RESEARCH ARTICLE

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GENOTYPE × ENVIRONMENT INTERACTION AND STABILITY ANALYSIS OF YIELD TRAITS AMONG EARLY GENERATION - PYRAMID PROGENY FAMILIES (EG-PPFS) IN RICE (*Oryza sativa* L.)

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SUMMARY

Forty six F_3 early generation-pyramid progeny families (EG-PPFs) of cross RB6 × QRT25, along with 9 check varieties (includes both parents and 7 well established varieties) were evaluated under three different moisture regimes in field condition *viz.*, aerobic condition (E_1), moisture stress at vegetative stage of crop growth (E_2) and reproductive stage of crop growth (E_3) for their yield performance and moisture stress tolerance. Pooled analysis of variance for stability revealed the presence of significant differences among the genotypes and environments for all the characters studied. Highly significant mean squares due to G × E interaction for all the traits when tested against the pooled error revealed that the genotypes interacted considerably with environmental conditions that existed in three different moisture regimes. On partitioning G × E into linear and nonlinear components, both were responsible for expression of the traits. However, the linear component was found larger in magnitude than the nonlinear component suggesting that the variation in the performance of EG-PPFs and check cultivars could be predicted. The genotypes,23-5-274, 23-5-62, 23-5-302, 23-5-296 (among EG-PPFs) and MAS 26 (among check varieties) were found to be stable across environments for grain yield, while genotypes such as 23-5-103, 23-5-28, 23-5-168, 23-5-243 found stable under moisture stress (unfavourable) conditions. However, genotypes such as 23-5-55, 23-5-33, 23-5-108, 23-5-284, 23-5-315, 23-5-277, 23-5-265, 23-5-311 (among EG-PPFs) and BL122 (among check varieties) were found stable under most favourable environment (aerobic condition). Based on the findings, it is recommended to forward the identified stable EG-PPFs to further generations to derive moisture stress tolerant varieties/breeding lines in a continued breeding pipeline.

Key words: Stability, G × E interaction,moisture stress, aerobic condition, rice

Key findings: Among forty six F_3 EG-PPFs genotypes 23-5-62 and 23-5-302 were found to be most stable over the 3 different moisture regimes for grain yield per plant, 23-5-103, 23-5-168 and 23-5-243 were proved most stable under moisture stress conditions. These families could be further forwarded and tested in multi-location trials to develop elite moisture stress tolerant breeding lines.

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INTRODUCTION

Achieving food security for the continuously increasing population is a major concern in India. The solution to the food problem largely depends on the increase and stabilization of grain productivity through crop improvement projects. Rice (*Oryza sativa* L.) constitutes one of the five major crops of the world and the first most important cereal crop in India. It has been used as a major source of food since prehistoric times, feeding more than two third of world's population and even in Indian subcontinent. Rice is providing food to over 70-80% of Asian population and 2.4 billion of world population. This population will increase to over 4.6 billion by 2050 (Khush, 1996; Honarnejad *et al.,* 2000) which demands greater crop production needs to be produced what is produced at present to cope with the growing population (Sreedhar *et al.,* 2011; Kahani and Hittalmani, 2015)

Therefore, attempts to enhance rice productivity coupled with stability of performance under varying environments must receive top priority. India is largest rice growing nation in the world next to China, however its productivity per unit area is very low. In India, rice is cultivated on 44 million hectares with a production of 103 million tons and productivity of 2.34 t/ha (Viraktamath*et al*., 2012; Kumar *et al.,* 2013).

Rice growing areas spanthetropics, subtropics, semi-arid tropics and temperate regions of the world since rice is unique in its ability to grow in a wide range of hydrologic environments. Rice is cultivated in several ecosystems like upland, rainfed lowland, flood prone and irrigated. The variations in the climatic factors brought water unavailability to rice cultivation which leads to reduction in the production and productivity.

The severity of drought stress varies with rainfall, irrigation source, soil type, water availability within and between seasons, and stage of crop growth, causing the varied responses of rice cultivars in rice growing environments (Shamsudin *et al.,* 2016)

To keep up the rice production during the water shortage regime, alternate cultivation methods of rice is very essential. One alternative option is cultivation of rice under aerobic conditions (Hittalmani and Shivashankar, 1987; Venkataravana and Hittalmani, 1999).

Hence, development of stable high yielding rice varieties which can resist under moisture stress condition is extremely important. The ideal genotype for such moisture stress conditions must contain a reasonably high yield potential with specific plant characters which could buffer against severe moisture stress at critical growth stages of crop (Blum, 1983).

Identification of rice varieties with wider adaptability and stability are the important aspects in varietal recommendation to achieve better economic benefits for farmers. Stability factor is a complex product of genetic yield potential to stress conditions. Hence, multi-location trials are conducted in different locations/seasons/environments to test and identify the consistently performing varieties in wider environments and location specific high performing varieties. Information on the genotype × environment (G × E) interaction and stability parameters provides a better measure of stable variety and varietal adaptability. The interaction aspect of varieties with environment is complex and highly variable across locations. Thus, identifying varieties under these circumstances are difficult for varietal recommendations. However, several statistical methods have been proposed in the recent past with the complex computation requirements for consideration of genotype × environment interaction and its relationship with stability. The aid of statistical software and other programs capabilities ease the complexity to a large extent (Anputhas *et al.,* 2011; Sedghi-Azar *et al.,* 2008). Environments are not necessarily the locations and years/seasons only. Even the differential fertilizer and irrigation schedules, spacing or sowing intervals, etc. under the standard agronomic experiments may constitute environments (Jawahar Sharma, 2006). Keeping all these in view, this study was conducted to assess and identify the early generation-pyramid progeny families (EG-PPFs) of rice for their stable yield under three different moisture regimes at critical growth stages .

MATERIAL AND METHODS

Experiment location

Field experiments were conducted at experimental block (K), Dept. of Genetics and Plant Breeding, University of Agricultural

Sciences (UAS), GKVK, Bengaluru, India (12°58' North latitude, 77°35' East longitude and 930 meters above mean sea level) during dry season 2012.

Plant material

A total of 314 F_2 plants of cross RB6/QRT25 were subjected to trait specific DNA marker assisted selection and 46 plants were selected, and forwarded further. Forty six $F_{2:3}$ early generation-pyramid progeny families (EG-PPFs) of cross RB6/QRT25, along with parental genotypes (*viz*., RB6, QRT25), three well established rice varieties (*viz*., IR64, RpBio, BL122), two aerobic rice varieties (MAS946-1, MAS26) released from UAS, Bengaluru, two wild cultivated species (*viz*., Azucena, Moroberekan) as checks, were used in this study. The parental lines RB6, a recombinant inbred line derived from RpBio/BL122 with blast and bacterial leaf blight disease resistance and QRT25, a near isogenic line derived from IR64/Azucena with drought tolerance (Vaishali *et al*., 2003), were used to develop EG-PPFs. The plant material was evaluated under three different moisture regimes. Namely, environment 1 (E_1)-aerobic condition (non-flooded irrigated), environment 2 (E_2)-moisture stress at vegetative stage of crop growth and environment 3 (E_3)-moisture stress at reproductive stage of crop growth. The schematic diagram showing complete details of plant material development, marker assisted selection and field evaluation under test environments are given in Figure 1**.**

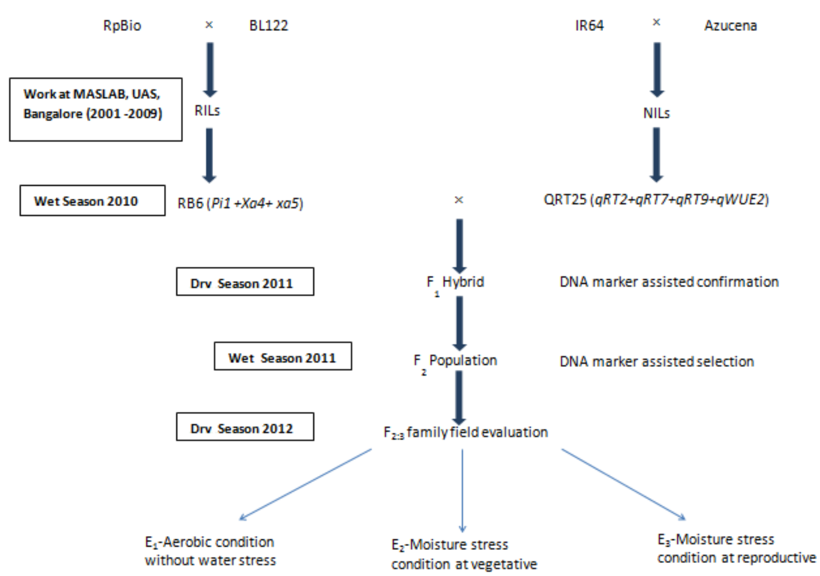

Figure 1. Schematic diagram showing breeding scheme used to develop EG-PPFs, marker assisted selection and evaluation of pyramid genotypes under moisture stress environments at critical growth stages of rice

Marker assisted selection

The leaf samples from F_2 individual plants were collected in the morning hours and total DNA was extracted using procedure given by Dellaporta *et al*., 1983. DNA of 314 F_2 plants were subjected to marker assisted selection using trait specific SSR markers *viz*., three root QTLs, *qRT2* (RM221-RM318) on chromosome 2 , *qRT7* (RM248-RM234) on chromosome 7 and *qRT9* (RM242-RM201) on chromosome 9 (Shen *et al*., 2001; Steele *et al*., 2006), one QTL for water use efficiency *qWUE2* (RM263) on chromosome 2 (Zhang et al, 2001), one blast resistance gene *Pi1*(RM144) on chromosome 11 (Fjelstorm *et al*., 2004), two bacterial blight resistance genes *Xa4* (RM224) on chromosome 11 (Sun *et al.*, 2003) and *xa5* (RM13) on chromosome 5 (Davierwala *et al.*, 2001). The gel pictures depicting marker allele banding pattern of the F_2 plants along with donor parents are presented in the Figures 2, 3, 4 and 5.

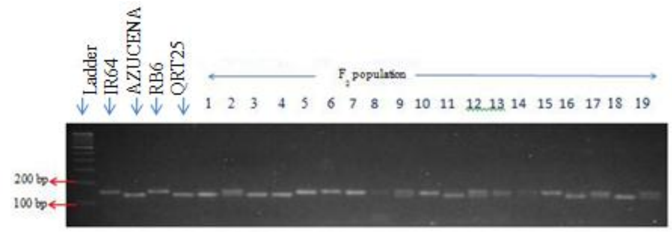

Figure 2. Marker assisted selection for the bacterial blight resistance gene '*xa5*' on chromosome 5 linked by the marker RM13 (donor parent – RB6).

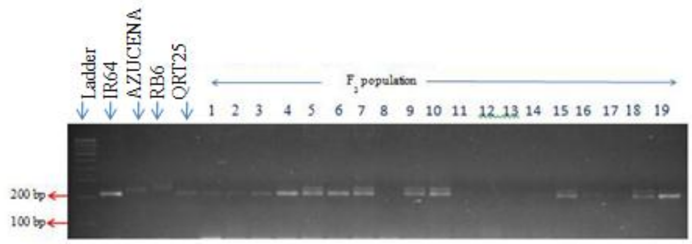

Figure 3. Marker assisted selection for the blast resistance gene '*Pi1*' on chromosome 11 linked by the marker RM144 (donor parent – RB6)

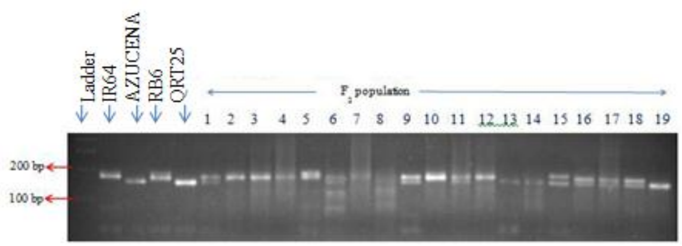

Figure 4. Marker assisted selection for the root QTL '*qWUE*2' on chromosome 2 linked by the marker RM263 (donor parent – QRT25).

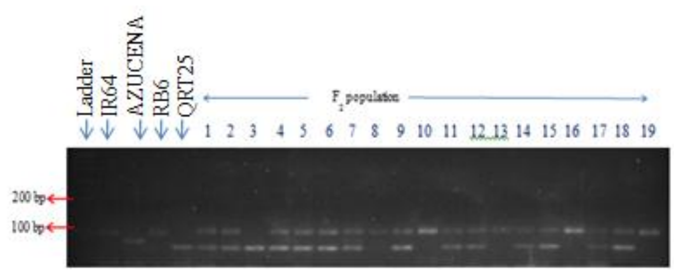

Figure 5. Marker assisted selection for the root QTL 'qRT7' on chromosome 7 linked by the marker RM248 (donor parent – QRT25).

Field experiment

The plant material was planted (one seedling per hill) in randomized complete block design (RCBD) with two replications. Spacing of 20 cm between rows and 20 cm between plants of a row was followed. The cultural practices and crop management measures carried out during the crop stand were fairly uniform in all the environments except moisture stress imposition. Moisture stress was imposed for the period of 15 days at vegetative stage 61 to 75th day of crop growth (E_2) and reproductive stage 91 to 105th day of crop growth (E_3) by with-holding irrigation under rainout shelter structures. However, aerobic condition (E_1) was used without imposing moisture stress throughout the crop growth. The complete details of moisture stress imposition and environments considered in this study are detailed in Table 1. Observation on yield and yield component traits were recorded at appropriate crop growth stages both at pre-harvest and post-harvest stages. Observations were recorded on 10 randomly selected plants per genotypes in all the replications at three environments as per the IRRI standard evaluation system (IRRI, 1996). The trait abbreviation and measurement units that are followed in the text are detailed in Table 2.

Table 1. Details of moisture stress imposed for evaluation of 46 F_3 EG-PPF genotypes and checks during dry season 2012.

Treatment	Environments		
	E1	E2	E3
Stress period	Not imposed	61 DAS - 75 DAS	91 DAS - 105 DAS
Crop Growth Stage	No stress	Vegetative stage	Reproductive stage
Duration of stress (Days)	No stress	15	15
Moisture stress induction	None - Aerobic Condition	Withholding irrigation, avoiding seepage and rainfall	Withholding irrigation, avoiding seepage and rainfall
Rain out structures	Absent	Present	Present

E_1-Environment 1- Aerobic condition without moisture stress.
E_2-Environment 2- Moisture stress at vegetative stage of crop growth.
E_3-Environment 3- Moisture stress at reproductive stage of crop growth.

Table 2. Trait measured in RB6 × QRT25 F_3 EG-PPFs in three environments.

Trait Abbreviation	Trait Description	Measurement Unit
PHT	Plant height	(cm)
FT	Flowering time	(days)
MAT	Maturity time	(days)
PT	Productive tillers per plant	
SPW	Single panicle weight	(g)
SYLD	Straw yield per plant	(g)
BM	Biomass per plant	(g)
HI	Harvest Index	
GYLD	Grain yield per plant	(g)

Statistical analysis

The mean values for all the traits across the environments were subjected to statistical analysis. Analysis of variance was done as per Panse and Sukhatme (1967). The stability analysis was carried out as per the Eberhart and Russel (1966) model using Windostat version 9.2 statistical software from Indostat services, Hyderabad.

Among various stability analysis methods, Eberhart and Russell (1966) model evidently judged as the best method to determine adaptability and stability of genotypes based on its three stability parameters as listed below.

1. The mean performance of the genotype over the environment

2. The regression coefficient (b_i) = 1 (i.e. linear response)

3. The mean deviation from linear regression (S^2d_i) = 0 (i.e., No deviation from linearity)

The estimate of deviations from regression (S^2d_i) suggests the degree of reliance that should be put to linear regression in interpretation of the data. If these values are significantly deviating from zero, the expected phenotype cannot be predicted satisfactorily. When, deviations from regression (S^2d_i) are not significant the conclusion may be drawn by the joint consideration of mean yield and regression coefficient (b_i) values (Eberhart and Russel, 1966) as listed in the Table 3.

Table 3. Regression coefficient (b_i) and mean yield in deriving conclusions on stability of genotypes under study.

Regression coefficient (b_i)	Stability	Mean yield	Remarks
1	Average	High	Well adopted to all environments
1	Average	Low	Poorly adopted to all environments
> 1	Below average	High	Specially adapted to favourable environments
< 1	Below average	High	Specially adapted to unfavourable environments

According to this model, a genotype is judged as the most stable that its average yield is highest, b_i value is equal to unity and S^2d_i non-significant with zero. Overall, adaptable varieties are those cultivars that can express stable genetic potential in diverse environmental conditions. Cultivars in a series of environments have stable average yield are known to have vast adaptability. However, cultivars, which show high yielding genetic potential only in desirable conditions but poor yielding potential in un-desirable conditions known as varieties with finite adaptability (Lin and Bins, 1991).

RESULTS AND DISCUSSION

Pooled analysis of variance for stability is presented in Table 4, revealed the presence of significant differences among the genotypes and environments for all the characters studied. Highly significant mean squares due to G × E interaction for all the traits when tested against the pooled error revealed that the genotypes interacted considerably with environmental conditions that existed in three different moisture regimes (Dushyanthakumar *et al.*,2010; Rasyad *et al*., 2012; Biswas *et al*., 2012; Mall *et al*., 2014; Mosavi *et al*., 2013; Shinde and Patel, 2014; Selvi *et al.,* 2015). Trait wise mean performance of genotypes, spread of variation and environmental index across three environments on nine traits are detailed in Table 5. Similar findings for mean performance of the genotypes over different environments were also reported by Lohitashwa *et al.* (1999) and Hittalmani *et al.* (2003). Further, environment + (genotype × environment) interaction was also found significantly different in pooled analysis of variance for stability of all the traits. The environment (linear) component for all the traits was significant indicating that variation among the environments is linear and their predominant effects on all the traits. Genotype × environment (linear) interaction was significant for all the traits except productive tillers per plant and biomass per plant emphasizing the importance of linear regression in the prediction of these significant traits with some reliance under different environments. Highly significant pooled deviation for all the traits except harvest index suggested that the genotypes differed considerably with respect to stability over the three different environments under study.

Table 4. Pooled analysis of variance for different traits over environments.

Source of Variation	df	PHT	FT	MAT	PT	SPW	SYLD	BM	HI	GYLD
Genotypes	54	339.1**	182.2**	192.2**	24.7**	0.2*	303.8**	412.7**	63.7**	25.6**
Environments	2	4089.9**	624.5**	634.5**	277.5**	23.0**	499.8**	7655.8**	526.2**	1233**
Genotypes × Environments	108	41.2**	8.3**	9.3**	5.1**	0.1**	71.3**	103.1**	22.1**	11.9*
Env. + (Genotypes ×Env.)	110	114.8**	17.3**	19.5**	10.1**	0.5**	79.1**	240.4**	31.2**	34.1**
Environment (linear)	1	8179.8**	988.6**	1249.1**	555.0**	46.0**	999.6**	15311.7**	1052.4**	2466.0**
Genotypes ×Env. (linear)	54	49.8*	10.6*	10.2*	5.4	0.2*	92*	120.1	30.2**	29.1**
Pooled deviation	55	31.6**	6.3**	6.2**	4.7**	0.1**	48.9**	84.6*	13.7	14.6**
Pooled error	162	12.0	3.7	3.6	2.8	0.01	29.8	56.1	12.4	8.1

* , ** = significant at 5%and 1% level of probability, respectively.

Table 5. Environmental wise trait mean, range and environmental index over three moisture regimes.

No.	Characters	Environment 1			Environment 2			Environment 3			CV %	Overall Mean
		Mean	Range	E_i	Mean	Range	E_i	Mean	Range	E_i		
1	PHT	82.9	56.7-122.5	9.3	65.9	47.9-100.9	-7.5	71.7	49.9-97.1	-1.7	14.5	73.5
2	FT	95.7	85.6-116.1	-3.2	101.6	88.4-120.8	2.7	99.5	86.5-123.8	0.5	7.5	98.9
3	MAT	125.5	113.8-150.1	-3.6	132.1	117.7-153.9	2.9	129.8	115-155.5	0.6	6.0	129.1
4	PT	13.8	4.3-24	2.4	11.0	2.6-22	-0.3	9.3	2.3-15.7	-2.0	25.2	11.3
5	SPW	2.2	1.0-3.5	0.7	1.2	0.5-2.1	-0.2	1.0	0.4-1.8	-0.4	17.3	1.4
6	SYLD	36.8	17.5-77.6	0.4	39.2	21.5-102.2	2.8	33.2	18.1-61.5	-3.1	27.6	36.3
7	BM	65.2	34.5-102.5	12.9	49.5	27.9-108.0	-2.7	42.1	19.8-70.3	-10.1	22.0	52.3
8	HI	26.0	8.8-39.0	3.3	22.1	5.3-34.4	-0.5	19.9	12.3-26.2	-2.7	20.2	22.7
9	GYLD	17.2	4.9-30.7	5.2	10.3	4.0-20.6	-1.2	7.7	4.0-12.0	-3.9	23.7	11.7

Ei – Environmental index; CV-Coefficient of variation

Both the linear and non-linear components of G × E interaction were significant for grain yield and other component traits studied, thereby indicating the importance of stability parameters in determining the stability of grain yield and its component traits. These findings are in agreement with the earlier reports (Lohitashwa *et al.,* 1999; Hittalmani *et al.,* 2003; Kumar *et al.,* 2005; Waghmode and Mehta, 2011; Ahamad and Torabi, 2011; Mahalingam *et al.,* 2013; Shinde and Patel, 2014; Selvi *et al.,* 2015; Patel *et al.,* 2015). The water availability or unavailability at critical stages of crop growth plays major role in contributing to large G × E interactions in aerobic and rainfed rice conditions (Ouk *et al*., 2007). This emphasizes the need of identifying stable high yielding rice genotypes under rainfed lowland and aerobic conditions.

Primary requisite for sustainable crop production is the requirement of a genotype with high grain yield and stable performance over different environments. The estimates on the three stability parameters *viz*., mean performance of genotype, regression co-efficient (b_i) and mean deviation from regression (S^2d_i) for nine yield and yield component traits are presented in Tables 6a, 6b and 6c. For plant height, genotypes 23-5-297, 23-5-166 had desired mean performance, b_i value approaching unity and non-significant mean deviation from linear regression revealing their wider adaptability and stability across environments. Whereas genotypes 23-5-235, 23-5-237 with regression coefficient less than 1 and genotypes 23-5-85, 23-5-236 with regression coefficient more than 1 along with non-significant deviation from regression indicating their adaptability for unfavourable and favourable environments, resp.Plant height lesser than checks mean performance was considered in identifying stable EGPPF genotypes.

Table 6a. Estimates of stability parameters of rice EG-PPFs for plant height (PHT), flowering time (FT) and maturity time (MAT).

No.	Genotypes	PHT			DF			DM		
		Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di
1	23-5-55	78.6	0.7	-2.8	94.3	1.2	-3.7	124.6	1.1	-6.2
2	23-5-85	65.3	1.3	-2.3	112.8	2.1	105.0**	142.8	2.0	117.7**
3	23-5-103	82.1	1.3	91.9**	97.7	1.0	-6.6	128.1	0.8	-7.3
4	23-5-224	76.0	1.7	163.4**	89.9	0.1*	-6.6	121.1	0.8	-3.5
5	23-5-235	57.8	0.6	-8.6	95.0	1.3	-5.2	124.6	1.3	-5.7
6	23-5-236	70.2	2.0	23.3	101.3	1.4	114.8**	130.3	1.4	116.1**
7	23-5-250	76.2	1.2	84.1**	101.2	1.7	26.5*	130.7	1.7	-2.4
8	23-5-260	66.6	1.7	57.9*	99.3	1.9	7.0	129.6	1.6	9.0
9	23-5-265	84.1	1.5	11.5	95.5	2.0	17.7	125.2	2.0	11.5
10	23-5-274	82.6	1.5	38.7*	96.3	1.4*	-6.7	125.8	1.4	-7.5
11	23-5-284	79.0	1.3	33.6	95.2	1.2*	-6.7	127.8	1.1	-7.6
12	23-5-297	62.8	1.0	-10.7	99.1	1.5	-4.0	130.5	1.3	-2.3
13	23-5-298	62.3	1.4	9.4	104.7	0.2	1.1	134.4	0.1	-5.2
14	23-5-300	77.9	1.2	102.2**	98.2	1.0	-4.3	128.6	1.7	-7.3
15	23-5-303	64.7	0.7	77.1**	118.1	1.2	31.2*	149.3	1.1	37.0
16	23-5-313	78.9	1.3	69.8**	100.6	1.3	0.2	130.4	1.3	-5.4
17	23-5-319	72.1	0.9	-0.0	99.5	1.1	-6.3	128.4	1.4	-6.6
18	23-5-321	69.6	0.6	31.8	96.5	0.5	-6.5	126.3	0.7	-5.2
19	23-5-33	77.0	0.8	14.0	90.2	-0.3	-6.2	120.2	-0.1	-7.2
20	23-5-28	79.2	1.4	-9.4	94.5	0.0	-4.1	124.7	0.2	-4.1
21	23-5-287	87.8	0.4	-6.2	99.1	1.1	-6.6	130.2	1.1	-7.6
22	23-5-131	71.8	0.7	-7.9	105.4	2.4	6.8	136.2	1.7	-4.7
23	23-5-280	79.4	0.2	2.7	98.1	0.6	15.8	127.0	1	-7.6
24	23-5-166	67.2	1.1	-8.0	110.9	1.2	-1.9	140.6	1.3	-5.0
25	23-5-115	69.8	0.6	19	97.3	0.5	-6.5	127.4	0.7	-7.3
26	23-5-302	80.6	-0.1	-10.1	95.0	1.1	-1.3	127.2	1.0	-3.5
27	23-5-296	75.3	0.4	-1.7	97.3	0.3	2.0	128.5	0.4	10.6
28	23-5-145	61.8	0.5	125.4**	89.1	0.9	-4.8	120.3	1.3	-6.2
29	23-5-26	74.3	1.2	-11.9	92.6	1.1	-4.4	122.0	1.3	-6.8
30	23-5-168	77.7	0.6	19.7	95.4	0.6	-5.8	126.0	0.4	-7.5
31	23-5-108	80.6	0.7	221.2**	87.3	0.1	-5.3	115.5	0.5	-6.5
32	23-5-62	69.8	0.2	7.3	90.5	0.8	-5.4	120.3	0.8	-6.9
33	23-5-294	76.1	0.6	1.9	90.0	0.1	-6.5	119.0	0.0	-6.1
34	23-5-2	83.4	1.9	88.3**	106.9	0.1	-6.3	137.1	0.1	-6.5
35	23-5-311	83.2	0.7	18.0	97.6	0.9	17.1	128.0	1.1	3.3
36	23-5-271	77.0	1.3	118.9**	101.1	1.4	53.8*	129.9	1.3	53.4*
37	23-5-315	73.3	0.9	17.5	97.5	1.3	-4.5	126.8	1.4	-5.6
38	23-5-237	59.7	0.7	-8.0	91.4	0.6	-5.8	120.3	0.8	-7.6
39	23-5-335	81.1	1.4	176.6**	96.9	0.8	4.0	126.5	1.0	17.9
40	23-5-243	65.1	0.8	66.4*	93.0	0.9	-4.6	122.5	1.0	-5.7
41	23-5-234	54.2	0.8	0.4	100.0	1.5	-5.8	128.6	1.5	-6.5
42	23-5-6	78.9	0.8	75.6**	89.5	0.2	-4.1	119.1	0.6	-6.4
43	23-5-277	84.1	1.1	151.5**	92.3	0.6	-0.6	122.7	0.7	1.8
44	23-5-320	52.4	0.5	-9.8	97.8	0.9	-3.3	128.9	0.5	-4.4
45	23-5-92	74.2	1.2	-11.2	100.0	1.3	-1.5	130.7	1.1	-3.1
46	23-5-67	77.6	1.7	-11.3	90.1	0.3	3.9	120.2	0.3	2.2
EG-PPFs Mean		73.5			97.4			127.5		
47	RB6(P_1)(C_1)	57.1	0.4	-6.0	100.9	0.7	-5.0	131.8	-0.0	-5.5
48	QRT25(P_2)(C_2)	84.4	0.7	118.6**	91.1	0.1	-6.2	120.0	0.1	-7.4
49	IR64 (C_3)	64.6	1.1	23.5	106.3	1.4	-6.6	136.0	1.0	-7.6
50	AZUCENA (C_4)	106.8	1.4	68.7*	112.4	0.8	-6.1	144.2	0.6	-5.8
51	MORO (C_5)	101.2	0.6	45.9*	117.9	0.6	-5.4	151.1	0.4	-1.2
52	RPBIO (C_6)	61.5	0.6	-1.7	115.4	1.1	11.0	146.0	0.9	5.3
53	BL122 (C_7)	61.5	0.6	-4.4	101.0	0.9	-6.2	131.8	1.0	-7.6
54	MAS 946-1 (C_8)	64.0	0.9	47.7*	107.3	1.4	-6.1	136.4	1.3	-6.5
55	MAS 26 (C_9)	60.6	1.3	-10.9	107.4	2	-6.1	138.6	1.5	4.5
Checks Mean		73.5			106.6			137.3		
Grand Mean		73.5			98.9			129.1		
Stand. Error Mean		4.9			2.3			2.3		

* , ** = significant at 5% and 1% level of probability, respectively.

Table 6b. Estimates of stability parameters of rice EG-PPFs for productive tillers plant^{-1} (PT), single panicle weight (SPW) and straw yield plant^{-1} (SYLD).

No.	Genotypes	PT			SPW			SYLD		
		Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di
1	23-5-55	22.1	1.8	-8.4	1.9	0.9	-0.1	34.5	-0.1	-16.7
2	23-5-85	22.3	-0.8	65.7**	1.5	0.5	-0.0	37.3	2.1	-57.6
3	23-5-103	24.3	0.2	1.0	1.5	1.2	-0.1	43.3	1.3	-45.3
4	23-5-224	21.3	0.7	15.2	1.5	1.0	0.3	31.8	-1.1	-21.4
5	23-5-235	24.0	2.7	-7.1	1.1	0.5	0.0	24.5	-0.1	-28.0
6	23-5-236	23.3	3.9	-0.7	1.4	1.1	-0.0	30.7	1.3	-56.8
7	23-5-250	19.8	0.2	-7.9	1.5	1.3	-0.0	33.5	0.4	-59.5
8	23-5-260	24.5	2.5	47.7*	1.2	0.5	-0.0	26.7	1.7	-48.2
9	23-5-265	23.4	1.4	-2.8	1.6	1.0	0.7*	34.8	0.1	-52.9
10	23-5-274	21.3	1.8	-5.4	1.4	1.0	0.0	38.6	1.5	-35.8
11	23-5-284	19.7	1.3	-7.8	1.3	1.0	-0.0	49.0	2.9	64.9
12	23-5-297	20.3	0.4	-8.2	1.2	1.0	-0.0	25.8	-0.0	42.6
13	23-5-298	22.5	-0.7	10.3	1.1	1.3*	-0.1	33.5	-1.0	-12.1
14	23-5-300	22.5	1.3	-3.5	1.4	1.2	-0.0	36.7	0.1	-54.8
15	23-5-303	19.0	-1.5	-7.6	0.8	0.2	-0.1	34.8	-0.1	-50.6
16	23-5-313	23.0	1.3	-3.9	2.0	1.1	-0.0	50.8	-0.8	-54.3
17	23-5-319	25.0	1.0	1.4	1.7	0.9	-0.1	40.0	-3.2	-22.9
18	23-5-321	21.2	1.5	-7.9	1.7	1.0	-0.1	35.0	0.2	-50.2
19	23-5-33	20.3	2.4**	-9.4	1.8	0.7	-0.1	23.7	0.4	-59.4
20	23-5-28	20.5	2.1	-1.5	1.6	0.9	0.6*	27.2	1.1	-54.1
21	23-5-287	22.5	2.2	-2.6	1.5	0.9	0	42.9	1.1	-58.4
22	23-5-131	18.5	-0.4	-4.8	1.4	1.2	-0.1	42.6	-1.2	-57.6
23	23-5-280	20.1	1.6	-4.0	1.4	0.9	-0.1	48.6	-3.1	24.1
24	23-5-166	19.9	0.2	37.8*	1.1	0.5	-0.0	42.0	3.6	258.3*
25	23-5-115	19.6	1.8	-4.0	1.1	0.9	-0.0	25.8	0.2	-55.9
26	23-5-302	20.8	1.0	-9.0	1.4	0.8	-0.1	35.2	-0.7	-37.6
27	23-5-296	19.6	0.1	-3.8	1.4	0.7	0	34.9	-0.0	25.4
28	23-5-145	21.5	-0.2	-9.3	1.2	0.4	-0.0	28.1	-0.1	-54.0
29	23-5-26	19.9	-0.1	-9.3	1.3	0.9	-0.0	24.8	-0.5	-23.6
30	23-5-168	22.9	2.2	-6.9	1.5	0.7	-0.1	48.6	1.6	-32.8
31	23-5-108	25.7	0.4	4.2	1.7	1.1	-0.1	35.0	1.5	-40.2
32	23-5-62	22.7	1.2	47.8*	1.7	0.1	-0.1	34.1	2.5	-52.6
33	23-5-294	19.0	0.3	-8.3	1.6	0.5	0.1	26.0	0.1	-24.9
34	23-5-2	18.1	-0.1	1.2	1.3	1.3	-0.0	62.9	4.7	190.1*
35	23-5-311	23.3	0.8	6.3	1.4	1.2	0.0	38.7	0.4	-59.5
36	23-5-271	14.6	2.3	-8.0	1.8	1.1	0	34.3	2.4	-46.9
37	23-5-315	27.1	1.1	9.6	1.4	1.3	0.0	31.0	0.1	-48.3
38	23-5-237	19.9	0.0	-0.8	1.5	0.8	0.1	23.2	0.6	-51.3
39	23-5-335	20.7	2.8	3.5	1.9	1.5	-0.0	38.7	1.5	87.4
40	23-5-243	22.1	1.1	-4.5	1.2	0.9	-0.0	32.1	0.8	-35.4
41	23-5-234	18.0	-0.8	0.2	0.8	0.5	-0.1	20.9	0.9	-58.9
42	23-5-6	24.2	2.7	-2.7	1.7	1.8	-0.1	35.1	2.0	166.1
43	23-5-277	20.6	1.3	-9.3	1.7	1.6	0.1	45.7	1.5	-7.9
44	23-5-320	21.4	-0.1	-3.4	1.2	0.7	0.1	25.1	1.1	-56.3
45	23-5-92	19.9	2.2	15.6	1.6	1.7	-0.0	40.6	0.9	208.9*
46	23-5-67	23.6	0.2	-2.0	1.3	0.9	-0.0	46.1	0.4	-5.6
	EG-PPFs Mean	21.4			1.4			35.5		
47	RB6(P_1)(C_1)	19.4	0.1	12.0	1.2	0.9	-0.1	25.7	1.6	-48.7
48	QRT25(P_2)(C_2)	22.5	-0.4	-0.7	1.6	1.1	-0.1	37.2	0.1	-38.4
49	IR64 (C_3)	20.4	3.2	-1.5	1.2	0.7	-0.0	33.2	1.7	-53.8
50	AZUCENA (C_4)	12.5	-0.5	6.4	1.7	2.3	-0.0	62.8	6.4	-12.8
51	MORO (C_5)	8.7	0.1	-9.1	1.4	1.3	-0.1	69.8	11.8*	-56.8
52	RPBIO (C_6)	21.0	0.3	3.9	1.3	1.1	0.2	32.9	-1.9	-37.3
53	BL122 (C_7)	25.6	1.7	18.2	1.5	0.6	0.0	31.2	3.7	-34.9
54	MAS 946-1 (C_8)	29.9	1.5	-3.7	1.7	1.0	0.0	39.7	2.6	232.9*
55	MAS 26 (C_9)	24.0	0.0	24.4	1.6	0.4	-0.0	31.8	-0.8	-28.3
	Checks Mean	20.4			1.5			40.5		
	Grand Mean	21.3			1.4			36.3		
	Stand. Error Mean	2.4			0.2			4.9		

* , ** = significant at 5%and 1% level of probability, respectively.

Table 6c. Estimates of stability parameters of rice EG-PPFs for biomass per plant (BM) harvest index (HI) and grain yield plant^{-1} (GYLD).

No.	Genotypes	BM			HI			GYLD		
		Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di
1	23-5-55	53.2	0.9	-111.7	27.8	3.0	-0.1	15.7	1.9	-3.4
2	23-5-85	43.8	1.2	98.6	17.2	-0.3	-11.3	8.5	0.2	-5.1
3	23-5-103	58.9	0.7	-99.7	20.8	1.2	-6.9	12.0	0.9	-8.0
4	23-5-224	39.2	0.6	-113.4	22.8	2.5	-1.0	10.0	0.8	-2.4
5	23-5-235	35.1	1.1	-89.8	25.5	1.3	-11.4	9.2	0.9	-4.4
6	23-5-236	45.1	1.3	-101.9	24.9	1.3	-12.4	12.0	1.2	-7.9
7	23-5-250	47.2	0.6	-113.7	23.0	2.4	-9.2	11.2	1.2	-7.3
8	23-5-260	38.2	1.0	-80.3	24.5	0.3	-10.6	9.7	0.7	-5.2
9	23-5-265	53.7	1.4	13.8	23.5	2.4	33.7	14.0	2.3	21.0
10	23-5-274	53.1	1.1	-116.0	20.3	0.8	-9.2	11.2	1.0	-7.3
11	23-5-284	66.1	0.8	-34.9	19.2	2.0	48.6*	12.6	1.4	1.5
12	23-5-297	37.6	0.2	-114.0	27.3	2.7	3.4	10.6	0.9	-2.2
13	23-5-298	45.0	-0.1	-84.4	22.8	2.4	-1.7	9.6	0.8	-3.3
14	23-5-300	54.3	0.9	-45.1	20.1	1.6	4.4	11.3	1.3	4.5
15	23-5-303	44.3	0.2	-94.4	16.7	-1.4	-8	6.3	-0.2*	-8.0
16	23-5-313	73.5	1.3	19.7	20.2	1.2	1.6	14.9	1.4	-8.1
17	23-5-319	62.4	0.5	152.8	26.3	3.8	26.6	15.7	1.9	-7.1
18	23-5-321	56.8	1.6	-104.7	26.9	1.5	30.3	15.5	1.5	-1.7
19	23-5-33	45.4	1.4	-105.1	30.6	0.6	14.1	14.1	1.3	-6.5
20	23-5-28	47.1	1.0	-114.7	28.4	0.0	6.6	12.6	0.7	-0.7
21	23-5-287	62.1	1.3	-101.0	17.8	1.3	-9.6	11.3	1.3	-5.8
22	23-5-131	53.6	0.2	-83.8	15.6	-0.5	-5.5	7.8	0.1	-6.9
23	23-5-280	62.4	-0.1	7.2	17.2	1.4	-8.6	10.4	0.6*	-8.1
24	23-5-166	55.1	0.0	197.8	17.1	0.9	22.2	9.1	0.4	-7.9
25	23-5-115	37.3	0.5	-113.5	24.2	-0.6	-7.74	9.0	0.2	-7.9
26	23-5-302	52.8	0.7	-72.5	22.9	1.8	-10.7	12.0	1.0	-7.8
27	23-5-296	51.2	1.4	-37.6	23.0	0.5	-5.5	11.3	0.9	-8.0
28	23-5-145	39.9	0.5	-103.4	22.7	-0.4	-0.6	8.8	0.2	-7.6
29	23-5-26	40.9	0.8	-97.4	26.9	2.7	-10.9	11.9	1.5	-5.6
30	23-5-168	66.6	1.2*	-115.9	19.5	0.8	-11.9	12.3	0.8	-7.3
31	23-5-108	56.4	0.9	-115.7	28.0	1.7	0.4	16.3	1.6	-5.4
32	23-5-62	53.1	1	-41.8	27.4	1.5	-11.4	14.0	1.0	-1.6
33	23-5-294	39.8	0.2	-114.9	27.7	1.9	-0.1	10.7	0.7	-6.9
34	23-5-2	77.4	2.1	-39.8	13.1	-0.9	-11.3	9.4	0.1	-7.1
35	23-5-311	54.2	0.8	-84.8	19.9	1.5	10.3	11.2	1.2	1.5
36	23-5-271	47.3	1.1	-102.9	19.7	-0.9	7	8.73	0.3	-7.7
37	23-5-315	50.9	1.8	-91.0	28.6	1.6	-11.6	14.7	1.7	-7.7
38	23-5-237	36.1	0.7	-84.2	26.9	-0.0	18.9	10.0	0.3	1.5
39	23-5-335	56.8	2.0	-80.2	23.4	1.2	-5.8	13.5	1.7	-1.4
40	23-5-243	51.0	1.9	-113.1	23.5	-0.2	17.1	12.0	0.9	-5.2
41	23-5-234	29.0	0.5	-72.9	22.6	-1.8	-2.7	6.7	-0.2	-4.2
42	23-5-6	55.2	2.4	-103.8	25.6	0.4	-6.1	14.1	1.7	-7.9
43	23-5-277	67.4	2.2	-90.1	22.4	2.1	-6.5	16.4	2.5	1.8
44	23-5-320	40.0	0.7	-112.1	25.8	-1.1	19.8	9.9	0.1	3.0
45	23-5-92	59.6	2.2	-47.6	23.5	1.4	-8.9	14.7	2.1	-7.7
46	23-5-67	66.1	1.6	-48.7	20.8	1.2	-10.8	13.9	1.7	-7.5
	EG-PPFs Mean	51.4			22.9			11.7		
47	RB6(P_1)(C_1)	37.0	0.2	-76.4	22.4	1.7	-6.6	8.0	0.5	-0.0
48	QRT25(P_2)(C_2)	55.2	1.0	-76.4	23.9	1.5	-2.9	13.5	1.4	-8.1
49	IR64 (C_3)	47.2	0.5	-80.6	22.6	0.4*	-12.4	10.5	0.4	-5.2
50	AZUCENA (C_4)	76.9	1.5	87.5	10.8	-0.9	7.8	7.2	0.1	-7.6
51	MORO (C_5)	80.5	2.1	1643.4**	12.0	-0.5	63.8*	8.0	0.6	-4.8
52	RPBIO (C_6)	42.9	-0.2	-45.3	15.4	-0.2	10.9	6.2	-0.1	-7.6
53	BL122 (C_7)	53.0	0.8	35.7	28.7	1.3	-11.8	14.6	1.2	10.6
54	MAS 946-1 (C_8)	72.5	0.6	-19.7	27.9	1.7	-5.1	19.8	1.4	36.6*
55	MAS 26 (C_9)	49.3	0.1	-96.6	30.0	2.2	-12.0	14.7	0.9	-8.1
	Checks Mean	57.1			21.5			11.4		
	Grand Mean	52.3			22.7			11.6		
	Stand. Error Mean	6.5			2.6			1.5		

* , ** = significant at 5%and 1% level of probability, respectively.

The grand mean for flowering time over three environments was 98.9 days. Early flowering being a favourable trait, low means are considered as desirable in identifying stable genotypes. The genotypes 23-5-243 and 23-5-302 had early flowering with regression coefficient approaching unity and non-significant mean square deviation from regression, indicating stability in their mean performance over the environments. However, genotypes 23-5-280 and 23-5-335 showed late flowering. Under moisture stress condition early flowering genotypes are better considered since they can escape the moisture stress condition at their critical growth stages. Hence late flowering genotypes are seldom preferred during selection programmes under moisture stress condition in rice.

Genotypes 23-5-55, 23-5-243 showed early maturity with b_i reaching unity and non-significant deviation from linear regression, indicating they are stable and suitable across all the environments under study. Whereas genotypes 23-5-103, 23-5-224 found with early maturity, $b_i< 1$ and non-significant deviation from regression, revealing above average stability and their adaptation to unfavourable environment. Early maturity with high grain yield are highly preferred in crop improvement programmes for drought tolerance.

Among EG-PPFs, genotypes 23-5-274, 23-5-313 and 23-5-319 for productive tillers per plant; genotypes 23-5-55, 23-5-287 23-5-319, 23-5-271 and 23-5-321 for single panicle weight; genotype 23-5-287 for straw yield per plant; genotypes 23-5-55, 23-5-300, 23-5-62 for biomass per plant; 23-5-235, 23-5-236 and 23-5-335 for harvest index were found to be stable across environments as evident from their high mean performance with b_i value reaching unity and non-significant mean square deviation. Patel *et al.* (2015), Selvi *et al.* (2015) and Biswas *et al.* (2012) also reported the similar findings where stability of plant height, flowering time, maturity, number of productive tillers per hill and biomass per plant varied in compensating manner in different genotypes imparting them for stable yield.

The grand mean, checks mean, EG-PPFs mean for grain yield per plant over environments was 11.66, 11.41, and 11.71, respectively. It is evident from the stability parameter estimates, EG-PPFs 23-5-274, 23-5-302, 23-5-62, 23-5-296 and MAS26 had high mean grain yield over grand mean, regression coefficient (b_i) value near to 1 and non-significant mean deviation from linear regression (S^2d_i), indicating their wider adaptability and stability across the environments. Genotypes such as 23-5-103, 23-5-28, 23-5-168 and 23-5-243 found with high mean grain yield along with b_i value less than 1 and non-significant deviation (S^2d_i), exhibiting above average stability and adaptation to unfavourable environment (i.e., moisture stress condition). While, genotypes such as 23-5-55, 23-5-33, 23-5-108, 23-5-315, 23-5-277 and BL122 had high mean grain yield with b_i more than unity and non-significant deviation from linear regression (S^2d_i) which reveals below average stability and they are suitable under most favourable environments (i.e., aerobic irrigated condition).

Based on the mean performance, regression coefficient (b_i) and non-significant deviation from regression values, some of the stable genotypes have been identified under favourable and unfavourable environments in relation to yield and its component traits (Table 7). On the basis of mean performance and stability parameters, EG-PPF genotypes 23-5-243, 23-5-62, 23-5-274 were significantly superior and showed wider stability with least sensitivity to changing environments in regard to flowering time, maturity, productive tillers per plant, single panicle weight, harvest index and grain yield per plant on par with the check genotypes over all the three different moisture regimes. However, EG-PPF 23-5-265, 23-5-315, 23-5-277 were significantly superior and stable with regard to flowering time, maturity, productive tillers per plant, single panicle weight, biomass per plant harvest index and grain yield under favourable environment over the check genotypes. These are highly sensitive to the changing environments but responds well under input rich environments. While, genotypes 23-5-237, 23-5-103, 23-5-28 were found to be superior and suitable under unfavourable conditions which are input poor environments. These genotypes are least sensitive to poor environments and assures minimum average yield.

Table 7. Trait wise grouping of stable EG-PPFs genotypes of cross RB6 × QRT25 over unfavourable and favourable environments.

Charac-ter	Genotypes Suitable					
	Overall environments (All three env.)		Over unfavourable environment (Moisture stress)		Over favourable environment (Aerobic)	
	Individual trait	Across traits	Individual trait	Across traits	Individual trait	Across traits
PHT	23-5-297, 23-5-166	23-5-243, 23-5-274, 23-5-302,	23-5-235, 23-5-237, 23-5-234, 23-5-115	23-5-108, 23-5-224, 23-5-237,	23-5-85, 23-5-236, 23-5-298, 23-5-62	23-5-2, 23-5-277, 23-5-315,
FT	23-5-243, 23-5-302, 23-5-145	23-5-55, 23-5-62	23-5-108, 23-5-62, 23-5-237, 23-5-6, 23-5-277	23-5-85, 23-5-103, 23-5-234,	23-5-55, 23-5-265	23-5-265, 23-5-311
MAT	23-5-55, 23-5-243		23-5-103, 23-5-224, 23-5-28, 23-5-115, 23-5-108, 23-5-294, 23-5-221, 23-5-62	23-5-28, 23-5-115	23-5-335, 23-5-311, 23-5-265	
PT	23-5-274, 23-5-313, 23-5-319		23-5-67, 23-5-145		23-5-315	
SPW	23-5-55, 23-5-287, 23-5-319, 23-5-321, 23-5-108, 23MAS26		23-5-85, 23-5-294, 23-5-237, 23-5-33, 23-5-168, 23-5-62		23-5-224, 23-5-277	
SYLD	23-5-287		23-5-300, 23-5-313, 23-5-311		23-5-284, 23-5-335	
BM	23-5-55, 23-5-300, 23-5-62		23-5-284, 23-5-108, 23-5-311, 23-5-103, 23-5-131		23-5-265, 23-5-313	
HI	23-5-235, 23-5-236, 23-5-335		23-5-260, 23-5-115, 23-5-296, 23-5-6		23-5-236, 23-5-108, 23-5-315, 23-5-265, 23-5-297	
GYLD	23-5-274, 23-5-302, 23-5-62, 23-5-296		23-5-85, 23-5-103, 23-5-243, 23-5-28, 23-5-168		23-5-265, 23-5-285, 23-5-300, 23-5-311, 23-5-277	

Further these identified 3 to 5 prominent stable EG-PPFs for grain yield and component traits are advanced in the plant to progeny pattern following pedigree approach and tested for their inheritance of stable performance under test environments across the locations in a replicated trails with focused breeding effort to release for their large scale cultivation in the farmer's field.

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