice samples were spread thinly in a single layer on clean tarpaulin and placed in an open area with maximum exposure to sunlight and minimal obstruction any shading. Samples were stirred periodically, approximately every 1-2 hours and the moisture content of the rice was monitored regularly using a portable moisture meter (Riceter F501) until the moisture content reduced to 14%. (Ambient temperature: 35-38°C and relative humidity: 30-70% were recorded at regular intervals (morning, midday, and afternoon) using a digital hygrometer).
- B. Shade Drying: rice samples were placed in a well-ventilated shaded area under a roof with open sides and was protected from direct sunlight and rain. Moisture content and ambient temperature was measure as for sun drying.

- C. Mechanical Drying: rice samples were placed in perforated trays and loaded into a mechanical dryer (CLJ Paddy Dryer Plant - 5H-10 Model). The dryer was set to a constant temperature of 45°C, airflow rate and temperature were controlled and monitored to ensure consistent drying conditions throughout the process as described in Zhang & Zhang (2020). The dried samples were immediately packed as whole grains in a plastic bag and kept in a polystyrene box overnight (to avoid moisture migration). The samples were then stored for 1 week at room temperature prior to quality assessment and the grains were subjected to a husking and polishing process.

## 2.4 Determination of Milling Quality

The milling qualities was measured according to Müller et al. (2022) with little modification; approximately 1 kg sample of dried rice (per drying condition per variety) was dehusked using a laboratory-scale rice dehusker (Kett TR-130) to obtain brown rice and milled rice with the timer set at 15 s. Whitening of the brown rice was done by abrasive action, using the Whitener with the timer set at 60 s to obtain the white rice (milling yield). The separation of broken grains from the head rice was done through indented cylinder (5.5 mm) by selecting the grading mode with the timer set at 60 s. The whole kernels (head rice) was separated from the broken kernels using rice grader, both whole and broken kernels were weight, respectively. The parameters were calculate using the formula:

$$\text{Head Rice Yield (\%)} = (\text{Weight of whole kernels} / \text{Total weight of milled rice}) \times 100$$

$$\text{Broken Rice Percentage (\%)} = (\text{Weight of Broken Kernels} / \text{Total Weight of Milled Rice}) \times 100$$

The total weight of the paddy rice before dehusking and whitening, and the total milled rice (head rice + broken rice) after whitening were measured, respectively and calculated Milling Recovery using the formula:

$$\text{Milling Recovery (\%)} = \left( \frac{\text{Weight of Milled Rice}}{\text{Total Weight of paddy}} \right) \times 100$$

## 2.5 Determination of Cooking Quality

As previously described in Patria et al. (2020) with a slight modification; 100 grams of polished rice is cooked in a standardized amount of water (usually 1:2 rice to water ratio) using a rice cooker (SRE-3800 Model). The cooking time is recorded from the start of cooking until the rice is fully cooked (soft and fully gelatinized). The end point of cooking is determined by pressing a grain between fingers to ensure there is no hard core. The weight of rice before and after cooking is measured using a precision balance.

- a. For the gel consistency, 100 mg of rice flour is mixed with 2 ml of 0.2N KOH in a test tube. The mixture is heated in a boiling water bath for 8 minutes and then cooled at room temperature for 5 minutes. The test tube is then placed horizontally on a flat surface. After 30 minutes, the length of the gel spread in the test tube is measured using a ruler. Gel consistency is classified based on the length of the gel spread (e.g., soft, medium, or hard gel).

b. Water Absorption Ratio =  $\left( \frac{\text{Weight of Cooked rice}}{\text{Weight of Uncooked rice}} \right)$

- c. The length of 10 uncooked rice grains and 10 cooked rice grains is measured using a vernier caliper, elongation ration was calculated as: =  $\left( \frac{\text{Average length of Cooked rice}}{\text{Average length of Uncooked rice}} \right)$

## 2.6 Statistical Analysis

Data collected from the experiments were analysed using Analysis of Variance (ANOVA) to determine the significance of differences among the drying treatments. To evaluate significant differences between the means, Tukey's HSD (post-hoc test;) was employed, using SPSS package software (Chicago, USA).

## 3. Results and Discussion

### 3.1 Inducement of Drying Methods on Milling Quality of Rice

The result in Table 2 shows that mechanical drying resulted in the highest HRY, particularly for FARO 44 (92.92%), FARO 52 (79.22%), and FARO 60 (67.71%). In contrast, sun drying led to the lowest HRY, with

FARO 44 at 73.78%, FARO 52 at 59.33%, and FARO 60 at 57.48%. Shade drying produced intermediate HRY values, highlighting its moderate effectiveness in comparison to mechanical drying but still outperforming sun drying. The effects of various drying methods—mechanical, shade, and sun drying—on the milling quality of rice have been extensively studied on different varieties and locations (Mahmood et al. 2024). Consistent with previous research, mechanical drying significantly improves the head rice yield (HRY) and reduces the broken rice percentage (BRP) across all rice varieties examined in this study. Jindal and Siebenmorgen (1987) demonstrated that mechanical drying reduces grain breakage by providing better control over drying temperature and humidity. Mechanical drying also resulted in the lowest BRP, with FARO 44 showing 2.21%, FARO 52 at 8.05%, and FARO 60 at 10.24%, further confirming its superiority in preserving grain integrity. Conversely, sun drying led to the highest BRP values due to the rapid moisture loss and uneven drying that often induce fissures in the grains. Shade drying reduced BRP compared to sun drying, but it was still not as effective as mechanical drying, aligning with Choudhury et al. (2009), who observed that slower drying rates, such as those in shade drying, alleviate thermal stress on the grains but cannot fully prevent breakage. The milling recovery (MR) followed a similar trend. Mechanical drying yielded the highest MR for FARO 44 (78.51%), FARO 52 (66.65%), and FARO 60 (63.1%), indicating that this method is the most efficient in maximizing the proportion of whole grains after milling. Sun drying had the lowest MR, especially for FARO 60 (50.05%), likely due to thermal stress during the drying process, which causes grain breakage. These results corroborate the earlier findings by Khush et al. (2018), who observed that controlled drying methods enhance milling recovery by reducing the risk of grain damage.

### 3.2 Influence of Drying Methods on Grain Breakage and Quality

Grain breakage is a key determinant of rice quality and market value. The comparison of three drying methods reveals that mechanical drying consistently minimized grain breakage, with FARO 44 exhibiting the lowest breakage rate (7.08%), FARO 52 at 24.8%, and FARO 60 at 31.66% (Table 3). Sun drying, in contrast, showed the highest breakage rates, particularly for FARO 60 (49.95%), which is more susceptible to breakage due to its longer grains and susceptibility to fissures. These findings are consistent with Kumar and Kalita (2017), who reported that mechanical drying preserves grain structure by maintaining moisture balance and preventing rapid shrinkage of grains. Shade drying also reduced breakage compared to sun drying but remained less effective than mechanical drying. The intermediate performance of shade drying is in line with the conclusion by Perdon et al. (2017) that uniform but slower drying helps maintain grain integrity but cannot fully eliminate the adverse effects of drying stress, such as those caused by environmental variations in temperature and humidity. The head rice to broken rice ratio followed a similar trend (Table 3), with mechanical drying producing the highest ratio for FARO 44 (42.05), FARO 52 (9.84), and FARO 60 (6.61). Shade drying, while less efficient than mechanical drying, produced better ratios than sun drying, suggesting it provides a moderate improvement in preserving head rice yield. Donlao (2023) reported a positive effect of shade drying in reducing the negative impacts of rapid sun drying on rice milling quality. This higher milling efficiency reflects the proficiency of mechanical drying in reducing broken grains ratio and improving the proportion of whole grains post-milling, as previously reported in Li, Yi, and Jin (2024).

### 3.3 Cooking Quality Under Different Drying Methods

Cooking quality is a critical aspect of consumer preference, and drying methods have a notable impact on cooking parameters such as cooking time, elongation ratio, and gel consistency (Fig. 1). Mechanical drying generally resulted in the shortest cooking time across all rice varieties, with FARO 44 cooking in 15-25 minutes (Fig. 1A), FARO 52 in 18-26 minutes, and FARO 60 in 19-27 minutes. In comparison, sun drying produced the longest cooking times, ranging from 25-30 minutes for FARO 44, and 27-32 minutes for FARO 60. The shorter cooking times associated with mechanical drying suggest that it enhances grain hydration and cooking efficiency, which is in agreement with previous studies that emphasize the importance of moisture uniformity in improving cooking properties (Khush et al., 2018). Mechanical drying also resulted in the highest elongation ratio (1.8-3.5 for FARO 44) and the best gel consistency, indicating superior cooking quality (Fig. 1B & C). Gel consistency, which measures the firmness of cooled cooked rice, was most favorable under mechanical drying (Fig. 1C). The improved gel consistency can be attributed to the

preservation of grain integrity during mechanical drying, which reduces the loss of soluble starch and maintains the desired texture in cooked rice (Patria et al. 2020). Shade drying produced moderate cooking times and elongation ratios, while sun drying had the poorest performance, resulting in stiffer gel consistency and longer cooking times. These observations align with the work of Kumar and Kalita (2017), who noted that mechanical drying not only optimizes milling performance but also enhances the cooking and sensory qualities of rice.

### 3.4 Variety-Specific Responses to Drying Methods

The study highlights the need for variety-specific recommendations for drying methods the variety-specific responses to drying methods were explored. The result shows that different rice varieties perform optimally under distinct drying conditions (Table 3). For instance, FARO 44 exhibited the most significant improvements in head rice yield (HRY), bran recovery percentage (BRP), and cooking quality when subjected to mechanical drying. This can be attributed to its ability to withstand the controlled temperature and moisture conditions offered by mechanical dryers, which prevent excessive cracking and breakage due to sudden moisture loss (Yu et al. 2024). The structure of FARO 44's endosperm might be better suited to gradual moisture removal, allowing for more uniform drying and less internal stress on the grains. FARO 52, although it also showed improvements under mechanical drying, performed relatively consistently across all drying methods. This suggests that FARO 52 is more resilient to the stress imposed by various drying techniques. A possible explanation for this resilience could be its denser endosperm structure or a more adaptable starch composition, which reduces the likelihood of internal fissures when exposed to changes in moisture and temperature (Lang et al. 2018). Conversely, FARO 60 showed increased susceptibility to breakage and a lower milling recovery (MR) under all drying methods (Table 2), with the greatest negative impact observed during sun drying. The high vulnerability of FARO 60 to sun drying can be attributed to its lower structural integrity, possibly due to a more brittle grain structure or a higher amylose content, which makes it prone to stress during rapid moisture loss in uncontrolled drying conditions (Yousaf, Chen, and Yu 2022). This highlights the need for specialized drying protocols, such as gentler or more controlled methods, to preserve the milling and cooking quality of FARO 60. The comparative analysis demonstrates that while some varieties thrive in controlled drying environments, others, like FARO 52, exhibit greater versatility, and still others, such as FARO 60, require more delicate handling during the drying process to optimize their post-harvest quality.

Table 6 provide a comparative analysis of three rice varieties (FARO 44, FARO 52, and FARO 60) under different drying methods—mechanical, sun, and shade—highlighting the variations in quality indices and drying efficiency. For FARO 44, the impact of mechanical drying was significantly higher compared to sun and shade drying methods, with a value of 19.14 for the mechanical-sun comparison and 11.07 for mechanical-shade. FARO 52 exhibited a similar trend with values of 19.89 and 12.19, respectively. In contrast, FARO 60 had the lowest values, indicating its higher susceptibility to degradation during drying, particularly in sun-drying conditions, with values of 10.23 and 9.18 ( $p \leq 0.05$ ). These findings highlight that mechanical drying is superior for maintaining the quality of FARO 44 and FARO 52 compared to sun drying, which caused more significant losses in FARO 60 due to increased susceptibility to breakage (Müller et al. 2022). The relative milling recovery (RMR) for FARO 44 was highest under mechanical drying (0.1454), followed by shade (0.1273), and was lowest under sun drying (0.1059). FARO 52 and FARO 60 followed the same trend, though FARO 60 had significantly lower RMR values across all drying methods. This confirms the negative impact of sun drying, which is likely due to the uncontrolled drying conditions leading to grain fissuring and higher breakage rates (Müller et al. 2022). FARO 44 consistently outperformed the other varieties in milling recovery, demonstrating that it is better suited for mechanical drying, while FARO 60 is more sensitive and requires gentler handling.

The overall quality index (OQI) for FARO 44 showed a marked improvement with mechanical drying, reaching 3770.62, compared to 757.79 for shade drying and 388.34 for sun drying. Similarly, FARO 52 and FARO 60 showed improved OQI with mechanical drying but to a lesser extent, with FARO 60 having the lowest values across all drying methods. These results suggest that FARO 44 responds best to mechanical

drying, while FARO 60 suffers greater losses in quality when subjected to harsher drying conditions, such as sun drying. This could be due to the structural composition of FARO 44, which may have a more robust grain morphology that tolerates mechanical drying better (Donlao 2023). The drying efficiency index (DEI) also followed a similar pattern, with FARO 44 having the highest DEI under mechanical drying (0.1422), followed by shade drying (0.115), and sun drying (0.0962). FARO 52 showed intermediate performance, while FARO 60 had the lowest DEI across all methods, particularly under sun drying (0.0574). These differences highlight the varying adaptability of rice varieties to drying-induced stress, where FARO 44 and FARO 52 are better suited to controlled drying environments like mechanical drying, whereas FARO 60 may require more specialized and gentle drying protocols to minimize damage (Jiang & Huang, 2022).

### 3.5 Interrelationship Between Milling Efficiency and Cooking Quality Attributes

The analysis in Table 7 reveals significant correlations between milling quality parameters, such as BRP and milling recovery (MR), and cooking quality metrics, including water absorption ratio (WAR), elongation ratio (ER), and gel consistency (GC). BRP was found to have a negative correlation with MR, WAR, ER, and GC, suggesting that higher rates of breakage during milling are associated with inferior cooking quality (Sun & Xie, 2019). Specifically, rice with higher BRP tends to exhibit lower water absorption and elongation, which leads to extended cooking times and a less desirable texture. This could be attributed to the fact that broken grains have more surface area exposed to water during cooking, resulting in uneven water absorption and reduced swelling capacity. In contrast, MR showed a positive correlation with WAR, ER, and GC, indicating that improved milling performance, characterized by higher recovery of whole grains, contributes to better cooking properties (Chen et al., 2021). Rice with higher MR typically absorbs water more uniformly, expands better during cooking, and has a softer texture due to more consistent gel consistency. The positive relationship between MR and these cooking quality parameters underscores the importance of minimizing grain breakage during milling, as it directly influences the final product's cooking behavior and consumer acceptability. Hence, these findings highlight the interconnectedness of milling and cooking qualities, reinforcing the need to focus on milling practices that minimize breakage to optimize both the appearance and cooking characteristics of rice. Efforts to enhance milling efficiency, therefore, not only improve milling yield but also contribute to better cooking performance, making it essential to adopt strategies that reduce damage to grains during processing.

## 4. Conclusion

The findings of this study emphasize the superiority of mechanical drying in enhancing both milling and cooking qualities, with significant implications for commercial rice processing. Mechanical drying not only maximizes HRY and reduces BRP but also improves cooking efficiency by reducing cooking time and enhancing the texture of cooked rice. These advantages make it a preferred method for large-scale rice processing, where maintaining grain integrity and optimizing quality are critical for market competitiveness. Furthermore, the variety-specific responses to drying methods underscore the need for tailored drying protocols to maximize the quality of different rice varieties in Hadejia axis. The results indicate that FARO 44 is the most resilient variety under mechanical drying conditions, achieving the highest values across the quality and efficiency indices. FARO 52 also benefits from mechanical drying but performs reasonably well under all drying methods, indicating its resilience. Though, FARO 60 is more prone to quality degradation, especially under sun drying, necessitating careful handling and potentially specialized drying protocols to maintain its milling and cooking quality. These findings accentuate the importance of fitting drying methods to specific rice varieties for optimizing quality and efficiency. Nevertheless, further research may be necessary to develop more efficient drying methods and breeding for varieties like FARO 60, which showed lower resilience to drying-induced stress. Overall, the study confirms that drying method and variety selection is a crucial factor in determining rice quality, with mechanical drying emerging as the most effective method across the board, as well as FARO 44 particularly for enhancing both milling and cooking qualities.

**Table 2:** Impact of Different Drying Methods on the Milling Quality Parameters of Three Rice Varieties

	Variety	Sun drying	Shade drying	Mechanical drying
<b>Head Rice Yield</b>				
	FARO 44	73.78±1.8 <sup>a</sup>	81.85±3.11 <sup>a</sup>	92.92±2.26 <sup>a</sup>
	FARO 52	59.33±3.6 <sup>b</sup>	67.03±1.86 <sup>b</sup>	79.22±3.61 <sup>b</sup>
	FARO 60	57.48±1.6 <sup>b</sup>	58.53±0.87 <sup>c</sup>	67.71±1.83 <sup>c</sup>
<u>Interaction</u>	DM*Variety	Sun*Shade	Sun*Mechanical	Shade*Mechanical
	F-value: 2.67	*	**	*
<b>Broken Rice %</b>				
	FARO 44	12.41±1.2 <sup>c</sup>	8.48±0.85 <sup>c</sup>	2.21±0.03 <sup>c</sup>
	FARO 52	15.63±0.91 <sup>b</sup>	13.68±2.0 <sup>b</sup>	8.05±0.05 <sup>b</sup>
	FARO 60	20.85±1.6 <sup>a</sup>	15.27±1.44 <sup>a</sup>	10.24±0.13 <sup>a</sup>
<u>Interaction</u>	DM*Variety	Sun*Shade	Sun*Mechanical	Shade*Mechanical
	F-value: 3.12	*	**	*
<b>Milling Recovery %</b>				
	FARO 44	65.32±2.21 <sup>a</sup>	78.51±4.1 <sup>a</sup>	89.68±2.67 <sup>a</sup>
	FARO 52	60.12±2.0 <sup>b</sup>	66.65±3.6 <sup>b</sup>	75.2±2.8 <sup>b</sup>
	FARO 60	50.05±3.4 <sup>a</sup>	63.1±4.3 <sup>c</sup>	68.34±2.9 <sup>c</sup>
<u>Interaction</u>	DM*Variety	Sun*Shade	Sun*Mechanical	Shade*Mechanical
	F-value: 2.89	*	*	*

\*Significant at the 0.05 probability level, \*\*Significant at the 0.01 probability level. Different letters within the columns indicate a significant difference between varieties at  $P \leq .05$  level.

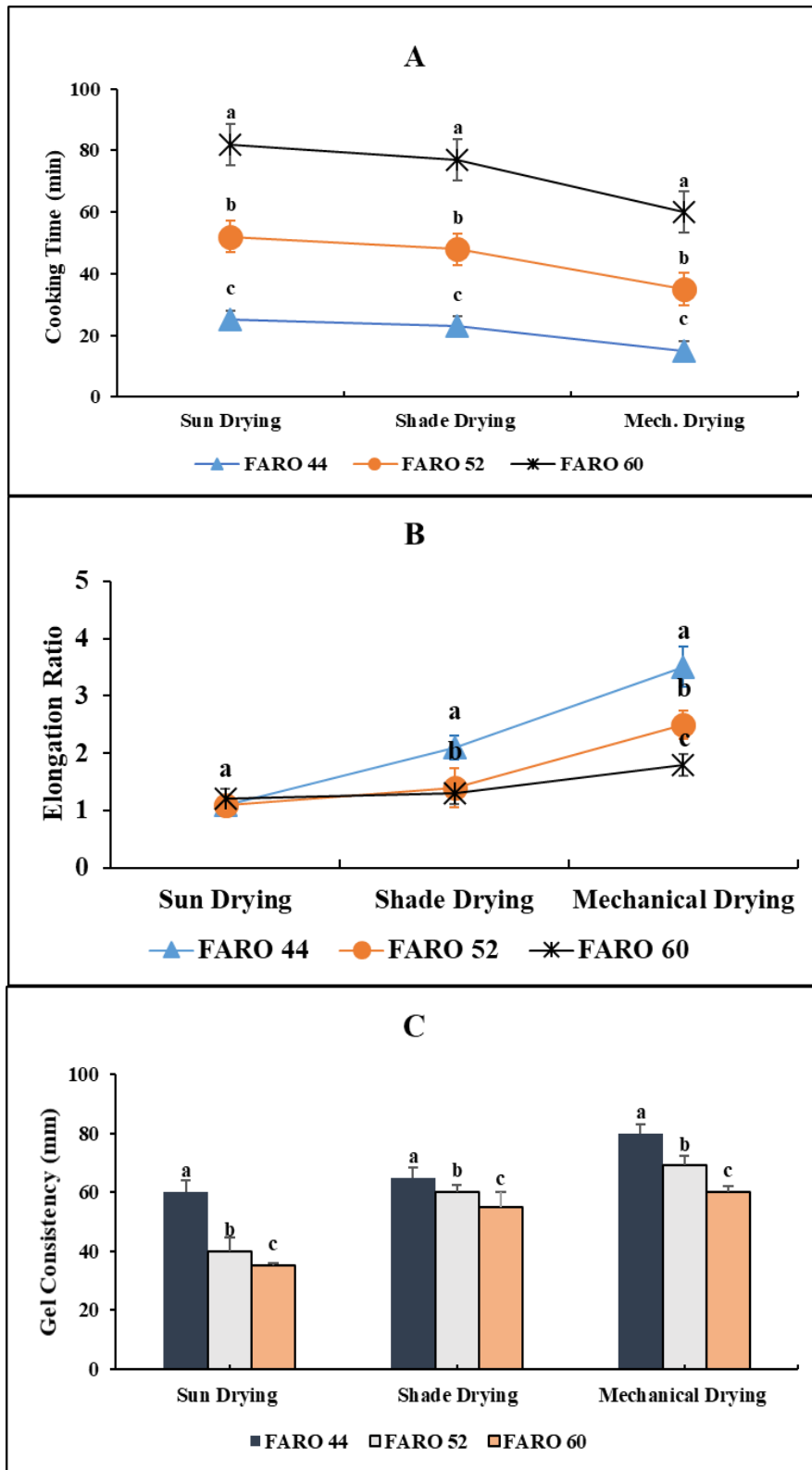


**Table 3:** The Comparison of the Milling Quality Index for Three Rice Varieties under Different Drying Methods

Variety	Drying Method	Grain Breakage Rate <sup>1</sup>	Broken Grain Ratio	Head Rice to Broken Rice Ratio	Milling Efficiency <sup>2</sup>
<b>FARO 44</b>	Sun drying	26.22 <sup>a</sup>	0.17	5.95 <sup>c</sup>	5.26 <sup>c</sup>
	Shade drying	18.15 <sup>b</sup>	0.10	9.65 <sup>b</sup>	9.26 <sup>b</sup>
	Mechanical drying	7.08 <sup>c</sup>	0.024	42.05 <sup>a</sup>	40.56 <sup>a</sup>
	<u>Means</u>	17.15C	0.098B	19.21A	18.36C
<b>FARO 52</b>	Sun drying	39.88 <sup>a</sup>	0.21	3.80 <sup>c</sup>	60.12 <sup>c</sup>
	Shade drying	33.35 <sup>b</sup>	0.17	4.90 <sup>b</sup>	66.65 <sup>b</sup>
	Mechanical drying	24.80 <sup>c</sup>	0.09	9.84 <sup>a</sup>	75.20 <sup>a</sup>
	<u>Means</u>	32.67B	0.15A	6.18B	67.32A
<b>FARO 60</b>	Sun drying	49.95 <sup>a</sup>	0.27	2.76 <sup>b</sup>	50.05 <sup>c</sup>
	Shade drying	36.9 <sup>b</sup>	0.21	3.83 <sup>b</sup>	63.10 <sup>b</sup>
	Mechanical drying	31.66 <sup>c</sup>	0.13	6.61 <sup>a</sup>	68.34 <sup>a</sup>
	<u>Means</u>	39.50A	0.20A	4.40C	60.49B

Different letters within the columns indicate a significant a difference between drying methods and means value indicate a significant difference between varieties under all the drying methods at P ≤ .05 level. <sup>1</sup>Grain Breakage Rate (%) = (Total Weight of Milled Rice/Weight of Broken Grains) ×100.

<sup>2</sup>Milling Efficiency (%) = (Weight of Paddy Rice/Weight of Milled Rice) ×100



**Figure 1:** Common Cooking qualities elements with differential response to drying condition. Different letters show significant differences between varieties at 5% probability level.

**Table 4:** The Drying Method Comparison on Differences in Cooking Time, Elongation Ratio, and Gel Consistency

Variety	Comparison	Cooking Time Difference	Elongation Ratio Difference	Gel Consistency Difference
FARO 44	Sun vs. Shade	2	-1	-5
	Sun vs. Mechanical	10**	-2.4**	-20
	Shade vs. Mechanical	8	-1.4	-15
FARO 52	Sun vs. Shade	2	-0.3	-20
	Sun vs. Mechanical	7	-1.4	-29**
	Shade vs. Mechanical	5	-1.1	-9
FARO 60	Sun vs. Shade	1	-0.1	-20
	Sun vs. Mechanical	5	-0.6	-25
	Shade vs. Mechanical	4	-0.5	-5

\*Significant at the .05 probability level, \*\*Significant at the .01 probability level. The absolute difference between the means of different drying methods were calculated as Difference=Mean Method A–Mean Method B

**Table 5:** The Impact of the Percentage Changes on Varieties and Drying Methods on Some Physical Cooking Properties of Rice

	Comparison	Cooking Time (%)	Elongation Ratio (%)	Gel Consistency (%)
FARO 44	Sun vs. Shade	-0.08	0.909	0.083
	Sun vs. Mechanical	-0.4	2.182**	0.333
	Shade vs. Mechanical	-0.348	0.667	0.231
FARO 52	Sun vs. Shade	-0.074	0.273	0.5
	Sun vs. Mechanical	-0.259	1.273	0.725**
	Shade vs. Mechanical	-0.2	0.786*	0.15
FARO 60	Sun vs. Shade	-0.033*	0.083	0.571
	Sun vs. Mechanical	-0.167	0.5	0.714
	Shade vs. Mechanical	-0.138	0.385	0.091

Significant at the\*0 .05 probability level, Significant at the\*\* 0 .01 probability level.

**Table 6:** Comparative Analysis of the Impact of Different Drying Methods on the Overall Quality Index, and Drying Efficiency Index for Three Rice Varieties

	FARO 44	FARO 52	FARO 60
<b>Impact of Drying (Mechanical - Sun)</b>	19.14 <sup>a</sup>	19.89 <sup>a</sup>	10.23 <sup>b</sup>
<b>Impact of Drying (Mechanical - Shade)</b>	11.07 <sup>a</sup>	12.19 <sup>a</sup>	9.18 <sup>b</sup>
<b>Relative Milling Recovery (Sun)</b>	0.1059 <sup>a</sup>	0.0974 <sup>ab</sup>	0.0811 <sup>b</sup>
<b>Relative Milling Recovery (Shade)</b>	0.1273	0.108	0.1023
<b>Relative Milling Recovery (Mechanical)</b>	0.1454	0.1219	0.1108
<b>Overall Quality Index (Sun)</b>	388.34 <sup>a</sup>	228.21 <sup>b</sup>	137.98 <sup>c</sup>
<b>Overall Quality Index (Shade)</b>	757.79 <sup>a</sup>	326.58 <sup>b</sup>	241.86 <sup>c</sup>
<b>Overall Quality Index (Mechanical)</b>	3770.62 <sup>a</sup>	740.04 <sup>b</sup>	451.88 <sup>c</sup>
<b>Drying Efficiency Index (Sun)</b>	0.0962	0.0685	0.0574
<b>Drying Efficiency Index (Shade)</b>	0.115	0.0836	0.0678
<b>Drying Efficiency Index (Mechanical)</b>	0.1422 <sup>a</sup>	0.1116 <sup>a</sup>	0.0901 <sup>b</sup>

Different letters within the row indicate a significant difference between varieties at  $P \leq .05$  level.

Relative Milling Recovery= (Paddy weight/Milled weight) ×100, Overall Quality Index= $\sum$ Quality Scores/3

Drying Efficiency Index=Energy Used (kWh) Moisture Reduction (kg). Where: Moisture Reduction was calculated as the difference in moisture content before and after drying. Energy Used is the average temperature during the drying process (for sun and shade drying) and energy consumed for mechanical

**Table 7:** The Correlation Matrix Overview of the Relationships Between Key Rice Quality Parameters

	HRY	BRP	MR	CT	WAR	ER	GC
Head Rice Yield (HR)	1	-0.912	0.845	-0.860	0.925	0.910	0.905
Broken Rice Percentage (BRP)		1	-0.855	0.845	-0.890	-0.880	-0.865
Milling Recovery (MR)			1	-0.87	0.875	0.861	0.853
Cooking Time (CT)				1	-0.88	-0.875	-0.862
Water Absorption Ratio (WAR)					1	0.895	0.890
Elongation Ratio (ER)						1	0.871
Gel Consistency (GC)							1

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