Original Research Article

SONA SUPER BASMATI: A NEW EXTRA-LONG GRAIN HIGH YIELDING RICE VARIETY WITH EXCELLENT COOKING QUALITY

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Abstract *Rice crop feeds about half of the world's population which is getting larger and hungrier with every tick of the clock. Basmati rice being a geographical speciality of Pakistan is widely proclaimed as one of the finest rice available throughout the world due to its unique aroma, taste, and texture. Changing consumer behavior and preferences for basmati rice i.e., extra-long grain length along with excellent cooking quality, reiterates the revitalization of rice breeding objectives to develop suitable basmati rice varieties. In this context, plant breeders at Rice Research Institute, Kala Shah Kaku identified a suitable transgressive segregant from F2 segregating population of a cross (PK 10436) between the famous basmati rice variety "Basmati 515" (female parent) and 99417 (male parent). The initial cross of PK 10436-4-2 was accomplished during Kharif, 2010 followed by its rigorous selection and purification in succeeding generations through the pedigree method till F4 generation in Kharif, 2014. After its development, PK 10436-4-2 was evaluated in Station Yield Trials (Kharif, 2016 - 2019) for various yields and its attributing traits in which it gave a cumulative 31.37 % yield advantage over the check variety (Super Basmati). Meanwhile, multi-locational yield evaluation was accomplished in Micro-plot Yield Trials and National Uniform Yield Trials for two consecutive years (Kharif, 2020 - 2021) at various locations across Pakistan; in which, PK 10436-4-2 out-yielded the check variety by 17.50 % and 19.75 % respectively. In addition to superior yield indices, PK 10436-4-2 showed excellent cooking quality i.e., extra-long grain length (AGL = 9.5 mm; CGL = 17.5 mm), with strong aroma. The aforementioned superior credentials of this candidate line led to its approval for general cultivation as "Sona Super Basmati" in the 56th meeting of the Punjab Seed Council, Punjab, Pakistan. In the future, prospects of cultivating Sona Super Basmati could create new vistas not only in local rice consumption but also in the basmati rice export of Pakistan.*

Keywords*: Basmati Rice; Rice Export; Pedigree Method; Station Yield Trial; Micro-plot Yield Trial; National Uniform Yield Trial; Extra-long Grain*

Introduction

Basmati rice is a geographical indication (GI) of Pakistan, which is extensively recognized. It is regarded as some of the finest rice in the world as a result of its unique aroma, flavor, and texture. Rice is the second most significant staple sustenance crop and export commodity, following wheat. It is responsible for 0.4% of the nation's GDP and 1.9% of the value produced in agriculture. In recent years, the production of coarse hybrid types has increased as producers cultivate them on larger plots of land. In 2022-2023, the crop was cultivated on 2,976 thousand hectares, a 15.9 percent decrease from 3,537 thousand hectares the previous year. The production of 9.323 million tonnes in 2021-2022 decreased to 7.322 million tonnes in 2022-2023, with a negative growth rate of 21.5%. Nevertheless, the production of rice this year is lower than that of the previous year. Paddy prices have increased as a result of reduced production and rising input costs. The superior cooking qualities of basmati rice have made it the most popular variety of rice grown in Pakistan and India. It is also highly esteemed in other countries. The global demand for this type of rice is on the rise as a result of its distinctiveness, the positive relationship between producers and customers, and the evolving dietary preferences (Ghasal et al., 2015). The majority of Pakistan's basmati rice is produced in the Kalar Tract region of Punjab, which is situated between the Ravi and Chenab rivers. Gujranwala, Hafizabad, Nankana Sab, Narrowal, Sheikhupura, and Sialkot are among the districts in this region that are particularly well-known for their rice production. The rice was granted Geographical Indication (GI) status (GI No. 01-R) on January 21, 2021, following sections 7 and 24 of the Geographical Indications Registry,

Government of Pakistan, as this location has been classified as a Geographical Indication (GI) for Basmati rice. Traditional basmati cultivars are more susceptible to lodging, diseases, photoperiod, and temperature fluctuations, and they produce less than non-basmati cultivars (Verma et al., 2017). In the 1920s, Pakistan's Rice Research Institute Kala Shah Kaku (RRI KSK) initiated endeavors to modify basmati rice (Ahmad et al., 2005). New basmati cultivars with improved grain quality metrics, resistance to lodging and a variety of maladies, and increased genetic output potential had been anticipated for an extended period. The initial initiatives were largely unsuccessful as a result of a lack of infrastructure for analyzing grain quality and defined selection criteria. Although pure line selections resulted in varieties with lower yields and were more susceptible to diseases, lodging, and insects, they were still suitable for culinary quality (Shobha, 2009; Inayatullah et al., 1986). Combining acceptable agronomic characteristics with grain quality and aroma criteria is the primary obstacle to Basmati improvement (Khush & Juliano, 1991). Super Basmati succeeded Basmati 385 and 370 as a result of its superior grain quality and increased production capacity. However, it exhibited a higher incidence of insects and a lower stem rigidity (Akhtar et al., 2014; Akhtar et al., 2015). Super Basmati remains a popular choice among regional producers; however, its demand in global markets has declined as consumers increasingly prefer extra-long grain varieties that cook efficiently (Khan & Khan, 2010; Jafar et al., 2015). Additionally, producers in traditional rice regions are in high demand for cultivars that mature early and produce high yields of high-quality grain. The "Sona Super Basmati" rice variety, which is high-yielding and extra-long grain, was developed by breeders at the Rice Research Institute in Kala Shah Kaku, Punjab, Pakistan. This rice variety adheres to the aforementioned specifications and boasts superior culinary quality.

Material and methods

Experimental Description

PK 10436 was the designated name destined for a superior cross combination between Basmati 515 (female parent) and 99417 (male parent). The cross was accomplished during Kharif 2010-11 at Rice Research Institute (RRI), Kala Shaha Kaku (KSK). After that, a suitable transgressive segregant was selected from the F_2 progeny followed by its advancement through the pedigree method up to F_4 generation from Kharif 2012-13 to 2014-15 (figure 1).

During Kharif 2016-17, a uniform line with the pedigree of PK 10436-4-2 was selected from F_4 generation for its evaluation in the Preliminary Yield

Trial (PYT) against the check (Super Basmati). Based on its superior performance, PK 10436-4-2 was evaluated against the check (Super Basmati) in an Advanced Yield Trial for three consecutive years from Kharif 2017-18 to 2019-20. The experiment was conducted at RRI, KSK by following a Randomized Complete Block Design (RCBD) with three replicates.
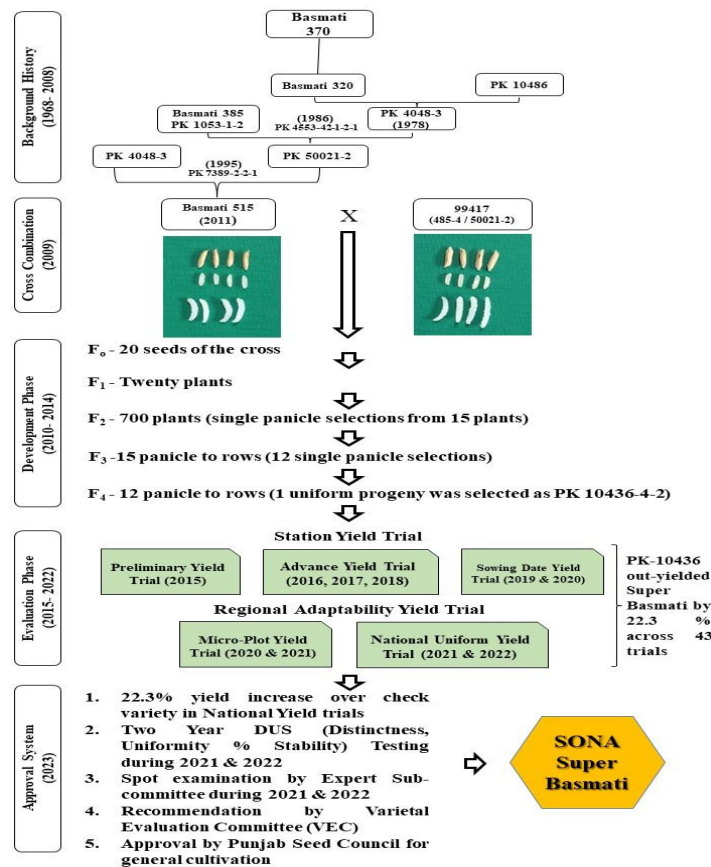

Figure 1: Comprehensive history pertaining to the development, evaluation, and approval of "Sona Super Basmati"

To assess the yield stability of PK 10436-4-2 in a diverse range of environments, a Micro-plot Yield Trial (MYT) was carried out for two consecutive years from Kharif 2020-21 and 2021-22. Under this trial, PK 10436-4-2 was evaluated against the standard check of Super Basmati in different locations throughout Punjab viz., Gujranwala, Sheikhupura, Faisalabad, Sargodha, Kala Shah Kaku and Bahawalnagar. The experiment was carried out by following a Randomized Complete Block Design (RCBD) with three replicates.

PK 10436-4-2 was then evaluated as a "candidate line" in the National Uniform Rice Yield Trial for two consecutive years from Kharif 2020-21 and 2021-22. Under this trial, PK 10436-4-2 was evaluated against the check variety "Super Basmati"

at various locations of Punjab, Sindh, and Khaybar Pakhtunkhwa (KPK). Detail of all locations is given below:

1. Agriculture Research Institute (ARI), Dera Ismail (DI) Khan, KPK.
2. Usta Muhammad, Sindh.
3. Rice Research Institute, Dokri, Larkana, Sindh.
4. Soil Salinity Research Institute (SSRI), Pindi Bhattian, Punjab.
5. Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Punjab.
6. Rice Research Institute, Kala Shah Kaku, Punjab.
7. Pulses Research Institute (PRI), Sialkot, Punjab.
8. Pakistan Agricultural Research Council (PARC), Kala Shah Kaku.
9. Rice Research Station, Bahawalnagar, Punjab
10. National Institute for Biotechnology and Genetic Engineering (NIBGE), Faisalabad, Punjab.

To optimize the date of sowing of the candidate line (PK 10436-4-2), a Sowing Date Yield Trial (SDYT) was conducted. Transplanting of the candidate line along with the check cultivar (Super Basmati) was carried out at different dates i.e., June 03, July 01, July 15, and August 09, during Kharif 2020-21 and 2021-22. The experiment was carried out by following a Randomized Complete Block Design (RCBD) with three replicates.

DUS (Distinctness, Uniformity and Stability) study
DUS studies were carried out under the supervision of the Federal Seed Certification and Registration Department (FSC&RD) during Kharif 2020-21 and 2021-22. For the partial fulfillment of the DUS study, SSR-marker-based DNA fingerprinting of the candidate line along with different checks i.e., Super Basmati, Super Basmati 2019, and Basmati 370, was carried out at Agricultural Biotechnology Research Institute (ABRI), Faisalabad.

Agronomic interventions
All experiments were carried out by following the Puddled Transplanted Rice (PTR) method. Nursery sowing was done in the last week of May. Recommended plant populations were ensured by maintaining plant-to-plant and row-to-row distances at 8 cm and 9 cm respectively. All agronomic interventions were keenly optimized i.e., in time fertilization, weed, and insect-pest management etc.

Data recording
Data regarding various yields and their attributes were recorded in PYT and AYTs. Ten plants in each replication were selected and data were recorded viz., plant height at maturity (cm), No. of tillers per plant, days to maturity, and yield (kg/ha). While yield (kg/ha) estimation was accomplished in MYT, NUYT, and SDYT.

Results
Station Yield Trials

The uniform line PK 10436-4-2 was selected from F_4 generation (due to its erect plant type high yielding attributes and extra-long grains) during the growing season 2015-16. Due to its genetic superiority of various yields and its attributing characters, this advance line was evaluated in the Preliminary Yield Trial (Kharif, 2016-17) against the check variety i.e., Super Basmati (table 1). Comparative analysis based on yield and its attributing characters showed a superior yield performance of PK 10436-4-2 in comparison with Super Basmati. The average yield showed a 15.66 % yield advantage of PK 10436-4-2 over Super Basmati. Based on higher yield estimates, PK 10436-4-2 was further evaluated in Advance Yield Trials for three consecutive years i.e., 2017-18, 2018-19, and 2019-20, and showed higher estimates for % yield advantage over the check (Super Basmati) viz., 7.41 %, 58.33 % and 44.06 % respectively. Cumulatively, on an average across all Station Yield Trials, PK 10436-4-2 (av. 5627.5 kg/ha grain yield) showed an overall 31.37% yield advantage over the check variety (av. 4367.5 kg/ha grain yield) which was a testament for its advancement and evaluation in Micro-Plot Yield Trial and National Uniform Yield Trial.

Table 1: Comparative analysis of PK 10436-4-2 and Super Basmati (check) based on various yields and its attributing estimates in station yield trials

Name of Station Yield Trial	No. of Entries	Plant height (cm)		Tillers Per Plant		Maturity days		Grain Yield (Kg/ha)		% Yield Advantage Over Check
		PK 10436-4-2	Super Basmati	PK 10436-4-2	Super Basmati	PK 10436-4-2	Super Basmati	PK 10436-4-2	Super Basmati	
Preliminary Yield Trial Kharif, 2016	15	130	120	16	16	110	115	4800	4150	15.66
Advance Yield Trial Kharif, 2017	13	125	109	20	23	115	114	6090	5670	7.41

Advance Yield Trial Kharif, 2018	10	126	120	16	22	110	115	6650	4200	58.33
Advance Yield Trial Kharif, 2019	10	134	120	20	23	108	115	4970	3450	44.06
Average across the trials		**129**	**117**	**18**	**21**	**111**	**115**	**5627.5**	**4367.5**	**31.37**

Micro-Plot Yield Trials

Based on higher yield estimates in Station Yield Trials, PK 10436-4-2 was advanced for its evaluation in various agroecological zones of Punjab, Pakistan for two consecutive Kharif seasons i.e., 2020-21 and 2021-22 (figure 2). Under Micro-Plot Yield Trials, PK 10436-4-2 was evaluated in a diverse range of rice-cultivated areas of Punjab i.e., Gujranwala, Sheikhupura, Faisalabad, Sargodha, Kala Shah Kaku, and Bahawalnagar. During Kharif 2020-21, among these locations, PK 10436-4-2 showed the highest yield performance in Gujranwala (5920 Kg/ha) as compared to that of check variety i.e., Super Basmati (4920 Kg/ha.). On the other hand, the lowest yield performance of PK 10436-4-2 was recorded at Bahawalnagar (3070 Kg/ha) as compared to that of the check variety (3460 Kg/ha). During Kharif 2021-22, PK 10436-4-2 showed the highest yield performance in Faisalabad (5420 Kg/ha) as

compared to that of check variety i.e., Super Basmati (5042 Kg/ha.). On the other hand, the lowest yield performance of PK 10436-4-2 was recorded at Gujranwala (2570 Kg/ha) as compared to that of the check variety (2442 Kg/ha). On an average account of year-wise multilocational yield evaluation, PK 10436-4-2 showed a 7.48 % and 28.56 % yield increase over check variety during Kharif 2020-21 and 2021-22 respectively. On average account of two-year multilocational yield performance, PK 10436-4-2 sustained a 7.32 to 41.13 % yield advantage over check variety with the highest at Sheikhupura and followed by 34.82 % at Sargodha. Bahawalnagar was the only location with a disadvantage (-1.68 %) of yield which was the resultant of a lesser yield of PK 10436-4-2 compared to that of check variety during kharif-2020 at this location. The cumulative average % yield advantage for PK 10436-4-2 across the locations and years was 16.27 % in Micro-Plot Yield Trials.
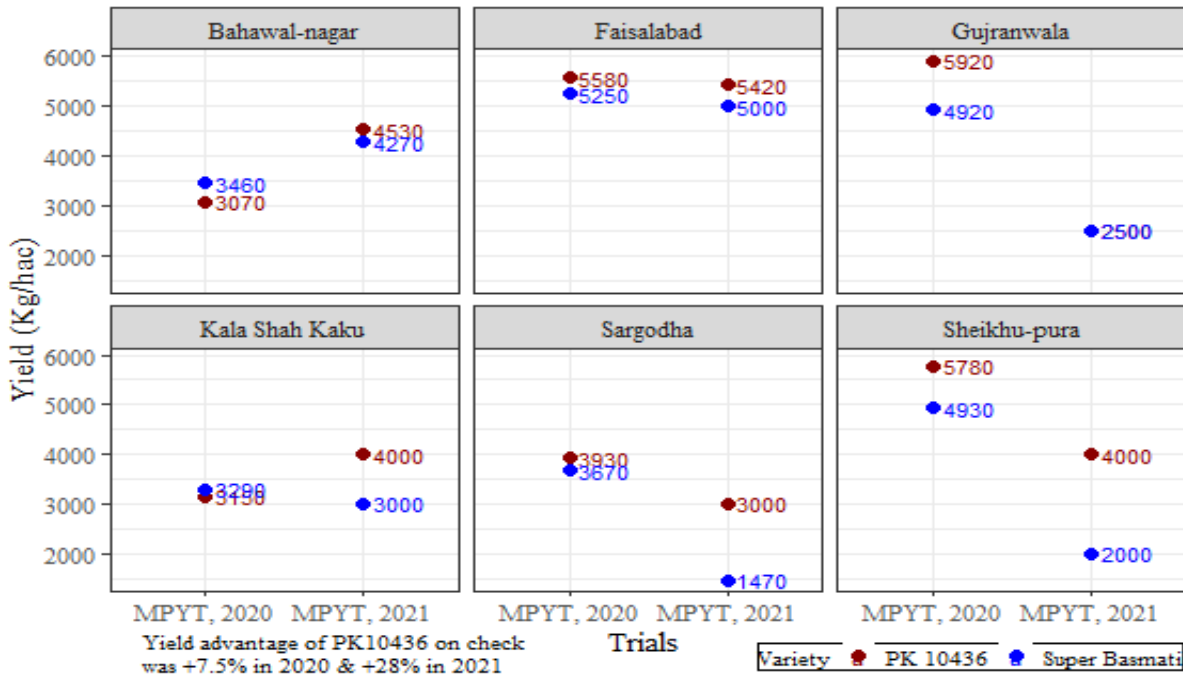

Fig.2 Performance of PK 10436 and Super Basmati under Micro-Plot Yield Trials

National Uniform Rice Yield Trial (NURYT)

A country-wide evaluation of PK 10436-4-2 under the National Uniform Rice Yield Trial (NURYT) of Fine Varieties was conducted during Kharif, 2020-21 and 2021-22. A total of 19 trials were performed at 10 locations across Punjab, Sindh, and KPK region

(figure 3). During NURYT 2020-21, PK 10436-4-2 recorded the highest yield performance at the Nuclear Institute of Agriculture and Biology (NIAB), Faisalabad, Punjab (5939 Kg/ha) in comparison with that of check variety i.e., Super Basmati (5942 Kg/ha). On the other hand, PK

10436-4-2 recorded the lowest yield performance (2160 Kg/ha) at the Agriculture Research Institute, DI Khan, KPK. On an average account of all locations, PK 10436-4-2 exhibited a higher yield (4316 Kg/ha) as compared to that of check variety (3928 Kg/ha) with an overall yield advantage over a check of 7.48 % during 2020-21 across all locations of Pakistan. Meanwhile, during NURYT 2021-22, PK 10436-4-2 showed the highest yield performance at Usta Muhammad, Sindh (9558 Kg/ha) in comparison with that of check variety (5051 Kg/ha). On the other hand, PK 10436-4-2 produced the lowest yield (2103 Kg/ha) at Soil Salinity Research Institute (SSRI), Pindi Bhattian, Punjab. On an average account of all locations, PK 10436-4-2 exhibits a higher yield (4806 Kg/ha) as compared to that of check variety (3631 Kg/ha) with an overall yield advantage over a check of 32.36 % during 2021-22 across all locations.

On average accounting for two-year location-wise yield performance in NURYT, PK 10436-4-2 maintained an 8.62 to 33.04 % yield advantage over check variety with the highest at Usta Muhammad and followed by 32.96 % at RRI, Dokri, Larkana, Sindh. In Punjab, RRI Kala Shah Kaku was the location with the highest % yield increase of 30.80 while ARI, DI. Khan, KPK was the only location with a disadvantage (-22.25 %) for PK 10436-4-2 compared to check variety in both years. Cumulative average % yield increase for PK 10436-4-2 across the locations and years under 19.29 % in NURYT.
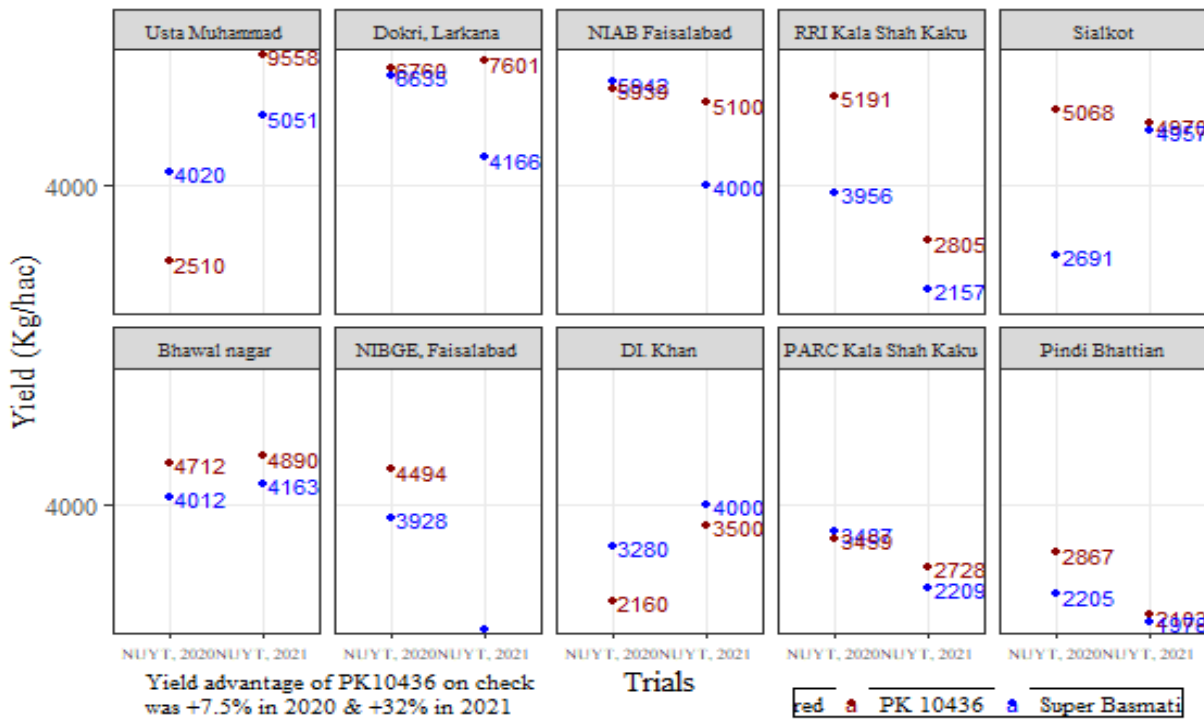

Fig.3 Performance of PK 10436 and Super Basmati under National Uniform Yield Trials

Optimization of Sowing Date

For the optimization of the sowing date, PK 10436-4-2 was evaluated in a series of sowing date trials viz., 03-June, 01-July, 15-July, and 09-August during Kharif 2020-21, and 2021-22 (table 2). PK 10436-4-2 showed the highest yield performance (4440 Kg/ha) as compared to that of check i.e., Super Basmati (2720 Kg/ha) when sown on July 01, 2020.

Similarly, during Kharif 2021-22, it produced the highest yield (4029 Kg/ha) when sown on July 15, 2021, in comparison with that of the check variety (2990 Kg/ha). In conclusion, the Sowing Date Yield Trials, uncover the first fortnight of July as the best window to start the cultivation of PK 10436-4-2 to maximize yield. PK 10436-4-2 showed a 22.52 % yield increase over check variety across all the sowing dates and years.

Table 2: Sowing date optimization of PK 10436-4-2 among four sowing windows 03-June, 01-July, 15-July and 09-August

Name of Yield Trial	Varieties	03-Jun	01-Jul	15-Jul	09-Aug	Average	% Yield Advantage

[Citation: Sabar, M., Ali, SS., Ijaz, M., Khan, R.A.R., Bibi, T., Riaz, M., Sehar, H., Shahzadi, F., Zafar, S.A., Javed, H.M. (2024). Sona super basmati: A new extra-long grain high yielding rice variety with excellent cooking quality. *Biol. Clin. Sci. Res. J.,* **2024**: 922. doi: https://doi.org/10.54112/bcsrj.v2024i1.922]

							Over Check
		Grain Yield (Kg/ha)					
Sowing Date Yield Trial Kharif, 2020	PK 10436-4-2	3090	4440	3150	3440	3530	**22.68**
	Super Basmati	2060	2720	3290	3440	2878	-
Sowing Date Yield Trial Kharif, 2021	PK 10436-4-2	2998	3969	4029	2070	3243	**22.36**
	Super Basmati	1605	3670	2990	2330	2650	-
Average	PK 10436-4-2	3045	4205	3575	2720	3386	**22.52**
	Super Basmati	1830	3195	3145	2885	2764	-

Distinctness, Uniformity and Stability (DUS) Analysis

Varietal Descriptors of PK 10436-4-2

As illustrated in the aforementioned yield trials, PK 10436-4-2 exhibits a higher yield as compared to that of check which is primarily due to the indirect contribution of various plant characteristics. Likewise, characteristics as mentioned in figure 4 showed the superiority and distinctness of PK 10436-4-2 in comparison with Super Basmati. Moreover, the distinctness of PK 10436-4-2 comprises of higher yield with batter No. of grains per panicle (110) and thousand-grain weight (27 g) having early maturity (110 days), extra-long grain length (9.5 mm), and excellent cooking quality cooked grain length (16.1 mm).
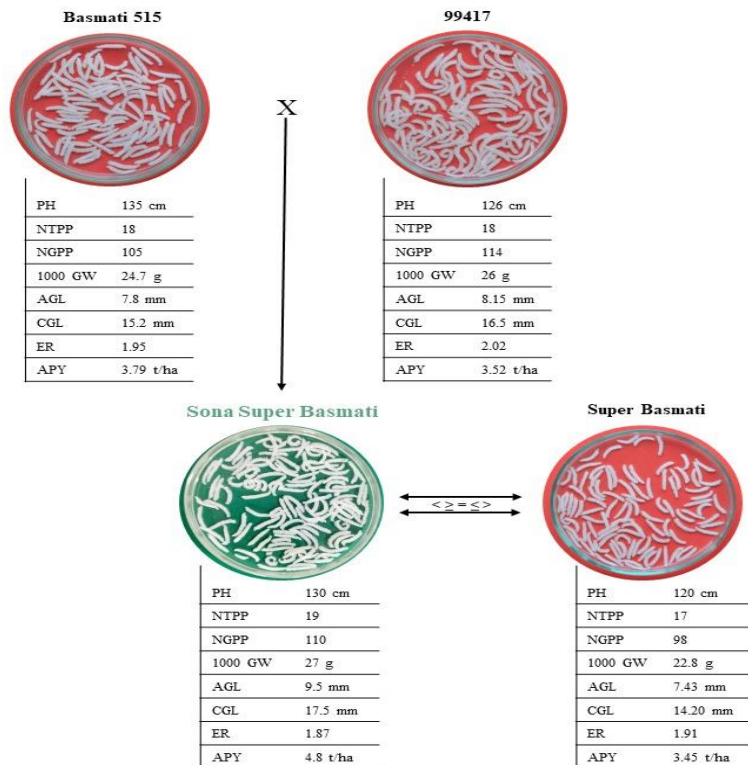
PH = Plant Height; **NTPP** = Number of Tillers per Plant; **NGPP** = Number of Grains per Panicle; **1000 GW** = 1000 Grain Weight; **AGL** = Average Grain Length; **CGL** = Cooked Grain Length; **ER** = Elongation Ratio; **APY** = Average Paddy Yield

Figure 4: Description of "PK 10436-4-2" in comparison with the existing commercial variety "Super Basmati"

Genetic diversity and DNA fingerprinting of PK 10436-4-2 discerned by SSR markers

Cultivar Identification Diagram (CID) as presented in figure 5 elucidated the association among check varieties (Super Basmati, Super Basmati 2019, Basmati 370) and candidate variety (PK 10436-4-2) was generated by unweighted paired group method with arithmetic means (UPGMA). The X-axis represents the genetic similarity coefficient between genotypes which ranged from 0.56 to 0.91. CID results concluded that candidate variety PK 10436-4-2 varied significantly from the check variety "Super Basmati" (26.2% dissimilarity), Super Basmati 2019 (32.7 % dissimilarity), and Basmati 370 (32.7 % dissimilarity).
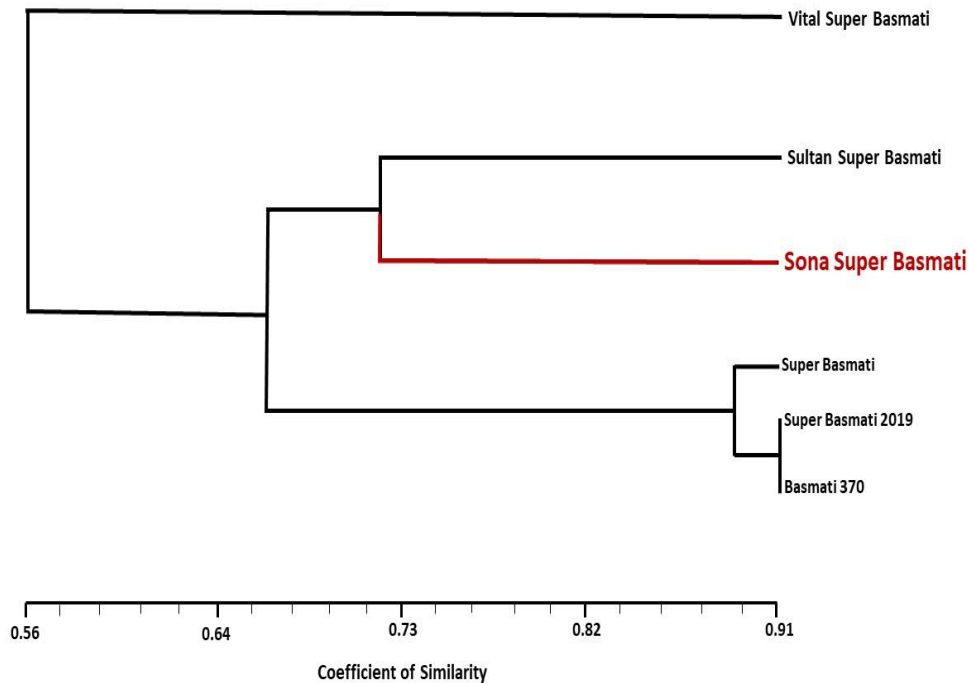

Figure 5: Cultivar Identification Diagram (CID) of PK 10436-4-2 in comparison with the check cultivars

Discussion

The pedigree method is regarded as the most widely followed method for variety development in rice (Biswas *et al*., 2024). Genetic variability being generated from a cross in F_2 segregating population provides a firm basis for the selection of superior variants i.e., transgressive segregants that may end up in a new cultivar (Ali et al., 2016; Ali et al., 2017; Ekka *et al*., 2023). In the present study, a high frequency of transgressive segregants was observed in F_2 segregating population of the "Basmati 515 x 99417" cross. This accumulation of diverse segregants might be due to the breakage of linkage blocks with subsequent mopping-up of desirable alleles (Ekka and Kumari, 2020). In addition to this, being the chief cause of transgressive segregation, additive gene action would be in high preponderance resulting in the accumulation of genes responsible for extra-long grain length and superior yield indices at all segregating loci (Ali and Malik, 2021; Patil et al., 2021). Unlike heterosis, extreme phenotypes caused by transgressive segregation explore heritable trait variation that encourages selection in the succeeding generations (Mackay *et al*., 2021). In this context, a superior segregant was selected in the present study from F_2 population followed by its advancement up to F_4 generation with a designated pedigree "PK 10436-4-2".

In plant breeding, yield is the ultimate benchmark that determines the value for cultivation and use of a breeding line (Ali et al., 2024; Bradshaw, 2017). However, it is determined by a series of independent components that represent the overall growth and development of a plant (Ali et al., 2013; Ali et al., 2014ab; Saroj *et al*., 2021). In the present study, the uniform line PK 10436-4-2 was advanced for its evaluation in a series of station yield trials. A cumulative yield advantage of 31.37% over the check variety (Super Basmati) was observed which coincides with the fact that genetic gain is due to the selection pressure being conferred by the process of selective breeding (Inayat et al., 2023; Lozada *et al*., 2020). Moreover, Manjunatha and Niranjana (2024) also indicated the genetic superiority of a breeding line – an outcome of systematic improvement of

various agronomic attributes through selective breeding.

Estimation of yield stability of a rice genotype under a diverse range of environments provides basic insights into its adaptability (Huang *et al.*, 2021). Climate change-mediated weather unpredictabilities reiterate stable yield performance across diverse environments as the prime objective of a variety of development programs in rice (Hussain *et al.*, 2020). In the present study, PK 10436-4-2 was evaluated in a diverse range of environments under the Micro-plot Yield Trial and National Uniform Yield Trial for two consecutive years. It showed higher yield performance than the check variety (Super Basmati) across all locations in both of the trials. This increased and stable yield performance might be due to the higher buffering capacity of PK 10436-4-2 as it has been bred in the face of changing climate. In a recent study conducted by Ghazy *et al.* (2023), the high buffering capacity of certain rice lines was identified as the chief cause of yield stability and superiority across a diverse range of environments.

On the other hand, Aggarwal *et al.* (2023) reported site-specific yield uncertainties due to unpredictable weather patterns that undermine the genetic potential of a genotype by deteriorating its yield stability. Similar results were reported during the Micro-plot Yield Trial where a clear yield disparity was shown by PK 10436-4-2 at the same location (Gujranwala) during Kharif, 2020-21 and Kharif, 2021-22. Likewise, in the National Uniform Yield Trial, PK 10436-4-2 showed similar behavior at the location of Usta Muhammad, Sindh during Kharif, 2020-21 and Kharif, 2021-22. Therefore, above discussed results identified the environment as the key determinant of genotypic yield stability under a diverse range of agroecological conditions.

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