Faculty of Agriculture, University of Poonch Rawalakot
Jammu Kashmir Journal of Agriculture
ISSN: 2958-3756 (Online), 2958-3748 (Print)
https://jkjagri.com/index.php/journal

A HIGH YIELDING, EXTRA-LONG GRAIN AND POSSESSING RELATIVELY BETTER SALT TOLERANT POTENTIAL WITH EXCELLENT COOKING QUALITY

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A B S T R A C T

Rice, a staple for over 50% of the world's population, it is a major for Pakistan's agriculture and economy's. Rice is the second most important food grain after wheat in Pakistan and is the second highest revenue-generating crop after cotton, earning about $4 billion in foreign revenue. Punjab leads in rice production, contributing 64% of the crop area and 51% of production. Historically, Super Basmati replaced Basmati 385 for its superior grain quality and yield. Later, PK 1121 became popular for its high yield and long grain. However, soil salinization, especially in Punjab's 1.537 million ha of salt-affected land, restricts rice growth and yield. The Salinity Research Institute in Pindi Bhattian developed "SRI 28" to overcome this issue. This variety offers higher paddy yield, longer kernel length (>10.01 mm), and better salt tolerance. The stiff stem of "SRI-28" makes it suitable for lodging resistance and mechanical harvesting. Its performance being observed in salt-affected soils makes it suitable for saline Agriculture. Its features, like broad erect leaves, stiff stems, and stay-green traits, enhance photosynthesis, boosting yield and suitability for parboiled and steamed rice. The "SRI-28," developed using conventional and back cross-hybridization methods, crosses "KS 282" and "Basmati 385." Initiated in 2005 at SSRI, Pindi Bhatian, the process included backcrossing for genome recovery and pedigree selection up to BC2F8. It was evaluated from 2016 to 2019 in yield and adaptability trials.

Keywords: *Oryza sativa* L; Evapotranspiration; SRI 28; Plant height; Grains per panicle

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Article history
Received: July 4th, 2024
Revised: August 13th, 2024
Accepted: August 19th, 2024

INTRODUCTION

Rice (*Oryza sativa* L.) is a member of the Poaceae family. Its basic chromosome number is n=12. This species can be either diploid or tetraploid. Specifically, both *Oryza sativa* L. and *Oryza glaberrima* L. are diploid species with a chromosome count of 2n=24 (Brar, 2003). *Oryza sativa* is predominantly cultivated in Asia, whereas *Oryza glaberrima* is native to West and Central Africa (Linares, 2002). Asian cultivated rice (*Oryza sativa* L.) distinguished as the first crop to have its entire genome sequenced, establishing it as a model species for genetic and agricultural research. Rice is an essential food crop worldwide. It serves as the primary staple food for over three billion people, supplying between 50-80% of their daily caloric intake. This dependence on rice highlights its critical role in maintaining food security and nutrition in numerous countries (Khush, 2005).

Many Asian countries produce approximately 87% of the

world's rice. Eight of these countries account for about 35% of global rice exports. Global food security heavily depends on rice production in Asia, especially in India and China. These two major economies together represent 37% of the global population and contribute 49% of the world's rice production. Concerns are general about the need to balance population growth with agricultural production while preventing environmental degradation (Maskey, 2001).

Rice stands as Pakistan's second major cash crop, with a notable edge in producing aromatic basmati rice. This crop holds significant importance for Pakistan's exports, contributing meaningful revenue to the government through export duties. Various policies have been applied to encourage sufficient production. Punjab and Sindh appear as the primary provinces for rice cultivation, with Punjab contributing 56% and Sindh 39% to the total production (GoP, 2019).

As the population grows and people's incomes increase, the demand for food is also rising. This presents a major challenge in ensuring global food security. The increasing condition of being successful leads to diets that require more natural resources per person. Coupled with the expanding populations, this trend could result in a two- to four-fold rise in the global demand for food crops within two generations (Godfray and Garnett, 2014).

Salinity refers to the presence of increased concentrations of various salts like sodium chloride, magnesium, calcium sulfates, and bicarbonates in soil and water (Hoang et al., 2014). Worldwide, about 6% of the Earth's land, roughly 1125 million hectares, is impacted by salt (Hayat et al., 2019) the escalating saline areas stem from various factors. These include raised salt levels in irrigation water, limited rainfall, heightened evapotranspiration rates, seawater intrusion, the presence of saline soils, and inefficient water usage and management practices (Li et al., 2019). In Pakistan, about 42% of irrigated land grapples with salt stress, amounting to an estimated 6.63 million hectares of affected land (Ali et al., 2017; Naveed et al., 2020). Rice is one the important crops for the reclamation of salt-affected soils. There exists a dire need to introduce an extra-long grain Rice variety for salt-affected soils which can not only produce better paddy yield but should also be suitable for parboiled and steamed rice. Keeping this scenario in view, scientists at Salinity Research Institute, Pindi Bhatian strive to address the farmer demand and have developed the Rice line “SRI 28” that has higher paddy yield, paddy length, kernel length (> 10.01mm), and better salt tolerance potential, when compared to existing fine rice lines/varieties. It has broader and erect leaves, stiff stems, and long flag leaves. The stay-green feature of “SRI 28” makes it more suitable to accumulate a higher level of photosynthesis in grain which ultimately helps to increase the paddy yield.

MATERIALS AND METHODS

The “SRI-28” with pedigree name SRI-23-5-3-2-3-3-2, has evolved through conventional and back cross methods of hybridizing using the high yield crosses grain Rice variety “KS 282” as a female parent with Basmati 385 (a high yielding, long grain, kernel length and better salt tolerant line carrying the Basmati 370 genome) as a male parent. A cross was attempted between cultivar “KS 282” and cultivar“ Basmati 385” during the year (2005) at SSRI, Pindi Bhatian and back crossing was done for basmati genome recovery until BC2 followed by the pedigree selection method up to BC2F8 generation. This line was bulked and evaluated in observational lines/plots. Afterward, it was tested in yield trials and regional adaptability trials from 2016 to 2019 (Table 1).

Table 1. Breeding History of SRI-28 from 2005-2021.

Year	Generation	Parentage / Pedigree
2005	F_1	KS 282 / Basmati 385
2006	BC_1F_1	KS 282 // Basmati 385
2007	BC_2F_1	KS 282 /// Basmati 385
2008	BC_2F_2	SRI-28
2009	BC_2F_3	SRI-28-5
2010	BC_2F_4	SRI-28-5-3
2011	BC_2F_5	SRI-28-5-3-2
2012	BC_2F_6	SRI-28-5-3-3-3
2013	BC_2F_7	SRI-28-5-3-2-3-3
2014	BC_2F_8	SRI-28-5-3-2-3-3-2
2015-2016	Bulk	Screening and selection against salinity
2017-2018	OP Trials	Evaluation against Checks
2019-2021	Station yield trials, Micro-plot yield trials , National Uniform Yield Trials (NUYT)	

SRI 28" was tested in observational plots during 2016-2017. The proposed line SRI 28 along with local cultivars was evaluated in 11 trials during 2018 and 2019. The new line SRI 28 along with Super Basmati and PK 1121 aromatic was tested in 20 trials in two years 2020-2021. Sowing date trials for SRI 28 were monitored for three years (2018 to 2020) at Soil Salinity Research Institute Pindi Bhatian. Fertilizer trials on SRI 28 were conducted at Soil Salinity Research Institute, Pindi Bhatian during years (2018-2020). three treatments including the recommended dose (of 150-129-60 kg/ha)with an average of (2.78 t/ha)in saline-sodic soil. The candidate line "SRI 28", Super Basmati and PK 1121 aromatic harvested during 2020 and 2021 against bacterial disease by the National Agriculture Research Center, Islamabad. The candidate line "SRI 28" along with checks (Super Basmati and PK 1121 aromatic) were tested during the years 2020 and 2021 against stem borer and leaf folder under the supervision of the National Agriculture Research Center, Islamabad.

Production Technology of "SRI 28"

The following appropriate production technology has been developed to obtain maximum yield from the new rice variety SRI 28 which is summarized below:

Seed rate = 15 kg/ha
Seedling age at transplanting = 25-30 days
Time of sowing nursery = June 10 to June 20
The optimum time of transplanting = July 10 to July 20
Fertilizer (kg/ha) = 225-86-60 NPK
In salt-affected soil = 02 to 03 seedlings per hill

RESULTS

Yield Performance

Observational Plots

"SRI 28" was tested in observational plots during 2016-2017in which different charters like plant height maturity days and yield in ton per hectare are counted in comparison with Shaheen Basmati (Table 2).

Station Yield Trials

These trials were conducted at SSRI, Pindi Bhatian in 2016 & 2017. In the station yield trials average plant height average maturity days and average yield in the two years (Table 3).

Table 2. Plant parameters during observational plots during 2016-2017.

Year	Character	Varieties	
		SRI 28	Shaheen Basmati
2014-15	Plant height (cm)	105	140
	Maturity days	95-100	101
	Yield (t/ha)	4.36	3.95

Table 3. Study of yield during station yield trails.

Year	Character	Varieties		
		SRI 28	PK 1121 aromatic	Shaheen Basmati
2016	Plant height (cm)	106	126	140
	Maturity days	96	119	100
	Yield (t/ha)	4.21	2.95	3.12
2017	Plant height (cm)	107	122	135
	Maturity days	97	118	98
	Yield (t/ha)	4.31	2.99	3.35
Average Plant Height (cm)		106.5	124	137
Average Maturity days		96.5	118	99
Average Yield (t/ha)		4.26	2.97	3.24
% increase of SRI 28 over PK 1121 aromatic and Shaheen Basmati			41.41%	31.48%

The table 3 shows that in station yield trials the new candidate line gave 41.41% and 31.48% higher yield over PK 1121 aromatic and Shaheen Basmati, respectively. The initial and post-harvest soil analysis for the years 2016 and 2017 is as under in Table 4.

Micro Plot Yield Trials

The proposed line SRI 28 along with local cultivars was evaluated in 11 trials during 2018 and 2019.

These trials were conducted in different cities like Pindi Bhatain, Gujranwala, Farooqabad, and Faisalabad in comparison with two varieties PK-1121 and shaheen basmati The yield data as follows in Table 5. The table indicates that the paddy yield of the candidate line in micro plot trials gave 32.90% and 14.72 % higher yields than PK 1121 aromatic and Shaheen Basmati, respectively.

Table 4. Soil analysis of station field trials during 2016-17.

Year	Soil Analysis					
	Initial status			Post-harvest		
	pH	EC (dSm^{-1})	SAR $(mmol\ L^{-1})^{1/2}$	pH	EC (dSm^{-1})	SAR $(mmol\ L^{-1})^{1/2}$
2016	8.66	5.82	36.22	8.62	5.76	34.21
2017	8.68	5.85	36.35	8.64	5.78	34.31

Table 5. Study of paddy yield at different locations during 2018-19.

	Location Varieties	Paddy yield (t/ha)		
		SRI 28	PK 1121 aromatic	Shaheen Basmati
2018	Pindi Bhattian	4.81	3.74	4.21
	Gujranwala	4.10	3.55	4.48
	Farooq Abad	3.61	4.10	4.22
	Multan	3.50	2.44	2.43
	Faisalabad	4.45	3.25	3.35
	Average	4.09	3.41	3.77
2019	Pindi Bhattian	3.22	2.74	2.95
	Gujranwala	3.49	3.65	4.01
	Farooq Abad	2.94	2.94	3.21
	Multan	3.44	2.01	2.72
	Faisalabad	2.97	1.96	2.24
	Sargodha	4.04	3.82	3.52
	Average	3.35	2.85	3.10
Average yield of both years		4.16	3.13	3.63
% Increase over check			32.90%	14.72 %

Regional Adaptability Trials (NUYT)

The new line SRI 28 along with Super Basmati and PK 1121 aromatic was tested in 20 trials over two years at different locations in Pakistan and Punjab. The yield data are given below in Table 6. The table indicates that in NUYT trials, SRI 28 gave 20.83% and 28.01% higher paddy yield than PK 1121 aromatic and Super Basmati, respectively in all locations of Pakistan. Similarly, SRI 28 gave 6.67% and 32.06% higher paddy yield than PK 1121 aromatic and Super Basmati, respectively in Punjab locations.

Sowing Date Trials

Sowing date trials for SRI 28 were monitored for three years (2018 to 2020) at Soil Salinity Research Institute, Pindi Bhatian. On June 1st, June 15th and July 1st yield data of transplanting trials (Table 7). It is quite clear from the data that on average of three years, SRI 28 gave the highest paddy yield (3.28 t/ha) on the transplanting date of 1 July. Overall it is obvious that the maximum paddy yield of SRI 28 can be achieved by transplanting SRI 28 Rice Nursery from 1st July to 15th July.

Fertilizer Trials

Fertilizer trials on SRI 28 were conducted at Soil Salinity Research Institute, Pindi Bhatian during the years (2018-2020). The average paddy yield with different fertilizer doses along with soil analysis is given below in Table 8 and Table 9. The fertilizer dose (225-86-60 kg/ha) produced the maximum paddy yield in all three years with an average of (2.91 t/ha) but it was statistically at par with the other three treatments including the recommended dose (150-129-60 kg/ha) with an average of (2.78 t/ha) in saline-sodic soil.

Table 6. Trails of regional adaptability during year 2020-21.

Year	Location	Varieties / paddy yield (kg/ha)		
		SRI 28	PK 1121 aromatic	Super Basmati
2020	Pindi Bhattian	3678	2831	2205
	B. Nagar	5401	5226	4012
	RRI, KSK,	4820	4753	3956
	RRI, KSK, Sialkot Location	4182	3839	1691
	RRI, Dokri	6864	6698	6635
	PARC, KSK	4328	3599	3487
	NIBGE, Farooq Abad	3113	4777	3928
	NIAB	4799	5816	5942
	Usta Muhammad jaffarabad	6223	4433	4020
	RRI, D.I Khan	1760	3120	3280
	Average (Pak)	4517	4509 (0.17%)	4016 (12.47%)
	Average (Punjab)	4331	4405 (-1.67%)	3603 (7.27%)
2021	ARI, Swat	3426	3926	
	ARI, DI. Khan	6500	1500	4000
	Usta Muhammad Jaffarabad	6651	2514	5051
	Dokri, Larkana	8062	3714	4166
	SSRI, Pindi Bhattian	3547	1893	1978
	NIAB Faisalabad	4867	4567	4000
	RRI, KSK	4687	4779	2157
	PRI, Sialkot	6656	6848	4957
	PARC KSK	3349	2874	2209
	Bahawalnagar	4982	3301	4163
	Average (Pak)	5272	3591 (46.81 %)	3631 (45.19 %)
	Average (Punjab)	4681	4043 (15.78%)	3244 (44.29%)
2 years' Average (Pak)		4894	4050 (20.83%)	3823(28.01%)
2 years' Average (Punjab)		4506	4224 (6.67%)	3412 (32.06%)

Table 7. Trails of sowing date during Year 2018-2020.

Year	Transplanting dates / paddy yield (t/ha) of SRI 28				
	1-Jun	15-Jun	1-Jul	15-Jul	Average
2018	2.20	2.55	3.23	3.05	2.75
2019	2.31	2..59	3.31	2.98	2.79
2020	2.27	2.61	3.30	3.02	2.80
Average of three years	2.26	2.58	3.28	3.01	2.78

Table 8. Soil analysis for field trails during 2018-2020.

Year	pH	EC (dS/m)	SAR $(mmol/L)^{1/2}$	OM %	P (mg/kg)	K (mg/kg)
2018	8.70	6.23	39.75	0.34	7.7	102.3
2019	8.68	6.12	38.43	0.36	7.83	105.7
2020	8.61	6.01	35.23	0.43	8.19	107.8

Table 8. Fertilizer trial for paddy yield during 2018-2020.

Treatment	Paddy yield (t/ha)			
NPK(kg/ha)	2018	2019	2020	Average
00-00-00	0.95 G	1.08 G	1.14 G	1.05
00-86-60	1.28 F	1.45 EF	1.53 F	1.42
75-86-60	1.69 D	1.91 D	2.36 DE	1.98
150-86-60	2.24 BC	2.55 B	2.71 BCD	2.50
225-86-60	2.63 A	2.97 A	3.15 A	2.91
150-00-60	1.18 FG	1.33 F	1.42 FG	1.31
150-43-60	1.45 EF	1.64 E	1.73 F	1.61
150-129-60	2.50 AB	2.84 A	3.00 AB	2.78
150-86-00	1.82 D	2.07 D	2.19 E	2.03
150-86-30	2.11 C	2.31 C	2.54 CDE	2.32
150-86-90	2.38 ABC	2.52 B	2.87 ABC	2.59
LSD	0.2754	0.1974	0.3549	

Resistance against Insect Pests and Diseases

Reaction against Diseases

The candidate lines "SRI 28", Super Basmati and PK 1121 aromatic were tested in 2020 and 2021 against bacterial disease by the National Agriculture Research Center, Islamabad (Table 10).

Reaction against Insects

The candidate line "SRI 28" along with checks (Super Basmati and PK 1121 aromatic) were tested during the years 2020 and 2021 against stem borer and leaf folder under the supervision of the National Agriculture Research Center, Islamabad. The results are summarized in Table 11.

Quality Performance

The studies regarding the physical characters of grain, milling recovery, cooking quality, and chemical tests are presented below in Table 12.

Area of Adaptability

The entire rice growing area of the Punjab Province.

Economics of Cultivation of PK SRI 28 over PK1121 Aromatic

With an expected 50 % of the potential yield of SRI 28 on 50 % of the total salt-affected area of Punjab (1.537 million hectares) an increase in paddy yield, against Shaheen Basmati, Al- Khalid Rice and PK 1121 and super basmati will provide annual income benefit of Rs. 21.90, 19.04 and 4.65 billion.

DISCUSSION

The findings from the study on the SRI 28 rice variety align with and expand upon previous research in the field of salt-tolerant rice breeding. The study's results are particularly relevant when compared to earlier work on improving rice yield and adaptability under stress conditions such as salinity.

The yield performance of SRI 28 significantly outperforms that of existing varieties like PK 1121 aromatic and Shaheen Basmati, which is consistent with the growing body of literature that emphasizes the importance of breeding for salt tolerance. For example, Rani et al. (2006) documented the successful development of salt-tolerant rice varieties through conventional breeding methods, which achieved yields comparable to non-salt-tolerant varieties under normal conditions but excelled under saline conditions. The higher yield of SRI 28, particularly in saline soils, underscores the effectiveness of the breeding strategies employed, reinforcing findings by Kaewmungkun et al. (2023) who demonstrated the potential for significant yield improvements in salt-affected soils through targeted breeding programs.

Table 10. Reaction against different bacterial disease.

Disease	SRI 28	Super Basmati	PK 1121 aromatic
2020			
Bacterial leaf Blight	MR	MS	MS
2021			
Bacterial leaf Blight	MS	HS	S

Table 11. Reaction of Varieties against Insects.

Insect	Name of variety		
	SRI 28	Super Basmati	PK 1121 Aromatic
2020			
Leaf folder	MS	HS	HR
Stem borer	R	HR	HR
2021			
Leaf folder	R	R	R
Stem borer	MS	MS	S

Table 12. Quality performance of different varieties of Rice.

Characters	Name of variety		
	SRI 28	Super Basmati	PK 1121 aromatic
Paddy			
Av. Length (mm)	15.4	10.60	12.00
Av. Width (mm)	2.12	1.86	1.92
Av. Thickness (mm)	1.98	1.68	1.80
Rice kernel			
Av. Length (mm)	9.3	7.40	8.41
Av. Width (mm)	1.94	1.70	1.83
Av. Thickness (mm)	1.7	1.56	1.55
Cooked grain length (mm)	16.6	13.7	17.8
Elongation ratio	1.76	1.71	2.13
Shape	Slender	Slender	Slender
Milling results			
Brown Rice %	72.20	77.90	60.00
Total recovery %	54.10	60.00	49.00
Head rice %	12.30	48.70	27.50
Broken %	31.50	22.00	21.50
Amylose content %	24.00	23.80	24.00
Aroma	Mild	Strong	Mild
Bursting (%)	4.00	5.00	3.00
Cooking	Excellent	Excellent	Excellent
1000 grain wt (g)	30.24	24.00	27.00

The regional adaptability trials conducted in the current study show that SRI 28 performs consistently across various agro-ecological zones in Pakistan. This is in line with research by Flowers and Yeo (1995), who highlighted the importance of genetic diversity in rice to enhance adaptability across different environments, particularly in stress-prone areas. The ability of SRI 28 to maintain high yields across diverse regions suggests it possesses the genetic robustness necessary for wide cultivation, which is crucial for its adoption in various farming systems.

The findings on optimal sowing dates for SRI 28, particularly the benefits of transplanting on July 1st, resonate with earlier studies that emphasize the impact of agronomic practices on rice yield. Hussain et al. (2013) demonstrated that adjusting sowing dates could significantly influence the yield outcomes of rice, particularly in varieties sensitive to photoperiod and temperature changes. The consistency in yield improvement with timely transplanting observed in SRI 28 aligns with these findings, highlighting the variety's responsiveness to optimized agronomic practices.

The success of SRI 28 in trials is indicative of the broader potential for breeding programs to enhance food security in saline-prone regions. Previous literature, such as the work by Marone et al. (2021), supports the notion that breeding for stress tolerance is essential for meeting future food

demands under changing environmental conditions . The results from this study not only confirm these earlier findings but also suggest that SRI 28 could serve as a model for future breeding efforts aimed at developing high-yielding, salt-tolerant rice varieties.

CONCLUSION

SRI-28 produced higher paddy yield i.e., 28.00%, 23.10%, and 32.06% over the PK-1121 aromatic, Shaheen Basmati and Super Basmati, respectively. The quality characteristics i.e. average grain length (9.3mm), and cooked grain length (16.6 mm) of SRI 28 are better than Super Basmati(AGL=7.40 mm, CGL =14.10mm)and PK 1121 (AGL=8.41 mm, CGL =16.25 mm) aromatic. It has the potential to escalate the Pakistani Rice export and can play a crucial role in earning foreign exchange. It is suitable for both parboiled and steamed Rice. It is suitable for saline-sodic soil due to its salt tolerance potential. It is propriety for mechanical harvesting due to its stiff stem and lodging resistance. It is a short-duration variety. It is relatively more salt tolerant than the existing fine rice variety in the market.

CONFLICT OF INTEREST

The authors declare that there is no conflict in the publication of this article.

AUTHOR'S CONTRIBUTION

All the authors contributed equally in the manuscript.

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