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Research Article

Multi-location assessment of yield and quality traits and insect-disease resistance in fine rice

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ABSTRACT

The identification and evaluation of genetically diverse and high-performing genotypes under varying environmental conditions is essential for developing stable and high-yielding rice varieties. This research aimed to assess the genetic variation among twenty-two (22) open-pollinated candidate and two (02) control varieties of fine rice for paddy yield, yield related traits, kernel quality, and resistant against insects and diseases grown at eight locations in National Uniform Yield Trials (NUYT) during 2019. Results revealed that genotypes EFLD, GC-75 and KSK-111-H produced the highest average paddy yields of 4039 kg ha⁻¹, 3980 kg ha⁻¹ and 3928 kg ha⁻¹, respectively and stayed statistically at par with each other. Genotype P-35 exhibited the maximum plant height (134.2 cm), while genotype PK-1121-Aromatic gave the highest tillers count per plant (15.7). Maximum length of panicle (30.1 cm) and grains count per panicle (121.0) were noted in genotype KSK-111-H. Genotype SRI-23 displayed the maximum 1000-grain weight (30.7 g), but it also took maximum days to achieve maturity. Highest paddy yield was recorded at the locations Bahawalnagar and Faisalabad, while lowest yield was documented at DI Khan. Genotypes 52-S and EFLD exhibited the highest recoveries of brown rice (85%) and head rice (62%), respectively. Maximum grain length (9.96 mm) and cooked grain length (18.6 mm) were measured in genotype SRI-23, while highest bursting (25%) was noted in genotype KSK-111-H. Most of the genotypes showed resistance against stem bore and leaf folder, whereas half of the genotypes were susceptible against bacterial blight disease. Based on these outcomes, genotypes EFLD, GC-75 and KSK-111-H could be recommended for general cultivation in order to achieve the highest paddy yield.

Keywords: National uniform yield trial; open-pollinated genotypes; paddy yield; grain quality; insect-disease resistance.

INTRODUCTION

Rice (*Oryza sativa* L.) is a cereal crop that is a main dietary staple for more than fifty percent of the world's population (Khush, 2005). In Pakistan's agricultural sector, rice is crucial as it acts as both a fundamental food source and a cash crop. It is considered the second most crucial staple food crop and ranks as the second highest export commodity, after wheat and cotton. The rice sector contributes approximately 0.6% to the country's gross domestic product and around 2.5% to the added value in agriculture (Economic Survey of Pakistan, 2024). During 2023-24, rice cropped area was 3.6 million hectares that increased by 22% as compared to 3.0 million hectares during previous year and production was 9.9 M tons which increased by 34.8% compared to previous year due to inputs availability through subsidy by government, increased cropped area, higher rice prices, and favorable monsoon



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season. In Pakistan, the average rice yield exceeds 2700 kg per hectare (Economic Survey of Pakistan, 2024), which is relatively lower than that of other rice-producing nations due to several limitations, particularly the poor selection of rice varieties suited for specific regions and the use of low-quality seeds by farmers.

Asian countries such as India and Thailand are major rice producers worldwide and Pakistan holds 9th position accounting highest production of rice globally (USDA Foreign Agricultural Service, 2024). After India, Thailand, and Vietnam, Pakistan was the fourth-largest rice exporter in the world in 2023-24 (Dawn, 2023). The two provinces in Pakistan that produce the most rice are Sindh and Punjab. The districts of Gujranwala, Sialkot, Gujrat, Mandi Bahaudin, Sheikhpura, Kasur, Hafizabad, Okara, Faisalabad, Jhang and Sargodha in Punjab, while Thatta, Jacobabad, Larkana, Shikarpur, Dadu and Badin in Sindh mainly contribute to the nation's total rice production (Abedullah et al., 2007; Memon, 2013; Ministry of National Food Security & Research, 2021). Through the export of rice, primarily to European and numerous Asian countries, Pakistan generates a substantial amount of foreign exchange (Shah et al., 2020). By introducing new fine rice varieties and adopting hybrid varieties in the provinces of Sindh and Punjab, which are expected to generate an average paddy yield of 4000 kg per acre, Pakistan is likely to become a significant producer of rice with even greater yield in the upcoming years (Alam, 2017).

Basmati rice is a unique type of rice characterized by its long, slender grains and distinct aroma, making it renowned as a top-quality rice globally. Aromatic rice is gaining popularity in regions like Europe, the USA, and the Middle East (Yousuf et al., 2014). The principal producers and key players in the international market for aromatic rice are Pakistan, India, and Thailand. The aromatic rice produced in Pakistan and India primarily includes basmati varieties. Basmati rice, known for its unique fragrance, showcases traits from both indica and japonica types, positioning it as an intermediate category between the two (Butt et al., 2008). Consumers are showing a growing interest in rice varieties that have exceptional cooking and eating characteristics. Basmati rice is classified as wax-free and non-sticky, featuring a moderate level of amylose. Additional key attributes related to grain size and appearance, such as kernel length, breadth, thickness, cooked grain length (CGL), elongation ratio (E/R), and percentage of bursting, together define the quality of rice cooking and eating (Sood & Siddiq, 1980).

Historical and scientific research clearly indicates that the quality of traditional basmati rice is ecologically contingent upon environmental and soil factors, and can only be attained when basmati cultivars are cultivated in the traditional basmati region, known locally as the 'kallar tract' in Punjab, Pakistan and certain parts of India (Shobharani & Krishnaiah, 2001). Pakistan generates about 2 billion USD annually from basmati rice exports. Since the Rice Research Institute in Kala Shah Kaku (KSK) was established, thirty-one (31) different varieties of basmati rice have been developed (AARI, 2025). The first basmati rice variety, "Basmati-370," was introduced for the rice farming community in 1933 by this rice research institute, which was formerly known as the Rice Farm (Akhter and Haider, 2020). Since the release of "Basmati-370", it has served as the mother variety for nearly all the basmati cultivars released afterward. Utilizing Basmati-370 as a parent variety through traditional hybridization, the RRI, KSK also launched another popular basmati variety, "Basmati-Pak", in 1968 which features an extra-long grain length. Additionally, "Super-Basmati", a highly regarded rice variety in the global market for its outstanding cooking quality, was also introduced by the same institute in 1996. Due to the agro-physiological attributes, firm yield benefits, and export price, Super-Basmati is equally a prominent cultivated variety among basmati rice growers in Pakistan (Akhter & Haider, 2020).

While global rice productivity has increased twofold over the past 30 years due to the adoption of improved varieties and better cultural practices, it remains insufficient to fulfill the rising global demand for rice (Sasaki & Burr, 2000; Rahman et al., 2024). The current average yield must be considerably enhanced to accommodate the growing demands for rice, which are predicted to increase by around 1% annually between 2001 and 2030 (Khush, 2013; Bin Rahman & Zhang, 2023). To maximize the potential paddy yield and quality and boost national production, improved genotypes of basmati fine rice with a diverse ecological adaptations and resistance to insects and diseases are required. However, it is rare for the provincial research institutions to test their improved varietal material all through the country due to the limited resources. The main procedures before releasing new varieties for general cultivation include the evaluation of superior rice genotypes at various levels, which entails initial evaluations at research stations, followed by preliminary assessments in micro-plot trials, and concluding with a final review in National Uniform Yield Trials (NUYT). This study focuses on the last stage of evaluation to suggest the cultivar for production on commercial scale. Therefore, the main goal of current research was to evaluate the performance of open-pollinated candidate lines with control basmati rice varieties for their paddy yield, grain quality and insect-disease resistance in order to identify and recommend better high-yielding fine rice genotypes following multi-location NUYT.

MATERIALS AND METHODS

Twenty-two (22) open-pollinated candidate genotypes along with two (02) control varieties of fine rice were evaluated for paddy yield, yield contributing traits, grain quality, and insect-disease resistance during the growing season of 2019. The control varieties were chosen because they performed well with regard to yield, quality, and insect-disease resistance. The name and source of the open-pollinated genotypes are enlisted in Table (1). The following eight sites were used to assess all open-pollinated candidate genotypes and control varieties: Rice Research Station (RRS), Bahawalnagar; Agricultural Research Institute (ARI), Dera Ismael Khan; PARC Rice Program, KSK; Potato Research Station (PRS), Sialkot; Rice Research Institute (RRI), KSK; Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad; National Institute for Biotechnology and Genetic Engineering (NIBGE), Faisalabad; Soil Salinity Research Institute (SSRI), Pindi Bhattian.

Table 1. Decoded name of twenty-four open-pollinated genotypes used for this experiment and their contributors.

Sr. No.	Decoded name of OPVs	Contributor
1	PK-10324-1-1	RRI, KSK
2	FBG-14	NIBGE, Faisalabad
3	PK-9444-8-1-2	RRI, KSK
4	P-47	NIAB, Faisalabad
5	Emkay-15	Emkay Seeds (Pvt) Ltd
6	NB-1827	NIAB, Faisalabad
7	PB-34	Emkay Seeds (Pvt) Ltd
8	SRI-25	SSRI, Pindi Bhattian
9	PK-9966-10-1	RRI, KSK
10	S-39	NIAB, Faisalabad
11	GC-75	NIAB, Faisalabad
12	P-35	NIAB, Faisalabad
13	NBF-BB-EM-25-7-2	NIBGE, Faisalabad
14	PK-10683-12-1	RRI, KSK
15	SRI-23	SSRI, Pindi Bhattian
16	EFLD	NIAB, Faisalabad
17	PK-10029-13-2-1	RRI, KSK
18	P-48	NIAB, Faisalabad
19	FBG-13	NIBGE, Faisalabad
20	52-S	NIAB, Faisalabad
21	NBF-AP-117-23-23	NIBGE, Faisalabad
22	KSK-111-H	RRI, KSK
23	PK-1121-Aromatic (control)	RRI, KSK
24	Super-Basmati (control)	RRI, KSK

The experimental treatments were arranged in a randomized complete block design (RCBD) using three replications. In June and early July, the nursery containing all twenty-four (24) genotypes was transplanted. Thirty-day-old rice seedlings were transplanted into a field that had already been prepared, maintaining a spacing of 20 cm both between plants and between rows. Net plot size was 2 m × 5 m, and 10 rows were planted in each plot. Every site was given a uniform application of 120:60:60 kg NPK ha⁻¹ during the entire growing season. Water from the irrigation system was used as needed. Every experimental location maintained a healthy crop by adhering to the best agronomic practices. Using standard techniques, data on paddy yield and yield traits (plant height, tillers count per plant, length of panicle, grains count per panicle, thousand-grain weight, days to maturity) were recorded. Only samples taken from RRI, KSK Lahore were used to measure the grain quality characteristics, which include length, width, thickness, CGL, percentage of bursting, E/R, and proportions of brown, milled, and head rice. The National Agricultural Research Center's Grain Quality Testing Laboratory in Islamabad was used to conduct grain quality analyses. Analysis for physical parameters was carried out using the methods of Adair et al. (1966) and ISO 7970-2000 (B). The rice husker was used to dehusk the grains of each genotype that had a moisture content of 14%. Brown rice was the rice that was obtained. Similarly,

rice obtained after removing bran was milled rice. The amount of entire grain that remained intact after milling was known as head rice. The proportions of brown, milled and head rice were calculated by dividing their respective weights by the weight of the paddy. The length, breadth, and thickness of paddy grain was gauged with a Vernier Caliper and reported in millimeters (mm). To assess CGL, E/R, and bursting, 50 milled grains were soaked for 10 minutes, then cooked in distilled water (20 ml) at 98°C for 10 minutes. The CGL was then measured using a Vernier Caliper (Juliano et al., 1965). The ratio of the average length of cooked rice grains to the average length of milled rice grains was utilized to calculate the E/R (Azeez & Shafi, 1966). Bursting was quantified by calculating the percentage of burst grains relative to the total grain count. Attack level of insects (stem borer and leaf folder) and disease resistance (bacterial leaf blight) was also evaluated. Genotypic resistance or susceptibility response against stem borer, leaf folder, and bacterial blight was noted and presented as resistant (R), moderately resistance (MR), moderately susceptible (MS), susceptible (S), and highly susceptible (HS). The data was subjected to the statistical analysis. The Statistix 8.1 computer program was used to perform the analysis of variance. Then, the least significance difference (LSD) test was applied to distinguish the significant means at a probability level of 5%.

RESULTS AND DISCUSSION

Paddy Yield

Assessing paddy yield in diverse settings is one way to confirm the stability and adaptability of distinct genotypes (Acuña et al. 2008). In our investigation, there were significant variations in paddy yield among genotypes cultivated at each site (Table 2). At RRS Bahawalnagar, genotype GC-75 gave significantly highest paddy yield (5843 kg ha⁻¹), while genotype FBG-13 gave significantly lowest yield (2780 kg ha⁻¹). At ARI DI Khan, genotype KSK-111-H produced significantly highest yield (4167 kg ha⁻¹), whereas genotype FBG-13 exhibited significantly lowest paddy yield (913 kg ha⁻¹). At PARC KSK, genotypes PK-10324-1-1, KSK-111-H, GC-75 and 52-S gave significantly highest paddy yields, while genotype P-47 furnished significantly lowest paddy yield (2164 kg ha⁻¹). At PRS Sialkot, genotypes PK-10683-12-1 exhibited significantly highest paddy yields of 3639 kg ha⁻¹, followed by genotypes PK-10029-13-2-1 and KSK-111-H (3637 kg ha⁻¹), while genotype PK-9444-8-1-2 produced significantly lowest paddy yield (1835 kg ha⁻¹). At RRI KSK, genotypes EFLD and PK-10324-1-1 showed highest yield (4457 and 4347 kg ha⁻¹, respectively), while genotype P-47 showed significantly lowest paddy yield (2180 kg ha⁻¹). At NIAB Faisalabad, genotypes GC-75 and EFLD gave significantly highest paddy yields (5401 and 5353 kg ha⁻¹, respectively), while genotype NBF-BB-EM-25-7-2 produced significantly lowest paddy yield (3081 kg ha⁻¹). Significantly highest paddy yields of 5289 and 5247 kg ha⁻¹, respectively were produced by genotypes NBF-AP-117-23-23 and NBF-BB-EM-25-7-2 at NIBGE Faisalabad, whereas genotype PK-9444-8-1-2 produced significantly lowest yield (3090 kg ha⁻¹). At SSRI Pindi Bhattian, genotype SRI-23 gave significantly highest paddy yield (3264 kg ha⁻¹), while genotype S-39 produced significantly lowest yield (1850 kg ha⁻¹). Overall, averaged across all genotypes, paddy yield was significantly highest at RRS Bahawalnagar (4070 kg ha⁻¹), NIBGE Faisalabad (4044 kg ha⁻¹) and NIAB Faisalabad (3878 kg ha⁻¹), while ARI DI Khan furnished significantly lowest paddy yield (1879 kg ha⁻¹). Thus, Faisalabad and Bahawalnagar had the best growing conditions for paddy yield. Similar outcomes were published by Jaruchai et al. (2018), who concluded that significant variation exists in paddy yield grown under multi-environments. Likewise, averaged across all locations, significantly highest paddy yield was achieved by the genotype EFLD (4039 kg ha⁻¹), GC-75 (3980 kg ha⁻¹), and KSK-111-H (3928 kg ha⁻¹), followed by genotype S-39 (3447 kg ha⁻¹), whereas genotype P-47 yielded significantly poorest (2749 kg ha⁻¹). The Control Super-Basmati was medium performer in terms of paddy yield (3108 kg ha⁻¹). The results of this research align with those reported by Kusutani et al. (2000), who also noted the significant variation in paddy yield between the genotypes of basmati rice. Similar outcomes have been reported by other researchers in their study (Shrestha et al., 2021). The selection for improved genotypes on the basis of yield is vital, as yield is a quantitative trait that is significantly affected by environmental variations.

Yield Contributing Traits

Rice genotypes exhibit variations in their growth behavior, yield characters, and maturation time. Before starting any successful breeding program, it is essential to establish key yield traits such as plant height, tillers count per plant, length of panicle, grain count per panicle and 1000-grain weight (Oladosu et al., 2018). In this study, yield contributing traits showed substantial variation among different genotypes (Table 3). The height of a plant is a crucial growth factor for any crop, as it influences or alters characteristics that contribute to yield and ultimately defines the final yield (Reddy & Redd, 1997).

Table 2. Paddy yield (kg ha⁻¹) of twenty-four open-pollinated candidate and control genotypes of fine rice grown at eight locations.

Decoded name of OPVs	RRS B. Nagar	ARI DI Khan	PARC KSK	PRS SKT	RRI KSK	NIAB FSD	NIBGE FSD	SSRI Pindi Bhattian	Average
PK-10324-1-1	2865 p	1833 e-i	4771 a	3317 a-e	4347 a	4164 b-d	3744 e-g	2004 i-j	3381 BC
FBG-14	3025 n	1333 g-j	3440 de	2834 f-h	2837 j-l	3930 d-f	4412 b-d	2099 gh	2989 EF
PK-9444-8-1-2	3095 mn	1250 h-j	-	1835 k	2799 j-l	4193 bc	3090 i	2983 b	2749 F
P-47	2895 op	2083 c-g	2164 k	3036 c-h	2180 m	3763 f-i	4124 c-e	1969 j-m	2777 F
Emkay-15	3135 m	2667 b-d	3519 cd	3128 b-g	3387 f-i	3626 g-j	3656 f-h	1894 mn	3126 B-F
NB-1827	2945 o	1083 ij	3448 de	2689 g-h	3480 e-h	4328 b	4116 c-e	2049 h-j	3017 D-F
PB-34	3487 l	1833 e-i	3190 d-f	2809 f-h	2865 i-l	3626 g-j	3723 e-g	2078 g-i	2951 EF
SRI-25	4665 f	1167 h-j	2459 i-k	2917 e-h	4182 ab	3100 l	3462 g-i	2982 b	3117 B-F
PK-9966-10-1	4146 j	1583 f-j	-	2368 ij	3970 a-e	3795 f-h	4148 b-e	2193 ef	3172 B-E
S-39	5607 b	1917 d-h	2942 f-h	3442 a-c	3241 f-k	4068 c-e	4505 bc	1850 n	3447 B
GC-75	5843 a	3333 b	4488 a	2821 f-h	4085 a-c	5401 a	3885 e-g	1983 j-l	3980 A
P-35	4571 g	2417 c-e	2387 jk	3368 a-d	3414 f-h	3706 f-i	4582 b	1968 j-m	3302 B-E
NBF-BB-EM-25-7-2	5607 b	1750 e-i	2776 g-i	3192 b-f	2996 h-l	3081 l	5247 a	2247 de	3362 B-D
PK-10683-12-1	4476 h	1833 e-i	3815 bc	3639 a	4175 ab	3862 e-g	3852 e-g	1909 l-n	3445 B
SRI-23	4382 i	2250 c-f		2950 d-h	2715 k-m	3719 f-i	3211 hi	3264 a	3213 B-E
EFLD	4382 i	-†	3974 b	3505 ab	4457 a	5353 a	4439 b-d	2162 fg	4039 A
PK-10029-13-2-1	3110 m	1542 f-j	3387 de	3637 a	4038 a-d	3237 kl	3839 e-g	1952 k-m	3093 B-F
P-48	5277 c	1333 g-j	2751 g-i	3202 a-f	3030 h-l	3737 f-i	3707 e-g	2369 c	3176 B-E
FBG-13	2780 q	917 j	2687 h-j	3276 a-e	3523 d-h	3543 ij	4576 b	2312 cd	2952 EF
52-S	4995 d	1500 f-j	4427 a	2319 ij	3664 b-f	3795 f-h	3825 e-g	1963 k-m	3311 B-E
NBF-AP-117-23-23	3105 m	1417 g-j	3092 e-g	2673 hi	3296 f-j	3428 jk	5289 a	2303 cd	3075 C-F
KSK-111-H	4853 e	4167 a	4716 a	3637 a	3607 c-g	3862 e-g	4472 bc	2105 gh	3928 A
PK-1121-Aromatic (control)	4005 k	2750 bc	-	1962 jk	2625 lm	4164 b-d	3155 i	2268 de	2990 D-F
Super-Basmati (control)	4429 hi	1250 h-j	2846 f-h	3317 a-e	3105 g-l	3590 h-j	3997 d-f	2330 cd	3108 B-F
Average	4070 A	1879 E	3364 B	2995 C	3417 B	3878 A	4044 A	2218 D	3237
C.V. (%)	1.11	26.88	6.49	8.93	6.69	3.85	6.73	2.32	3.43

This being a multifaceted trait resulting from various genetically controlled elements, primarily influenced by the genetic composition of the genotypes, which typically relates to the number and length of their internodes (Rahman et al., 2018).

In this study, genotype P-35 exhibited significantly highest plant height (134.2 cm), followed by genotypes PK-10029-13-2-1 and PK-10683-12-1, while genotype 52-S presented significantly lowest plant.

For each location, different small letters in a column indicate significant differences among varieties at 5% probability level. Similarly, for each varieties (averaged across locations) and locations (averaged across varieties), different capital letters indicate significant differences among means at 5% probability level. † denotes the missing values. Genotype EFLD at ARI DI Khan location and genotypes PK-9444-8-1-2, PK-9966-10-1, SRI-23 and PK-1121-Aromatic (control) at PARC KSK location failed to mature; therefore, their yield data was not presented. CV: Coefficient of Variance

Table 3. Yield contributing parameters of twenty-four open-pollinated candidate and control genotypes of fine rice averaged across locations.

Decoded name of OPVs	Plant height (cm)	Tillers per plant (No.)	Panicle length (cm)	Grains per panicle (No.)	1000 grain weight (g)	Days to maturity (seed to seed)
PK-10324-1-1	106.0 i	13.3 d-f	25.5 j	109.3 b	25.4 d	136 f-i
FBG-14	129.1 a-c	12.7 f-h	26.8 d-g	95.7 e-g	23.1 fg	137 e-h
PK-9444-8-1-2	116.0 fg	13.0 e-g	26.0 h-j	71.7 l	26.9 c	142 b-d
P-47	126.3 cd	14.0 b-e	26.5 e-h	94.0 f-h	22.3 h-k	139 b-f
Emkay-15	121.2 d-f	14.0 b-e	27.4 d	91.0 g-i	22.9 f-h	141 b-e
NB-1827	97.4 jk	14.0 b-e	25.9 h-j	89.7 hi	22.5 g-j	134 h-j
PB-34	129.8 a-c	12.7 f-h	30.0 ab	109.3 b	21.8 kl	138 b-g
SRI-25	131.2 a-c	13.3 d-f	28.5 c	83.0 jk	30.4 a	130 j
PK-9966-10-1	116.6 e-g	14.3 b-d	26.0 h-j	90.3 g-i	28.1 b	140 b-e
S-39	120.4 ef	15.0 ab	26.3 g-i	86.3 i-k	22.1 jk	141 bc
GC-75	108.7 hi	11.7 h	25.9 h-j	95.7 e-g	27.6 b	132 ij
P-35	134.2 a	14.3 b-d	27.0 d-f	97.0 ef	21.3 l	140 b-e
NBF-BB-EM-25-7-2	113.1 gh	14.3 b-d	26.4 f-i	95.0 e-h	22.2 i-k	140 b-e
PK-10683-12-1	133.3 ab	13.0 e-g	28.5 c	103.3 cd	24.1 e	142 bc
SRI-23	128.1 bc	12.7 f-h	29.4 b	88.3 ij	30.7 a	148 a
EFLD	99.2 j	14.3 b-d	24.3 k	100.0 de	23.2 f	137 c-h
PK-10029-13-2-1	133.6 ab	12.0 gh	28.6 c	107.3 bc	24.7 e	137 c-h
P-48	128.9 a-c	14.7 a-c	27.4 d	95.0 e-h	22.4 h-k	140 b-e
FBG-13	120.0 ef	13.0 e-g	26.8 d-g	100.3 de	22.1 jk	137 c-h
52-S	93.3 k	13.3 d-f	25.8 ij	111.7 b	22.0 jk	136 e-h
NBF-AP-117-23-23	122.0 de	13.7 c-f	26.9 d-g	103.7 cd	21.8 kl	134 h-j
KSK-111-H	130.3 a-c	12.7 f-h	30.1 a	121.0 a	22.8 f-i	134 h-j
PK-1121-Aromatic (control)	116.0 fg	15.7 a	26.9 d-g	82.3 k	26.6 c	143 ab
Super-Basmati (control)	119.3 ef	14.0 b-e	27.1 de	96.7 ef	22.2 i-k	140 b-e
C.V. (%)	2.86	4.61	1.44	3.45	1.61	2.27

For each parameter, different small letters in a column indicate significant differences among varieties at 5% probability level. Data of days to maturity is presented as average of seven locations excluding NIAB FSD. CV: Coefficient of Variance.

height (93.3 cm). This finding aligns with Das et al. (2012), where significant variation in plant height was noted among different rice genotypes. These discrepancies regarding plant height may be due to the unique characteristics of each variety. Shorter plant height is an important feature of the varieties to withstand lodging (Malini et al., 2006). Final yield is mainly a function of the number of panicles bearing tillers per unit area (Roy et al., 2014). Significantly highest number of tillers per plant were noted in control PK-1121-Aromatic (15.7), while lowest tillers count was observed in genotype GC-75 (11.7). This variation in tillers count per plant could be ascribed to differences in the genetic composition of the variety. Earlier research has also indicated significant variation among twelve rice cultivars regarding tillers count per plant (Zahid et al., 2005). The rice panicle produces spikelets that eventually become grains. A longer panicle will lead to a higher paddy yield. In this study, genotypes KSK-111-H and PB-34 exhibited significantly highest

panicle length of 30.1 cm and 30 cm, respectively, whereas genotype EFLD showed significantly lowest length of panicle (24.3 cm).

Table 4. Average data of yield contributing parameters of fine rice at eight locations (averaged across twenty-four openpollinated genotypes).

Location	Plant height (cm)	No. of tillers per plant	Panicle length (cm)	No. of grains per panicle	1000 grain weight (g)	Days to maturity (seed to seed)
RRS B. Nagar	94.9 f	14.5 bc	24.6 e	101 c	22.1 e	151 a
ARI DI Khan	110.7 e	10.9 f	26.7 d	123 a	23.3 c	127 e
PARC KSK	117.1 d	13.9 cd	26.5 d	68 f	21.0 e	149 ab
PRS SKT	116.8 d	13.4 d	25.2 e	92 d	24.7 b	122 f
RRI KSK	137.2 a	14.7 ab	28.0 bc	77 e	27.4 a	137 c
NIAB FSD	125.4 c	12.2 e	29.7 a	88 d	22.4 de	-†
NIBGE FSD	125.2 c	13.2 d	27.5 c	112 b	23.1 cd	147 b
SSRI Pindi Bhattian	131.0 b	15.4 a	28.4 b	110 b	27.8 a	134 d
C.V. (%)	9.47	17.09	7.50	19.11	10.34	7.22

For each parameter, different small letters in a column indicate significant differences among locations at 5% probability level. † denotes the missing values. CV: Coefficient of Variance

Table 5. Quality parameters of twenty-four open-pollinated candidate and control genotypes of fine rice samples harvested from PARC KSK location.

Name of OPVst	Milling Recovery (%)			Grain Measurements (mm)			Cooking Quality		
	Brown Rice	Milled Rice	Head Rice	Length	Width	Thickness	CGL (mm)	Bursting (%)	E/R
PK-10324-1-1	81.0	68.0	34.0	8.88	1.80	1.62	13.3	2	1.49
FBG-14	76.0	67.0	45.0	7.36	1.66	1.54	12.3	4	1.67
PK-9444-8-1-2	82.0	74.0	37.0	8.74	1.90	1.56	16.5	8	1.88
P-47	77.0	67.0	47.0	7.74	1.76	1.56	13.2	4	1.71
Emkay-15	81.0	71.0	62.0	7.70	1.72	1.54	13.4	5	1.74
NB-1827	77.0	64.0	28.5	8.58	1.58	1.48	14.3	3	1.66
PB-34	79.0	70.0	54.0	6.76	1.72	1.60	12.3	9	1.82
SRI-25	77.0	64.0	28.0	9.02	1.78	1.62	17.3	6	1.92
PK-9966-10-1	74.0	64.0	23.0	8.74	1.96	1.64	16.5	18	1.88
S-39	79.0	70.0	49.0	7.66	1.84	1.62	13.9	3	1.81
GC-75	84.0	63.0	51.0	8.38	1.88	1.68	11.5	8	1.37
P-35	76.0	66.0	52.0	7.46	1.60	1.48	13.2	5	1.77
NBF-BB-EM-25-7-2	79.0	68.0	57.0	7.80	1.72	1.22	12.8	1	1.64
PK-10683-12-1	84.0	65.0	38.0	7.90	1.80	1.64	14.3	2	1.81
SRI-23	71.0	62.0	37.0	9.96	1.92	1.76	18.6	4	1.87
EFLD	80.0	70.0	62.0	7.24	1.72	1.56	12.0	3	1.66
PK-10029-13-2-1	82.0	72.0	53.0	8.28	1.76	1.64	14.0	1	1.69
P-48	60.0	54.0	34.0	7.60	1.72	1.52	14.2	2	1.87
FBG-13	79.0	69.0	50.0	7.42	1.62	1.48	12.5	6	1.68
52-S	85.0	66.0	42.0	7.46	1.76	1.46	13.0	4	1.74
NBF-AP-117-23-23	77.0	69.0	48.0	7.64	1.68	1.54	13.4	3	1.75
KSK-111-H	81.0	70.0	54.0	7.36	1.70	1.56	13.6	25	1.85
PK-1121-Aromatic (control)	66.0	54.0	25.0	7.90	1.86	1.44	16.2	1	2.05
Super-Basmati (control)	82.0	70.0	44.0	7.56	1.66	1.48	12.8	1	1.69

† Only one samples of each genotype was analyzed for quality parameters due to limitation of work facility. Thus, no statistical analysis for performed to separate for means for comparison. CGL: Cooked Grain Length; E/R: Elongation

Ratio.

Table 6. Resistance/susceptibility data of twenty-four open-pollinated candidate and control genotypes of fine rice against damage by insects and disease.

Name of OPVs	Response to Insects		Response to Disease
	Stem Borer	Leaf Folder	Bacterial Blight
PK-10324-1-1	R	R	MS
FBG-14	R	MR	R
PK-9444-8-1-2	R	R	S
P-47	R	R	S
Emkay-15	R	R	S
NB-1827	R	R	R
PB-34	R	R	R
SRI-25	R	R	MS
PK-9966-10-1	R	R	S
S-39	R	R	S
GC-75	R	R	MS
P-35	R	R	S
NBF-BB-EM-25-7-2	R	R	R
PK-10683-12-1	R	R	S
SRI-23	R	R	MS
EFLD	R	R	MR
PK-10029-13-2-1	R	R	MR
P-48	R	MR	S
FBG-13	R	R	R
52-S	R	MR	R
NBF-AP-117-23-23	R	R	S
KSK-111-H	R	R	S
PK-1121-Aromatic (control)	R	R	MS
Super-Basmati (control)	R	MR	S

R= Resistant, MR= Moderately Resistant, MS= Moderately Susceptible, S= Susceptible, HS= Highly Susceptible.

Likewise, grains count per panicle contributes materially towards the final paddy yield. Genotype KSK-111-H produced significantly highest grains count per panicle (121), whereas the genotype PK-9444-8-1-2 showed the lowest count of 71.7 in this study. The kernel size is expressed by the 1000-grain weight. Higher yields are obtained from paddy with bold kernels. The genotype SRI-23 exhibited the highest maximum weight for 1000-grains at 30.7 g, while the genotype PK-9966-10-1 followed closely with a weight of 28.1 g. In contrast, the genotype P-35 recorded the significantly lowest weight for 1000-grains at 21.3 g. Tahir et al. (2002) also found considerable variation in various yield-related characteristics, indicating that such traits are influenced by the genotypic differences among the cultivars. The duration to maturity is a crucial factor in the cropping system. Crops that mature early can be managed promptly, free up land sooner for subsequent crops, and avoid insect pest infestations. In this study, genotype SRI-23 took significantly maximum days to reach maturity (148 days), while genotype SRI-25 took significantly minimum days for maturity (130 days). When averaged across all genotypes, significantly highest plant height (137.2 cm) was recorded at RRI KSK, while lowest plant height was noted at RRI Bahawalnagar (Table 4). Location SSRI Pindi Bhattian gave significantly maximum number of tillers per plant (15.4), while ARI DI Khan had lowest number of tillers (10.9). Significantly highest panicle length was recorded at NIAB Faisalabad (29.7 cm), whereas lowest panicle length was recorded at RRS Bahawalnagar (24.6 cm). At ARI DI Khan, there were noticeably more grains per panicle (123) than at PARC KSK, which had the fewest grains per panicle (68). 1000-grain weight was significantly highest at RRI KSK (27.4 g), while it was lowest at PARC KSK (21 g). RRS Bahawalnagar took significantly highest number of days to mature rice crop (151 days), whereas significantly lowest days to maturity were recorded at location PRS Sialkot (122 days). Paddy yield may be enhanced by selecting for yield-related traits, and the selection of parental varieties should be based on their yield characteristics (Tsehaye et al., 2018).

Quality Parameters of Open-Pollinated Genotypes

Grain quality is a primary focus in rice breeding. It encompasses various aspects such as milling quality, appearance of the grains, and cooking and eating quality (Birla et al. 2017). In terms of milling quality, key factors include brown rice, milled or white rice, and head rice. Brown rice is the grain obtained from paddy after the outer husk has been removed. In a similar manner, milled rice refers to paddy from which both the bran and hull have been removed through milling. The unbroken grain in milled rice is referred to as head rice (Butardo et al. 2019). In present study, genotype 52-S yielded the highest percentage of brown rice (85%), followed by genotypes GC-75 and PK-10683-12-1 (84%), whereas genotype PK-9444-8-1-2 furnished the highest amount of milled rice (70%) (Table 5). Meanwhile, genotype P-48 gave the lowest yields of brown rice (60%) and milled rice (54%). For head rice, genotype EFLD yielded the highest amount (62%), while genotype PK-9966-10-1 produced the lowest yield (23%), followed by control PK-1121-Aromatic (25%). Similarly, control PK-1121-Aromatic performed poorest in terms of milling quality and gave the lowest yield of brown rice (66%) and milled rice (54%). Grain size plays a crucial role in determining rice yield per unit area and is also vital for its appearance quality (Mao et al., 2010). In varietal development programs, breeders typically prioritize size traits (Adair et al., 1966). Since grain length exhibits greater variability than width (Anacleto et al., 2015), grain size is primarily characterized by its length. In this study, highest grain length (9.96 mm) and grain thickness (1.76 mm) was observed in the genotype SRI-23, while maximum grain width (1.96 mm) was observed in genotype PK-9966-10-1. Likewise, genotypes PB-34, NB-1827 and NBF-BB-EM-25-7-2 furnished the minimum grain length (6.76 mm), width (1.58 mm) and thickness (1.22 mm), respectively. The appearance quality of cooked rice is a significant issue in rice production across numerous countries (Candia et al., 2013). Appearance quality is greatly flexible and is affected considerably by both genotype and environmental factors (Bao et al., 2004). In terms of appearance quality, CGL is an important trait in relation to consumer preferences. Maximum CGL was found in genotype SRI-23 (18.6 mm), while minimum CGL was observed in genotype GC-75 (11.5 mm). Bursting was highest in genotype KSK-111-H (25%), followed by genotype PK-9966-10-1 (18%), while lowest bursting (1%) was observed in both control PK-1121-Aromatic and Super-Basmati and two other genotypes NBF-BB-EM-25-7-2 and PK-10029-13-2-1. Another crucial factor in assessing the rice cooking and eating quality is the E/R (Butt et al., 2008). There were substantial differences for E/R among varieties in this study. Maximum E/R was noted in control PK-1121-Aromatic (2.05), while minimum E/R was perceived in genotype GC-75 (1.37). The differences in E/R across various genotypes could be attributed to the differing levels of amylose. It has been observed that rice varieties with increased amylose concentration usually exhibit a higher gelatinization temperature (Juliano, 1985).

Resistance Against Insects and Diseases

The data regarding the attacks of stem borer, leaf folder, and bacterial blight was classified into five categories of resistance level which is displayed in Table 6. All the genotypes were resistant (R) against stem borer and leaf folder with the exception of genotypes FBG-14, P-48, 52-S and control Super-Basmati which were moderately resistant (MR) against leaf folder. Ensuring disease resistance is crucial for secure crop production. Bacterial blight is among the earliest identified diseases affecting rice (Nino-Liu et al., 2006). Currently, rice bacterial blight has been widely distributed across nearly all rice-growing areas globally (Naqvi, 2019). In present study, genotypes FBG-14, NB-1827, PB-34, NBF-BB-EM-25-7-2, FBG-13 and 52-S were resistant (R) against bacterial blight. Genotypes EFLD and PK-10029-13-2-1 were moderately resistant (MR), while genotypes PK-10324-1-1, SRI-25, GC-75, SRI-23 and control PK-1121-Aromatic were moderately susceptible (MS) against bacterial blight. All other genotypes including control Super-Basmati were susceptible to bacterial blight. This variation in insect pest and disease resistance among rice genotypes could be attributed to a complex interplay of genetic, biochemical, physiological, and environmental factors.

CONCLUSION

This study concludes that genotypes EFLD, GC-75 and KSK-111-H produced the highest average paddy yield. Likewise, genotypes P-35, control PK-1121-Aromatic and SRI-23 exhibited the maximum plant height, tillers count per plant, and weight of 1000-grains, respectively, while genotype KSK-111-H displayed the maximum length of panicle and grains per panicle. Average paddy yield remained maximum under the environmental conditions of Bahawalnagar and Faisalabad. Genotypes 52-S and EFLD yielded the maximum recoveries of brown rice and head rice, respectively, while genotype SRI-23 demonstrated the maximum grain length, thickness and CGL. Most of the genotypes stayed resistant against stem borer and leaf folder. Considering the paddy yield results, genotypes EFLD, GC-75, and KSK-111-H could be recommended for general cultivation in order to attain maximum yield. Conversely, if the focus is on

enhancing the appearance or aesthetic quality of rice, genotype SRI-23 would be a suitable choice due to its superior CGL.

AUTHOR'S CONTRIBUTION

Project administration and Supervision: Muhammad Yousuf. Writing original draft: Asif Ameen. Formal analysis: Asif Ameen, Ahmad Jawad, Atif Naeem. Investigation and Methodology: Muhammad Yousuf. Writing and Reviewing: Naveed Akhter, Muhammad Idrees, Muhammad Arif, Muhammad Akram, Muhammad Nawaz, Husnain Jawad, Hafiz Naveed Ramzan, Muhammad Kashif Ahmad. Correspondence: Asif Ameen. All authors have proofread and approved the final version of the manuscript.

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AVAILABILITY OF DATA AND MATERIAL

All data produced throughout this research is presented in this published article as tables.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

This study does not include any personal data from individuals in any capacity. All authors have consented to its publication.

CONFLICT OF INTERESTS

All authors attest to the validity of manuscript contents and agree for submission.

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REFERENCES

- Ayub Agricultural Research Institute (AARI). (2025). Achievements of Rice Research Institute, KSK. Retrieved May 5, 2025, from <https://aari.punjab.gov.pk/achievementsrri>.
- Abedullah, S., Kouser, S., & Mushtaq, K. (2007). Analysis of technical efficiency of rice production in Punjab (Pakistan). *Pakistan Economic and Social Review*, 45(2), 231-244.
- Acuña, T. L. B., Lafitte, H. R., & Wade, L. J. (2008). Genotype×environment interactions for grain yield of upland rice backcross lines in diverse hydrological environments. *Field Crops Research*, 108(1), 117–125.
- Adair, C. R., Beachell, H. M., Jodon, N. E., Johnston, T. H., Thysell, J. R., Green, V. E. Jr., et al. (1966). Rice breeding and testing methods in the United States. In: *Rice in the United States: Varieties and production* (pp. 19-64). U.S. Department of Agriculture, Washington, D.C.
- Akhter, M., & Haider, Z. (2020). Basmati rice production and research in Pakistan. In E. Lichtfouse (Ed.), *Sustainable Agriculture Reviews 39* (Vol. 39, pp. 119-136). Springer International Publishing.
- Alam, I. (2017). Pakistan all set to become major rice producer: Cultivation of hybrid rice in Punjab can increase production to double digit. *The Nation*. Retrieved from <https://nation.com.pk/13-Oct-2017/pakistan-all-set-to-become-major-rice-producer>.
- Anacleto, R., Cuevas, R. P., Jimenez, R., Llorente, C., Nissila, E., Henry, R. J., et al. (2015). Prospects of breeding high-quality rice using post-genomic tools. *Theoretical and Applied Genetics*, 128(7), 1449-1466. <https://doi.org/10.1007/s00122-015-2537-6>.
- Azeez, M. A., & Shafi, M. (1966). Quality in Rice. Tech. Bulletin No. 13, Department of Agriculture, Govt. of West Pakistan, p. 23.
- Bao, J., Kong, X., Xie, J., & Xu, L. (2004). Analysis of genotypic and environmental effects on rice starch; apparent amylose content, pasting viscosity, and gel texture. *Agricultural and Food Chemistry*, 52(19), 6010–6016. <https://doi.org/10.1021/jf049234i>.
- Bin Rahman, A. N. M. R., & Zhang, J. (2023). Trends in rice research: 2030 and beyond. *Food and Energy Security*, 12: e390. <https://doi.org/10.1002/fes3.390>.

- Birla, D. S., Malik, K., Sainger, M., Chaudhary, D., Jaiwal, R., & Jaiwal, P. K. (2017). Progress and challenges in improving the nutritional quality of rice (*Oryza sativa* L.). *Critical Reviews in Food Science and Nutrition*, 57(11), 2455-2481. <https://doi.org/10.1080/10408398.2015.1084992>.
- Butardo, V. M. Jr., Sreenivasulu, N., & Juliano, B. O. (2019). Improving rice grain quality: State-of-the-art and future prospects. *Methods in Molecular Biology*, 1892, 19-55.
- Butt, M. S., Anjum, F. M., Rehman, S., Nadeem, M. T., Sharif, M. K., & Anwer, M. (2008). Selected quality attributes of fine basmati rice: Effect of storage history and varieties. *International Journal of Food Properties*, 11(3), 698-711. <https://doi.org/10.1080/10942910701622706>.
- Candia, A., Oker, T. E., Muzei, J., Olupot, J., Yawe, J., Emapus, B., & Okiror, W. (2013). Effect of paddy drying depth using open-sun drying on drying time and mill recovery of Kasio variety in eastern Uganda. *Uganda Journal of Agricultural Sciences*, 14(2), 37-47.
- Das, B., Mannan, M. A., & Das, P. K. (2012). Performance study of three high yielding varieties of Bangladesh and one exotic rice variety. B.Sc. Agri. Thesis. Agro-technology Discipline, Khulna University, Khulna, pp. 19-27.
- Dawn. (2023). Rice exports earn Pakistan \$2.1 billion in tumultuous FY23. Retrieved on July 15 from <https://www.dawn.com/news/1767422/rice-exports-earn-pakistan-21bn-in-tumultuous-fy23>.
- Economic Survey of Pakistan. (2024). Govt. Pakistan finance division economic advisory wing Islamabad, pp. 21. Retrieved from http://www.finance.gov.pk/survey/chapter_20/02_Agriculture.pdf.
- Jaruchai, W., Monkham, T., Chankaew, S., Suriharn, B., & Sanitchon, J. (2018). Evaluation of stability and yield potential of upland rice genotypes in North and Northeast Thailand. *Journal of Integrative Agriculture*, 17(1), 28-36.
- Juliano, B. O. (1985). *Rice: Chemistry and Technology*. American Association of Cereal Chemists, Inc.: St. Paul, MN.
- Juliano, B. O., Onate, L., & Mundo, A. M. (1965). Relation of starch compaction, protein content, and gelatinization temperature to cooking and eating quality of milled rice. *Food Technology*, 19, 1006-1101.
- Khush, G. S. (2005). What it will take to feed 5.0 billion rice consumers in 2030. *Plant Molecular Biology*, 59(1), 1-6. <https://doi.org/10.1007/s11103-005-2159-5>.
- Khush, G. S. (2013). Strategies for increasing the yield potential of cereals: case of rice as an example. *Plant Breeding*, 132(5), 433-436. <https://doi.org/10.1111/pbr.1991>.
- Kusutani, A., Tovata, M., Asanuma, K., & Kui, J. (2000). Studies on the varietal differences of harvest index and morphological characteristics of rice. *Japanese Journal of Crop Science*, 69, 359-364.
- Malini, N., Sundaram, T., Ramakrishnan, S. H., & Saravanan, S. (2006). Prediction of hybrid vigour for yield attributes among synthesized hybrids in rice (*Oryza sativa* L.). *Research Journal of Agriculture and Biological Sciences*, 2, 166-170.
- Mao, H., Sun, S., Yao, J., Wang, C., Yu, S., Xu, C., Li, X., & Zhang, Q. (2010). Linking differential domain functions of the GS3 protein to natural variation of grain size in rice. *Proceedings of the National Academy of Sciences*, 107(45), 19579-19584. <https://doi.org/10.1073/pnas.1014419107>.
- Memon, N. A. (2013). Rice: Important cash crop of Pakistan. *Pak. Food Journal*, 21-23. Retrieved from <http://www.foodjournal.pk/Sept-Oct-2013/Sept-Oct-2013-PDF/Exclusive-article-Rice.pdf>.
- Ministry of National Food Security & Research. (2021). Crops area and production (Districts Wise) 2021-22. Government of Pakistan. Retrieved from <https://mnfsr.gov.pk/SitelImage/Publication/CAP.pdf>.
- Naqvi, S. A. H. (2019). Bacterial leaf blight of rice: An overview of epidemiology and management with special reference to Indian sub-continent. *Pakistan Journal of Agricultural Research*, 32, 359. <https://doi.org/10.17582/journal.pjar/2019/32.2.359.380>.
- Nino-Liu, D. O., Ronald, P. C., & Bogdanove, A. J. (2006). *Xanthomonas oryzae* pathovars: Model pathogens of a model crop. *Molecular Plant Pathology*, 7, 303-324. <https://doi.org/10.1111/j.1364-3703.2006.00344.x>.
- Oladosu, Y., Rafii, M. Y., Magaji, U., Abdullah, N., Miah, G., Chukwu, S. C., Hussin, G., et al. (2018). Genotypic and phenotypic relationship among yield components in rice under tropical conditions. *BioMed Research International*, 2018, 1-10. <https://doi.org/10.1155/2018/8936767>.
- Rahman, N. M. F., Malik, W. A., Baten, M. A., Kabir, M. S., Rahman, M. C., Ahmed, R., Hossain, A. M. Z., Hossain, M. M., Halder, T., Bhuiyan, M. K. A., Khan, M. A. I., Khan, R. H., Ahasan, N., & Piepho, H. P. (2024). Sustaining rice productivity through weather-resilient agricultural practices. *Journal of the Science of Food and Agriculture*, 104(4), 2303-2313. <https://doi.org/10.1002/jsfa.13119>.
- Rahman, S., Jahan, T., Rahman, S., Md, M. Rahman, M. M., Haque, M. M., & Khan, A. A. M. (2018). Evaluation of some transplanted AUS rice genotypes for morphology, yield and disease incidence. *European Academic Research*, Bangladesh, p. 295.
- Reddy, T. Y., & Reddy, G. H. (1997). *Principles of Agronomy*. Kalyani Publication, New Delhi, India, p. 515.
- Roy, S. K., Ali, M. Y., Jahan, M. S., Saha, U. K., Ahmad-Hamdani, M. S., Hasan, M. M., & Alam, M. A. (2014). Evaluation of growth and yield attributing characteristics of indigenous Boro rice varieties. *Life Science Journal*, 11(4), 122-126.
- Sasaki, T., & Burr, B. (2000). International rice genome sequencing project: The effort to completely sequence the rice genome. *Current Opinion in Plant Biology*, 3, 138-141.

- Shah, M. A. A., Özel, G., Chesneau, C., Mohsin, M., Jamal, F., & Bhatti, M. F. (2020). A statistical study of the determinants of rice crop production in Pakistan. *Pakistan Journal of Agricultural Research*, 33, 97-105. <https://doi.org/10.17582/journal.pjar/2020/33.1.97.105>.
- Shobharani, W., & Krishnaiah, K. (2001). Current status and future prospects for improvement of aromatic rice in India. In R. C. Chaudhary, D. V. Tran, & R. Duffy (Eds.), *Specialty Rices of the World: Breeding, Production and Marketing* (pp. 49-78). FAO Science Publishers Inc. USA.
- Shrestha, J., Subedi, S., Kushwaha, U. K. S., & Maharjan, B. (2021). Evaluation of rice genotypes for growth, yield and yield components. *Journal of Agriculture and Natural Resources*, 4(2), 339-346. <https://doi.org/10.3126/janr.v4i2.33967>.
- Sood, B. C., & Siddiq, E. A. (1980). Studies on cooking and nutritive qualities of cultivated rice (*Oryza sativa* L.). Ph.D. Thesis, IARI, New Delhi, 1980.
- Tahir, M., Waden, D., & Zada, A. (2002). Genetic variability of different plant yield attributes in rice. *Sarhad Journal of Agriculture*, 18(2), 13-17.
- Tsehaye, Y., Kinfu, H., Reda, A., Welegebrieal, R., Geretsadkan, G., Yalew, D., Gebrelibanos, W., Gebremikael, Y., Abebe, E., Asgele, K., & Girmay, A. (2018). Evaluation of performance for yield and yield components of upland rice under rain-fed condition. *Asian Journal of Biological Sciences*, 11, 78-82. <https://doi.org/10.3923/ajbs.2018.78.82>.
- USDA Foreign Agricultural Service. (2024). Production, supply, and distribution of rice. Retrieved from <https://www.fas.usda.gov/data/production/commodity/0422110>.
- Yousuf, M., Majid, A., Rehman, A., Khan, S., Hassan, N., Ali, N. (2014). Performance of candidate varieties of basmati rice in National Uniform Yield Trials. *European Academic Research*, 2(1), 1456-1462.
- Zahid, A. M., Akhtar, M., Sabrar, M., Anwar, M., & Mushtaq, A. (2005). Interrelationship among yield and economic traits in fine grain rice. *Proceedings of the International Seminar on Rice Crop* (pp. 21-24). Rice Research Institute, Kala Shah Kaku, Pakistan.