



Genetic Stability of TGMS Hybrids in Dry Direct Seeded Rice

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rice is a water-loving crop and traditionally sown in the nursery and then transplanted to the puddled and waterlogged main field. Owing to climate change, water scarcity and labour shortage problems, rice is now cultivated in the dry direct seeded method. Owing to potential of hybrid rice in increasing both rice production and productivity, many countries are focusing on exploiting the benefits of this technology. To break the yield plateau in rice cultivation, Thermosensitive Genetic Male Sterile (TGMS) hybrids were found to be very effective. In the present study, 41 TGMS hybrids and 9 checks were evaluated for their stability and adaptability by dry direct seeded method in four locations viz., E₁ - Allahabad, E₂ - Lucknow, E₃ - Dhamtari and E₄ - Raipur. The TGMS hybrid G44 was predicted as an ideal hybrid by the GGE stability model that possessed high grain yield

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and stable performance over environments. It was followed by hybrids viz., G10, G14, G34, G11, G20 and G47 that had a stable performance with high yield. Hence, these TGMS hybrids were identified as high and stable yielders across environments and suitable for dry direct seeded rice ecosystems. Among the environments, E₁ (Allahabad) and E₄ (Raipur) were considered favourable environments as they possessed the highest discriminating power. The hybrids identified in the study can be utilized for breaking the yield barriers in rice and can be recommended for dry direct seeding in marginal and rainfed areas.

Keywords: Hybrid rice; TGMS; CMS; Dry direct seeded; stability analysis.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the most vital and staple food crop for half of the world's population. Rice is a water-loving plant is grown in various agro-climatic zones and seasons in India. Although rice production has significantly increased from 34.5 million tonnes in 1960-61 to 117.5 million tonnes in 2020-21 in India [1], this significant increase over years was achieved by the introduction of semi-dwarf varieties, through improved crop management, adoption of hybrids and improved plant protection practices. Rice production needed to be increased by 42% by 2050 to feed the demands of an ever-increasing human population globally [2]. Due to the potential of hybrid rice in increasing both rice production and productivity, many countries are focusing on exploiting the benefits of this technology [3]. The over dependence of Cytoplasmic Male Sterility (CMS) through WA (Wild abortive) cytoplasm and the difficulties in identification of proper restorers and seed production and parental line development led us in search of other approaches to exploit heterosis in rice [4]. Although the two-line hybrid breeding system was developed relatively late, it provides essential advantages over the three-line system. Manonmani et al. [5] concluded that the Thermosensitive Genetic Male Sterile (TGMS) lines will reduce the cost of seed production apart from increasing the heterosis. TGMS lines with stable sterility can be exploited commercially for the development of two-line rice hybrids in India.

The soaring climate change en routes water scarcity and thereby restricting crop productivity [6]. Traditionally, rice is sown in the nursery and then transplanted to the puddled main field. This conventional method is cumbersome as it requires an intense water supply and is highly laborious [7]. Hence, it triggered to identify a tailor-made cultivation practice that increases the water use efficiency and less labour [8]. Dry Direct Seeded Rice (DDRS) is an innovative

technique in which dry seeds are sown in a seedbed and irrigated later [9]. This practice helps in efficient utilization of water, labour, time, helps better growth of succeeding crops and reduces the emission of greenhouse gases [10, 11].

Apart from biotic & abiotic stresses, the lack of custom-made genotypes to specific growing environments is the reason for a steady decline in the area, production and productivity in rice [12]. The cultivars/genotypes interact differently with different environments. Hence, the prime concern is to evaluate the rice cultivars for adaptation and stability over various environmental conditions [13]. To identify the superior cultivar for a target region, plant breeders conduct Multiple-Environment Trials (MET) to determine if the target region can be subdivided into different mega environments [14]. The genotype-environment interaction makes targeting of cultivars to specific locations difficult since yield is less predictable and cannot be interpreted only based on genotype and environment means [15]. Therefore, breeders must use tools to measure the response of these lines efficiently and accurately in multiple test environments [16]. A new technique in the GEI analysis called Genetics, Genetics \times Environment (GGE) biplot [17] to identify the stable genotypes over environments. GGE biplot pools the effect of genotype with genotype-environment interactions and submit it to principal components to form a biplot. The use of biplot to quantify the genotype-environment interaction is widespread since the genotype-environment effects can be visualized in a single graph, which facilitates the comparison of genotypes and their interaction with the environments [18]. Hence, to tackle the growing demand for rice production and water scarcity, the present study aimed to evaluate 41 TGMS hybrids and 9 Cytoplasmic Male Sterile (CMS) based check rice hybrids over different locations to test their stability and adaptability in dry direct seeded conditions.

2. MATERIALS AND METHODS

The three Corteva TGMS female lines that were used to produce the commercial hybrids were crossed with 36 male parents that were well adapted to dry direct seeding to produce hybrids. Considering the better visualization and effective testing only 41 hybrids were selected and further utilized for the stability analysis. The performance of the TGMS hybrids were compared with nine checks that are commercial CMS based hybrids. The details of the hybrids and parents are given in Table 1. Trials were conducted at four locations viz., E₁ - Allahabad (Uttar Pradesh), E₂ - Lucknow (Uttar Pradesh), E₃ - Dhamtari (Chhattisgarh) and E₄ - Raipur (Chhattisgarh) across two states of India (Fig. 1). The experiment was conducted in Randomized Block Design (RBD) with two replications in each location. Two seeds per hill were sown at the spacing of 20 × 15 cm in four rows with a plot size of 2.4 m² per hybrid. After the initial establishment of the crop, a single seedling per hill was maintained. A necessary package of practices was followed to raise a healthy crop as recommended in Crop Production Guide (CPG) by Tamil Nadu Agricultural University [19]. Each hybrid was harvested at the R9 stage [20] and observations on grain yield/plot were recorded and it was converted to kg/ha. The statistical analysis was done using the R package “metan” [21].

GGE (genotype main effect plus GE interaction) is a linear-bilinear model that removes the effect of environment and expresses the function of

genotypes and the genotype × environment interaction effects. This model is used when the environments are the main source of variation in relation to the contributions of the genotypes and the genotypes × environment (G×E) interaction with respect to the total variability. The GGE biplot were constructed using the first two principle components PC1 and PC2 that were derived from environment centered data for each trait. The data were not transformed unscaled and were environment centered. This provided information on the cultivars that were suitable for the different environments, investigation of stability of cultivars.

The linear model for GGE biplot

$$Y_{ij} = \mu + e_j + \sum_{n=1}^N \tau_n \gamma_{in} \delta_{jn} + \epsilon_{ij}$$

Where,

Y_{ij} = the yield of the ith genotype (i=1,...i) in the jth environment (j=1,...j)

μ = grand mean

e_j = environment deviations from the grand mean

τ_n = eigenvalue of the PC analysis axis n

γ_{in} = genotypes and environment principle components scores for axis n

δ_{jn} = genotypes and environment principle components scores for axis n

N = number of principle components retained in the model

ε_{ij} = error term

Table 1. List of 41 TGMS rice hybrids and nine checks used for the study

S. No.	Hybrid code	Parentage
1	G1	CortF1/IR78875207B2B
2	G2	CortF1/NANTH
3	G3	CortF1/IR80013B14141
4	G4	CortF2/IR79156G
5	G5	CortF1/WHITE PONNI
6	G6	CortF2/LEIGONGTSAN
7	G7	CortF2/IR77080B343
8	G8	CortF1/PAITAOTZU
9	G9	CortF2/WHITE PONNI
10	G10	CortF1/LEIGONGTSAN
11	G11	CortF2/DIANGLONG 201
12	G12	CortF2/HUNGMIHSUANTSAN
13	G13	NK5251Plus*
14	G14	CortF2/Pasak Jalan
15	G15	CortF2/IR73439-11-1-3
16	G16	CortF1/TAPOOCHO Z
17	G17	CortF1/IR78875207B1B

S. No.	Hybrid code	Parentage
18	G18	CortF2/HUANITHOU
19	G19	CortF2/HUANGPITSAN
20	G20	CortF2/NANKING 14
21	G21	CortF2/4593
22	G22	CortF2/IR78937B4BBB
23	G23	CortF2/IR78875207B1B
24	G24	CortF1/IR72164405511
25	G25	CortF2/SOKONI
26	G26	CortF2/PAITAOTZU
27	G27	CortF1/Indica3
28	G28	27P31*
29	G29	CortF2/CHIU KU AI 2
30	G30	CortF2/LUNGPITSAN
31	G31	PHB71*
32	G32	25P25*
33	G33	CortF1/CHITOUHUANG 2
34	G34	CortF1/IR6551451219R
35	G35	CortF2/HUANGGUATSAO
36	G36	CortF1/IR79971B36B
37	G37	CortF2/CHUNGHSIANGMA
38	G38	Arize TEJ GOLD*
39	G39	27P37*
40	G40	CortF3/CHINA 97391
41	G41	CortF2/Xu Xu Zhan
42	G42	27P22*
43	G43	CortF1/IR79913B176B1
44	G44	CortF1/PATOUHUNG
45	G45	US312*
46	G46	CortF2/KAOMAKU
47	G47	CortF2/IR65483141413R
48	G48	25P35*
49	G49	CortF2/KUANGTANGAI
50	G50	CortF3/WHITE PONNI

*Checks

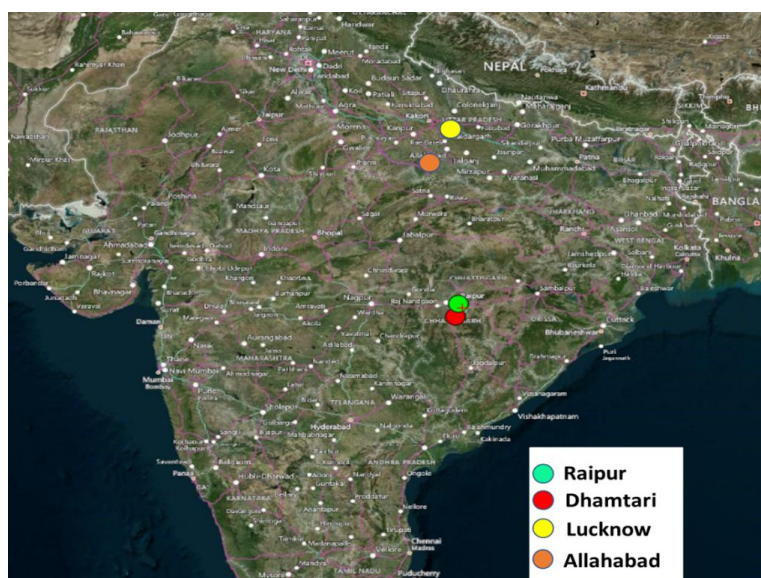


Fig. 1. Different environments used for the study

3. RESULTS AND DISCUSSION

In the present study, 41 selected hybrids along with nine checks were evaluated in four locations to test its phenotypic stability for the yield. The analysis of variance showed a highly significant difference for a plot yield in all the individual environments (Table 2). It indicated the differential performance of hybrids in different environments. Similarly, the pooled analysis of variance showed significant differences for the traits studied (Table 3). Hence, all the hybrids showed differential performance over different environments. Similar results were observed by Pujar et al. [22] in rice.

The GGE biplot technique breaks the complex genotype \times environment interactions (GEI) into simplified PCs and data are presented graphically against the various PCs. The genotypic view of the GGE biplot bifurcates the hybrids and checks into two groups namely, better performing group and lesser performing groups based on the perpendicular axes (Fig. 2). The 22 hybrids viz., G44, G10, G9, G50, G14, G33, G25, G5, G12, G34, G35, G11, G20, G3, G24, G37, G2, G38, G40, G4, G30, G23 and were placed on the left side of the perpendicular axis and they were predicted to be the low yielders. All the other hybrids and checks which are placed on the right side of the perpendicular axis were considered as the high yielders. The hybrid, G44 was prognosticated to be the ideal hybrid in the present study as it was placed near the centre of Average Environment Axes (AEA)

and near the centre of concentric circles. Hence, the hybrid G44 was predicted as the highest yielder and highly stable hybrid in the present study. It was followed by the hybrids viz., G10, G9, G14, G50, G33, G25, G12, G34 and G5 that were proximal to the ideal hybrid on AEA. Hence, these hybrids were also considered stable and high yielding. The vector length determines the stability of the hybrids. The hybrids viz., G10, G14, G34, G11, G20, G47, G2, G4, G30, G1, G28, G7 and G22 had very short vector length and they were predicted as highly stable hybrids. The hybrid G27 was placed far away from the AEA and had a higher vector length. Hence, it was considered highly unstable hybrid. The concept of AEA was used to bifurcate the better and least performing genotypes that were well studied by Ebdon and Gauch [23] in turf grass.

The GGE biplot also predicts the ideal environment based on the concentric circles [19]. In the present study, environments E_2 (Lucknow) and E_3 (Dhamtari) were nearer to the concentric circle and it was predicted to be the ideal environment for all the hybrids. The concentric circles also serve as a ruler to measure the distance between an environment and the ideal environment [24]. The environments E_1 (Allahabad) and E_4 (Raipur) were located further from the ideal environment. Hence, variation between the hybrids was more in these environments and it will be favourable to selective hybrids. Similarly, environments with high and low hybrid interaction were reported by Rana et al. [25] in garden pea.

Table 2. Environment wise ANOVA for 50 rice hybrids in four locations

Environments	Mean Grain yield (Kg/ha)	Df	Sum Sq	Mean Sq	F value	Pr(>F)	CV	h2
E_1	7223.44	49	4685823	32.49	0.00	1.00	5.25	0.96
E_2	5646.82	49	3858514	45.89	0.00	1.00	5.13	0.97
E_3	5577.69	49	1961365	65.69	0.00	1.00	3.09	0.98
E_4	7492.38	49	4136947	33.39	0.00	1.00	4.69	0.97

Table 3. Pooled ANOVA for grain yield on 50 rice hybrids over different locations

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
ENV	3	308586522	102862174	1077.00	0.00
REP(ENV)	4	529964	132491	1.00	0.23
GEN	49	490668471	10013642	105.00	0.00
GEN:ENV	147	226821311	1543002	16.00	0.00
Residuals	196	18718956	95505		
CV(%)	4.76	MSR+MSR-	4.82	Overall mean	6485.08 kg/ha

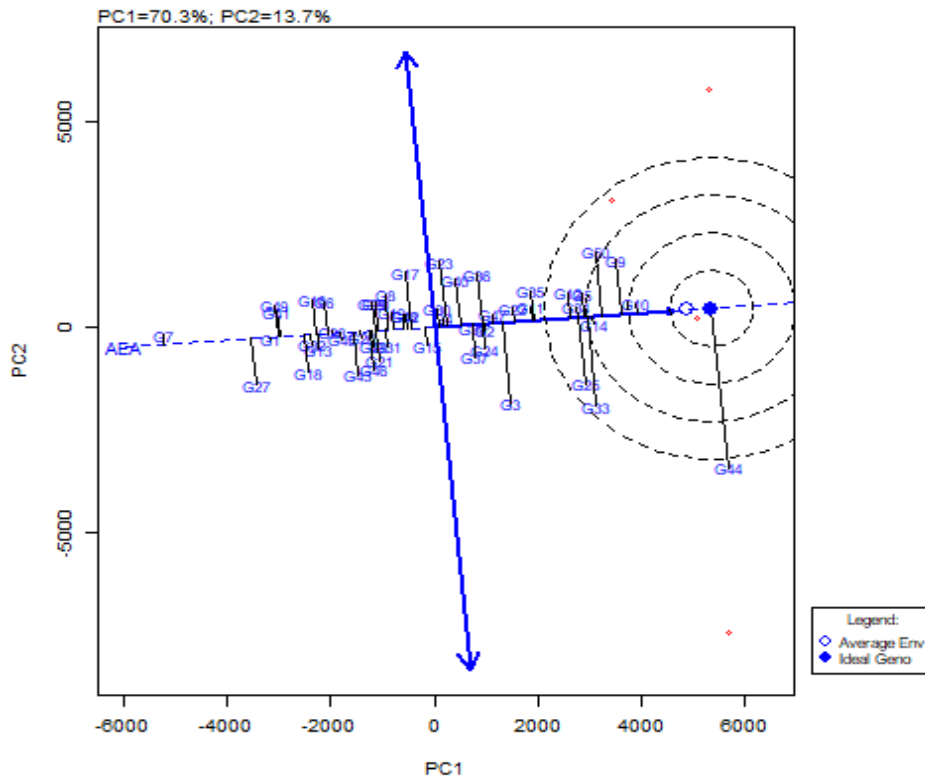


Fig. 2. Genotypic view in GGE biplot for plot yield of 50 TGMS based rice hybrids

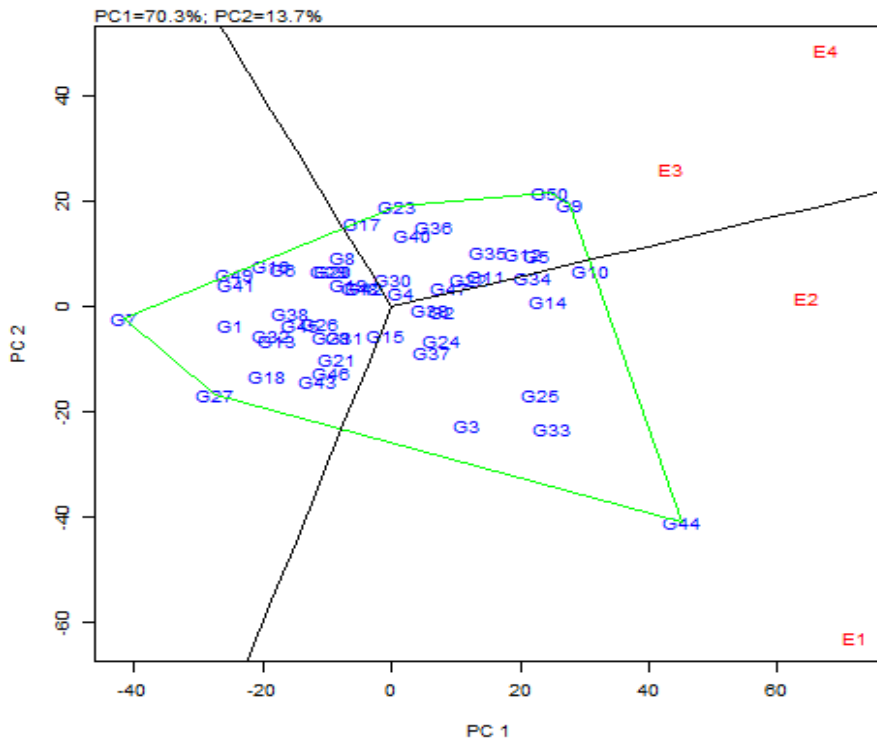


Fig. 3. What won where biplot for grain yield of 50 rice hybrids

Table 4. Best performing hybrids in each and across locations based on GGE biplot

S. No.	Environments	GGE
1	E ₁ – Allahabad	G44, G33, G25 and G3
2	E ₂ – Lucknow	G10, G14 and G34
3	E ₃ – Dhamtari	G9, G50, G5, G12 and G35
4	E ₄ – Raipur	G9 and G50
5	Across environments	G44, G10, G14, G34 and G11

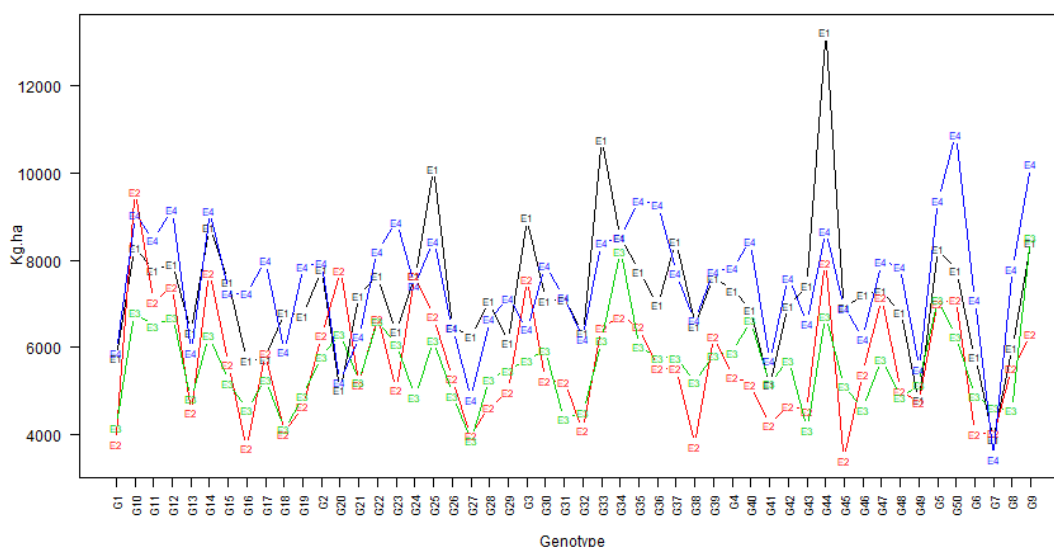


Fig. 4. Response plot of 50 rice hybrids for grain yield over environments

The which – won – where biplot predicts the hybrids suited for the particular environments (Fig. 3). The polygon view of a GGE biplot is the best way to visualize the interaction between genotypes and environments [26] and it helps estimate the possible existence of different mega environments to show the presence or absence of cross over GE interaction which helps estimate the possible existence of different mega environments. The hybrids viz., G7, G23, G50, G9, G44 and G27 were located far away from the origin and they were joined to form a polygon so that all other hybrids are contained in the polygon. Hence, these vertex hybrids were predicted to perform better in a favourable environment. It was in accordance with Gauch et al. [27] in rice. Hybrids suitable for each environment and across environments are given in Table 4.

The perpendicular lines to the sides of the polygon divide the biplot into sectors. Each sector had a vertex hybrid that was highly responsive to the particular environment. In the present study, vertex hybrid G44 fell towards location E₁ (Allahabad) and E₂ (Lucknow) and it

was predicted to perform better in the environment E₁ and E₂. The vertex hybrids G9, G50 and G23 are located in the sector with environments E₃ (Dhamtari) and E₄ (Raipur). Hence, G9, G50 and G23 were best suited for the locations E₃ and E₄. Similarly, the study on “what won where” biplots provided the possible existence of different mega environments in the target environment [28]. The performance of each hybrid over different environments is depicted in Fig. 4 as a response plot. Similarly, a response plot was utilized by Bose et al. [29] to depict the performance of genotypes in various environments in rice.

4. CONCLUSION

In a nutshell, based on the stability of genotypes and high yielding nature, G44 was predicted as the ideal hybrid by the GGE stability model that possessed high grain yield and stable performance over environments. It was followed by hybrids viz., G10, G14, G34, G11, G20 and G47 had a stable performance with a high yield based on its presence near AEA and shorter vector length. Hence, the TGMS hybrids

identified in the study could be further tested and released as commercial hybrids and that can grow well in water and labour scarcity areas without compromising the productivity. The Environments E₁ (Allahabad) and E₄ (Raipur) were found to be favourable environments for the selection of hybrids as it has the highest discriminating power. In the study, the GGE biplot provided higher discriminating power and a clear representation of the stability parameters. Hence, the GGE biplot stability model can be preferred over other stability models like AMMI and Eberhart and Russell models.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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