Association mapping of Grain Dimensions and Head Rice Recovery in Rice Varieties of Punjab, Pakistan

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Abstract

Head rice recovery (HRR) is an important measure of rice milling quality that plays an important role in defining the market and price of rice. Although consumers mostly favor long/extra-long grain kernels, these rice varieties often do not achieve optimal milling recovery. This study examined the relationship between grain dimensions (length and width) and HRR in Basmati and non-Basmati rice varieties of Punjab, Pakistan. Correlation and regression analyses were applied to evaluate this relationship. The results showed that length was negatively related to HRR, while kernel width had a positive effect on milling recovery. Varieties with longer grain size were more prone to breakage during milling and subsequently had a lower head rice percentage. In light of these findings, breeding efforts focused solely on grain length may compromise milling recovery, cooking quality, and economic returns. Future rice improvement programs for long/extra-long grain varieties should focus on parboiling technology and steam rice to strengthen kernels, reduce breakage, and improve head rice recovery while preserving other desired characteristics preferred by breeders and consumers.

Keywords: Grain length, kernel width, head rice recovery, milling fraction, regression

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1 Introduction

Rice (*Oryza sativa* L.) is one of the most extensively cultivated and widely consumed cereals globally. It is a key energy source for more than half of the population that consumes rice as a staple food. The rice crop significantly contributes to global trade and rural livelihoods, boosting agricultural growth beyond its role in food security. In Asian countries, especially Pakistan and India, rice is not only an essential staple but also a significant foreign-exchange commodity. Therefore, rice breeding programs aim to pool genes that provide not only high yield but also superior kernel quality (Custodio et al., 2019; Razavi & Farahmandfar, 2008). Post-harvest grain quality is a multifaceted trait influenced by physical and processing characteristics. Crop yield determines production potential, but grain quality largely drives market choice, volume, and economic value. The market sets rice variety prices mainly based on grain size, quality, and appearance. Long/extra-long and slender grains are usually highly priced in premium rice markets due to superior quality, especially in aromatic types such as Basmati and Jasmine (Bhattacharya, 2011; Fitzgerald et al., 2009; Juliano, 2010).

Pakistan and India play a unique role in the international rice market because of the geographical indication "Basmati rice." Pakistani premium Basmati rice is famous for its distinctive aroma, long and slender grain appearance, taste, and length-wise elongation upon cooking. Many rice consumers demand extra-long/long grains ranging from 7.5 to 9.5 mm in kernel length, which has encouraged breeders to focus on increasing grain length; however, visual appearance does not always reflect better milling and cooking performance. Consequently, disproportionate grain length may increase susceptibility to breakage during harvesting, ultimately reducing milling recovery and financial returns (Ali et al., 2024; Singh et al., 2020).

Milling quality is one of the most critical components of overall rice quality because it directly affects the profitability of rice millers throughout the rice value chain. The primary measure of milling quality is head rice recovery (HRR), the percentage of whole kernels remaining after milling (Siebenmorgen et al., 2013). Because broken rice generally commands a lower market price than whole kernels, even small improvements in HRR can yield substantial economic benefits for producers, millers, and exporters. Therefore, understanding the factors that influence HRR is essential to developing commercially successful rice varieties (Zhao et al., 2022). Numerous factors, including genetics, environmental conditions, harvesting practices, drying methods, storage conditions, and grain morphology, influence kernel breakage during

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milling. Among these factors, grain dimensions have received considerable attention because they are highly heritable and can be effectively manipulated through breeding (Kabir et al., 2024). Previous studies have reported that long and slender grains tend to experience greater mechanical stress during milling and are therefore more prone to fissuring and breakage. Conversely, wider grains often have greater structural integrity and resistance to mechanical damage, leading to higher head rice yields (Lanning et al., 2011).

The physical appearance of a rice grain principally regulates its ability to survive dehusking and polishing operations. Long/extra-long grains have a higher length-to-width ratio, which creates fragile points in the middle of the kernel and results in fissures (Cuevas et al., 2016). Moreover, uneven moisture content and uncontrolled drying produce internal pressure that is more pronounced in cooked grains. These stresses cause cracks, which further lead to milling breakage. Extra-long grain varieties may therefore exhibit lower milling recovery despite their attractive appearance (Cnossen et al., 2003; Paul et al., 2019).

In Pakistan, rice breeding efforts emphasize grain appearance and cooking quality, but relatively little scientific information is available on the relationship between grain dimensions and head rice recovery in these cultivars. Understanding this relationship matters because export competitiveness depends not only on grain appearance but also on milling efficiency and the proportion of whole, healthy kernels available for sale. A complete estimate of grain dimensions and their association with HRR is needed (Mihretu, 2025), given the growing demand for premium-quality rice and the economic importance of milling recovery. Therefore, this study investigated the relationship between grain length and width and rice milling efficiency in indigenous rice lines. The results will provide valuable information for breeders and millers working to develop and promote rice varieties that combine desirable grain appearance with superior milling recovery and economic value.

2. Materials and Methods

Nine rice varieties (Basmati and non-Basmati paddy) were collected from the research area of the Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan.

2.1 Grain Quality Analysis

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Paddy samples were cleaned and sun-dried to 12–14% moisture content before milling. Milling and polishing were carried out on a Stake husker (THU-35) and polisher (Seedburo, USA). The following traits were recorded following IRRI protocols (Tropical, 1983).

2.2 Head Rice Recovery: The percentage of whole kernels remaining after milling relative to the total weight of paddy was calculated.

HRR (%) = (Weight of Head Rice / Weight of Paddy Sample) × 100

Grain Length (mm): Kernel length was measured in millimeters using a calibrated micrometer.

Grain Width (mm): Kernel width was measured at the broadest point using a grain micrometer and expressed in millimeters.

Length-to-Width Ratio (L/W): Calculated by dividing grain length by grain width.

2.3 Statistical Analysis

Descriptive statistics, Pearson correlation coefficients, and regression analyses were performed to determine relationships among grain dimensions and milling quality parameters (1943- et al., 1992).

3. Results and Discussion

Substantial variation was observed among the indigenous rice varieties for grain dimensions and head rice recovery (HRR) (Table 1).

The shortest grain length was noted in KSK-133 (6.42 mm), and Sultan Super Basmati exhibited the longest grain at 8.85 mm. The literature shows that Basmati cultivars mostly have long/extra-long grains compared with coarse/medium grain cultivars. In premium rice markets, extra-long/long rice is widely purchased because of its attractive shape and excellent post-cooking behavior. However, a clear inverse relationship was observed between grain length and head rice recovery (r = -0.786). Sultan Super possessed the greatest grain length (8.85 mm) and highest L/W ratio (4.85), yet exhibited the poorest HRR (25.0%). Similarly, Kissan Basmati, with a grain length of 8.25 mm and L/W ratio of 4.61, also showed poor milling performance (27.0%). Exceptionally long-grain varieties (PK 1121 Aromatic and Sultan Super Basmati) presented lower head rice percentages, whereas medium-grain varieties (IRRI-6, KSK-133) presented higher HRR.

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Table 1. Grain dimensions and head rice recovery of selected rice cultivars

Variety	Grain Length (mm)	Grain Width (mm)	L/W Ratio	Head Rice Recovery (%)
Super Basmati	7.42	1.76	4.22	47.0
Basmati 515	7.68	1.73	4.44	50.0
Chenab Basmati	7.82	1.71	4.57	52.0
PK 1121 Aromatic	8.10	1.69	4.79	49.0
Sultan Super	8.85	1.76	4.85	25.0
Kissan Basmati	8.25	1.79	4.61	27.0
Punjab Basmati	7.65	1.81	4.23	48.0
IRRI-6	6.58	2.12	3.10	62.0
KSK-133	6.95	2.05	3.39	60.5

Literature confirms the trend that long-grain kernels are more prone to fissuring and mechanical damage during milling operations along the grain axis. (Lanning et al., 2011) stated that long/extra-long rice commonly showed lower head rice percentages because of greater vulnerability to breakage. (Fitzgerald et al., 2009; Paul et al., 2019) emphasized that kernel dimensions potentially affect rice quality features, i.e., milling recovery and consumer acceptability. Siebenmorgen et al. (2013) reported similar findings, noting that kernel dimensions strongly increase rupture vulnerability during milling.

Grain width exhibited a strong positive relationship with head rice percentage (r = 0.829). Rice varieties with relatively greater width resulted in higher HRR values than grains with a slender shape. The results show that width ranged from 1.69 mm in PK 1121 Aromatic to 2.12 mm in IRRI-6, with IRRI-6 and KSK-133 recording the highest head rice recovery. This confirms literature reports that wider grains possess superior tensile strength and better withstand the pressure exerted during milling (Ali et al., 2023). Similarly, Mihretu (2025) confirmed that grain width positively affects milling recovery percentage and is among the most consistent predictors of HRR in rice grains, especially due to its cross-sectional area, which more evenly distributes mechanical stress and lessens the possibility of fracture. Millers generally favor

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moderate grain width for good milling recovery without affecting grain appearance, because it directly determines the commercial value of rice varieties and their cost-effectiveness (El-Reheem et al., 2022; Siebenmorgen et al., 2013). The length-to-width (L/W) ratio ranged from 3.10 to 4.85, reflecting significant variation in kernel shape across different grain types (medium/slender to extra-long/long). Genes mainly control this variation in cereal morphology and significantly affect grain milling yield and market adequacy (Juliano, 2010; Razavi & Farahmandfar, 2008). It suggests that optimum kernel dimensions, rather than the longest grain length alone, result in better milling quality. Other parameters, i.e., kernel hardness, grain chalkiness, fissure susceptibility, and moisture content, also influence milling recovery and varietal suitability for end use (Nath et al., 2024).

Correlation Analysis

The correlation analysis demonstrated that kernel dimensions significantly influenced milling performance. Grain length revealed a highly significant negative correlation with head rice yield ($r = -0.883$, $p < 0.01$), confirming that cultivars with long/extra-long grains were more prone to breakage during milling operations. Similarly, the L/W ratio also presented a significant negative association with HRR ($r = -0.731$, $p < 0.05$), supporting the finding that long grains have less resistance to mechanical stresses during dehusking and polishing.

Table 2. Pearson correlation coefficients among grain dimensions and head rice recovery

Variable	Grain Length	Grain Width	L/W Ratio	HRR
Grain Length	1.000	-0.768	0.928	-0.883
Grain Width	-0.768	1.000	-0.948	0.534
L/W Ratio	0.928	-0.948	1.000	-0.731
Head Rice Recovery	-0.883	0.534	-0.731	1.000

Conversely, kernel width was directly proportional to HRR ($r = 0.534$), indicating that wider grains usually possess more tensile strength and are less susceptible to breakage. These findings agree with the literature reporting that kernel length, width, chalkiness, and fracture vulnerability play an important role in milling yield and HRR (Ali et al., 2024; Kabir et al., 2024). Therefore, grain breeding approaches should emphasize optimal kernel dimensions

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along with grain strength to improve HRR efficiency, rather than focusing solely on long-grain preference.

Regression Analysis

The regression analysis showed a significantly negative effect of grain length on HRR, as described by the equation:

HRR (%) = 95.74 – 6.18 (GL) ----------(1)

This indicates that each 1 mm increase in grain length reduced head rice recovery by approximately 6.18 percentage points. A high coefficient of determination ($R^2 = 0.67$) indicates that kernel length accounted for 67% of the observed variation in milling yield.

Table 3. Regression analysis for grain dimensions and head rice recovery

Predictor Variable	Regression Equation	Slope (β)	R^2	Relationship
Grain Length (mm)	HRR (%) = 95.74 – 6.18 (GL)	-6.18	0.67	Negative
Grain Width (mm)	HRR (%) = 14.21 + 22.43 (GW)	+22.43	0.58	Positive

This finding supports previous observations by (Lanning et al., 2011; Maneesha et al., 2024)produce lower head rice yields. Conversely, grain width exhibited a positive relationship with HRR; the positive gradient indicates that increasing width substantially improves milling recovery. The model explained 58% of the variation in head rice recovery, confirming the role of grain width in maintaining kernel integrity during husking and polishing. This shows that grain strength should not be evaluated solely on grain dimensions or consumer preference. In future, breeders must consider the combined effect of grain dimensions on milling quality and economic returns.

Overall, the study confirms that grain morphology strongly influences milling quality in rice. Grain length showed a negative relationship with HRR, while width was positively related to HRR, and long-grain varieties were more susceptible to breakage during polishing and husking; both traits are therefore crucial in determining milling efficiency. For long-grain varieties, post-harvest treatments such as parboiling and controlled steaming can help improve kernel strength and reduce breakage, ultimately enhancing HRR.

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Availability Of Data And Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' Contributions

Farah Shamim, Mohsin Ali Raza, and Muhammad Shahid Munir conducted the data collection and laboratory analyses and prepared the original manuscript draft. Rana Ahsan Raza Khan and Tahira Bibi contributed to the field experiment, statistical analysis, and study design, reviewed the data, and critically revised the manuscript. All authors read and approved the final version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Consent for Publication

Not applicable.

Ethical Approval

The study did not involve human participants, animals, or clinical experimentation. Therefore, ethical approval was not required.

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