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Stability Assessment of Yield & Yield Components and Micronutrient (Fe and Zn) Traits in Pearl Millet (*Pennisetum glaucum* [L.])

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

Multi-environment testing remains central to identifying pearl millet genotypes that perform predictably under climatic variability. We evaluated 83 entries—60 F_1 hybrids, 19 parental lines and four checks (PA9385, 9444, 86M20 and 86M22)—during Summer 2024 at Deesa, Palanpur and Tharad (Gujarat) using a Randomized block design with three replications for twelve agronomic and nutritional traits. Pooled ANOVA revealed significant environment effects and genotype × environment interactions (G × E) for key traits including plant height, panicle length, 1000-grain weight, zinc content, fodder yield and grain yield per plant, justifying stability analysis. Environmental indices indicated Palanpur as an overall favourable site; Deesa supported taller plants, higher harvest index and elevated Fe/Zn; Tharad predominantly favoured earliness. Stability was analyzed following Eberhart & Russell (1966), interpreting bi relative to unity and S^2di as predictability. The study revealed substantial genetic variability among parents and hybrids for yield and

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micronutrient traits across environments. Overall, PMPF-4 × PMPR-13 was identified as the best-performing hybrid for grain yield, whereas PMPF-1 × PMPR-1 for iron and PMPF-1 × PMPR-15 / PMPF-3 × PMPR-5 for zinc content showed stable and desirable performance across environments, making them promising genotypes for both productivity and micronutrient improvement.

Keywords: Eberhart and russell model; genotype × environment; pearl millet [Pennisetum glaucum (l.)]; stability

1. Introduction

Pearl millet (*Pennisetum glaucum* [L.] R. Br.) is a climate-resilient cereal cultivated widely across the Indian subcontinent and arid/semi-arid regions, valued for dual-purpose use (grain and stover) and micronutrient density (notably Fe and Zn) (Taylor et al. 2008, Pucher et al., 2014). In India it ranks among the major cereals by area and production, underpinning household food, feed and fodder security in low-input systems (Krishnan et al. 2018 & 2019; Singh et al., 2020). However, intensifying climate variability: erratic rainfall, terminal drought and heat episodes - amplifies genotype × environment (G × E) interactions, masking genetic potential and complicating selection (Jaleta et al. 2011; Serba and Yadav, 2016; Srivastava et al. 2022, Krishnan et al., 2019, Ramamoorthi et al., 1996). Breeding progress therefore depends on identifying genotypes that combine high means with predictable responses across variable environments. Linear-bilinear and regression-based stability frameworks are widely adopted; among them, the Eberhart–Russell model (Eberhart and Russell, 1966) remains a pragmatic choice because it partitions G × E into a predictable linear response (bi) and an unpredictable deviation (S^2di), providing an intuitive basis for both broad and specific adaptation. Within this context, we assembled a diverse line × tester panel to quantify stability for yield, component traits and micronutrient concentrations across distinct production environments in Gujarat, aiming to identify (i) widely adapted, high-yielding and biofortified candidates for broad recommendation and (ii) site-targeted options for favourable and stress-prone ecologies.

2. Materials and Methods

2.1 Genetic Materials and Crossing Scheme

The total 83 entries, it consist of 4 female lines (counterpart B-lines: maintainer lines) and 15 males (restorer lines) and its 60 F_1s (made by using LxT design) and 4 checks PA9385, 9444, 86M20, 86M22) were evaluated in randomized block design with three replications at Deesa (Latitude 24.26° N and Longitude 72.18° E), Palanpur (Latitude 24.17° N and Longitude 72.43° E) and Tharad (Latitude 24.39° N and Longitude 71.62° E) during summer 2024 for 12 yield and yield attributing characters and two micronutrient characters (Fe & Zn). The weather data for the summer 2024 cropping season at three locations, including total rainfall, minimum and maximum temperatures, relative humidity, total evaporation, solar radiation, and bright sunshine hours has been given in Supplementary table (Suppl. Table 1).

Observations were recorded on ten tagged plants per plot for grain yield per plant (g), fodder yield per plant (g), days to 50% flowering and days to maturity on plot basis productive tillers per plant, plant height (cm), panicle length (cm), panicle girth (cm), 1000-grain weight (g), harvest index (%) and micronutrient (iron & zinc in ppm) content were estimated by using X-Ray Fluorescence Spectrometry (XRF).

2.2 Statistical Analysis and Stability Model

Data were analyzed in R. The Eberhart–Russell model (Eberhart and Russell, 1966) was fitted as $Yij = \mu i + biIj + \delta ij + \varepsilon ij$, where bi reflects response to environmental index (Ij) and S^2di the deviation from the fitted regression. Genotypes were classified as: (i) widely adapted (high mean, bi ≈ 1, S^2di non-significant), (ii) favourable-site responsive (bi > 1, S^2di non-significant) and (iii) stress-site adapted (bi < 1, S^2di non-significant). Significant, positive S^2di indicated instability.

3. Results and Discussion

The analysis of variance using the Eberhart and Russell Model (1966) in pearl millet, and Estimation of environmental index under different locations (environments) are depicted in Table 1 and 2 respectively, while character wise stability has been shown in Table 3.

Table 1. ANOVA for stability as per Eberhart and Russell Model (1966) in pearl millet

Sr. No.	Sources	G	E	G×E	E + G ×E	E (L)	G ×E (L)	P.D. (Pooled deviation)	P.E. (Pooled error)
1	Days to 50% flowering	52.63*	3562.85**	0.00	42.93	7,125.70	3,340.93	0.05*	1.40
2	Days to maturity	65.08**	1257.29*	0.00	15.15**	2514.59**	-0.00	0.00	1.12
3	Plant height	2431.36**	24055.47**	165.53**	453.37*	48110.93**	263.60**	63.48**	73.89
4	Productive tillers per plant	0.37**	18.43**	0.01	0.23**	36.85*	0.01*	0.01	0.03
5	Panicle length	54.56**	1885.24*	3.84**	26.51**	3770.47**	5.30**	2.28*	2.01
6	Panicle girth	0.47**	30.46**	0.02	0.39**	60.93*	0.03**	0.01	0.03
7	Harvest index	55.03**	874.36**	4.86	15.34*	1748.72*	8.58**	1.02**	4.25
8	1000-grain weight	4.06**	29.37*	0.79**	1.14**	58.74**	0.94*	0.62	0.05
9	Iron content	229.88**	738.14**	0.00	8.89	1476.27	1.43E-12	2.29*	18.69
10	Zinc content	75.67**	1051.01**	3.33	15.95**	2102.03**	0.83	5.74*	9.95
11	Fodder yield per plant	152.86**	6031.26**	21.47	93.87*	12062.51*	33.40**	9.01**	29.65
12	Grain yield per plant	42.72**	5,260.40*	5.21**	68.52**	10520.79**	7.68*	2.61*	2.68

**, ** significant at 5% and 1% level of significance*

Table 2. Estimation of environmental index (Ij) under different locations (environments)

Sr. No.	Sources	Environmental index (Ij)		
		Deesa	Palanpur	Tharad
1	Days to 50% flowering	4.89	2.56	7.44
2	Days to maturity	-0.78	-3.44	4.22
3	Plant height	1.32	16.32	-17.65
4	Productive tillers per plant	-0.04	0.49	-0.45
5	Panicle length	-0.31	4.92	-4.60
6	Panicle girth	-0.04	0.62	-0.59
7	Harvest index	0.71	2.83	-3.54
8	1000-grain weight	-0.11	0.64	-0.53
9	Iron content	3.38	-2.26	-1.12
10	Zinc content	4.06	-2.59	-1.46
11	Fodder yield per plant	0.44	8.30	-8.73
12	Grain yield per plant	-0.04	7.98	-7.94

Table 3. Stability for days to 50% flowering and days to maturity

		Days to 50% flowering			Days to maturity		
S. No.	**Genotype**	**Mean**	**b_i**	**S^2di**	**Mean**	**b_i**	**S^2di**
1	PMPF-1 x PMPR-1	54.56	1.90	17.91*	79.78	1.46	17.90*
2	PMPF-2 x PMPR-1	55.89	2.40	6.66	81.44	2.44	7.83
3	PMPF-3 x PMPR-1	54.56	4.99	4.32	81.11	4.84	8.13
4	PMPF-4 x PMPR-1	54.89	2.72	24.42**	77.78	3.55	18.54*
5	PMPF-1 x PMPR-2	55.89	2.34	15.55*	79.78	2.49	11.20*
6	PMPF-2 x PMPR-2	54.89	4.54**	-2.52	80.78	4.45**	-1.73
7	PMPF-3 x PMPR-2	56.22	2.22*	-2.68	81.78	2.18	-2.40
8	PMPF-4 x PMPR-2	52.89	0.66	3.21	77.78	0.76	3.05
9	PMPF-1 x PMPR-3	56.56	1.94	22.47**	83.11	1.75	29.96**
10	PMPF-2 x PMPR-3	54.56	3.86	1.19	81.11	3.60	1.94
11	PMPF-3 x PMPR-3	55.22	5.81	8.40	76.44	5.65	9.32
12	PMPF-4 x PMPR-3	53.89	4.85	5.73	78.44	4.84	8.13
13	PMPF-1 x PMPR-4	54.89	1.67	27.67**	82.11	1.75	29.96**
14	PMPF-2 x PMPR-4	54.22	2.19	2.74	79.44	2.21	3.68
15	PMPF-3 x PMPR-4	54.89	2.33	1.60	81.44	3.10	1.07
16	PMPF-4 x PMPR-4	54.22	1.81	-0.95	81.78	2.55	-1.31
17	PMPF-1 x PMPR-5	54.56	-5.00	-2.30	81.11	-5.69	-3.20
18	PMPF-2 x PMPR-5	53.89	1.48	7.02	80.44	1.44	5.35
19	PMPF-3 x PMPR-5	51.89	4.66	16.38*	77.78	4.94	15.38*
20	PMPF-4 x PMPR-5	50.89	-0.62	1.03	76.78	-0.57	1.97
21	PMPF-1 x PMPR-6	57.56	-0.82	-2.90	85.11	-1.05	-2.67
22	PMPF-2 x PMPR-6	55.56	0.64	-0.47	82.11	1.24	-0.33
23	PMPF-3 x PMPR-6	56.56	0.94	-0.40	80.11	0.66	-1.88
24	PMPF-4 x PMPR-6	53.89	2.04	-0.96	80.44	1.79	-2.22
25	PMPF-1 x PMPR-7	57.89	0.23	-2.41	84.78	-0.29	-2.07
26	PMPF-2 x PMPR-7	51.89	1.36**	-3.23	78.78	1.40**	-3.29
27	PMPF-3 x PMPR-7	56.89	2.38	-2.14	84.44	2.74*	-2.05
28	PMPF-4 x PMPR-7	53.56	0.59	-0.72	83.11	1.29	-1.00
29	PMPF-1 x PMPR-8	56.56	0.33	-0.53	82.11	0.48	-1.29
30	PMPF-2 x PMPR-8	53.89	0.91	1.43	79.78	0.87	1.43
31	PMPF-3 x PMPR-8	58.56	-0.75	-3.25	85.11	-0.76	-3.32
32	PMPF-4 x PMPR-8	56.56	0.02	-0.59	84.44	-0.10	-2.53
33	PMPF-1 x PMPR-9	53.56	1.52	1.59	79.78	1.51	1.66
34	PMPF-2 x PMPR-9	53.89	-0.44	-3.26	81.44	-0.32	-3.41
35	PMPF-3 x PMPR-9	51.89	0.61**	-3.33	78.11	0.26	-3.17
36	PMPF-4 x PMPR-9	51.22	-1.32	-2.71	76.44	-1.35	-2.74
37	PMPF-1 x PMPR-10	54.89	-1.67	-3.22	81.44	-1.26	-3.40
38	PMPF-2 x PMPR-10	54.22	-0.69	-2.52	81.44	-0.10	-2.53
39	PMPF-3 x PMPR-10	54.22	-1.47	-2.14	80.78	-1.87	-2.35
40	PMPF-4 x PMPR-10	54.56	-0.65	-3.15	83.11	-0.95	-3.41
41	PMPF-1 x PMPR-11	52.22	-0.82	-2.90	79.44	-0.87	-3.00
42	PMPF-2 x PMPR-11	53.22	1.67**	-3.22	81.44	1.71**	-3.27
43	PMPF-3 x PMPR-11	54.56	1.56	-0.27	80.44	2.06	-0.90
44	PMPF-4 x PMPR-11	53.89	3.71**	-3.27	79.44	4.03**	-3.27
45	PMPF-1 x PMPR-12	54.89	1.56	-0.27	80.11	1.43	-1.06
46	PMPF-2 x PMPR-12	56.56	2.59**	-3.18	78.44	2.29*	-2.61
47	PMPF-3 x PMPR-12	56.89	2.38	-2.14	82.11	2.43	-2.11
48	PMPF-4 x PMPR-12	55.22	1.09**	-3.30	81.44	2.16**	-2.99
49	PMPF-1 x PMPR-13	60.89	3.03**	-2.90	87.44	3.24**	-2.47
50	PMPF-2 x PMPR-13	53.89	-0.04	-3.11	80.44	0.26	-3.17
51	PMPF-3 x PMPR-13	56.89	-0.89	-0.78	82.78	-1.10	-1.64
52	PMPF-4 x PMPR-13	53.22	-1.05	-3.24	78.11	-1.08	-3.31
53	PMPF-1 x PMPR-14	56.89	1.63	-2.68	83.44	1.29	-1.75

		Days to 50% flowering			Days to maturity		
S. No.	**Genotype**	**Mean**	**b_i**	**S^2di**	**Mean**	**b_i**	**S^2di**
54	PMPF-2 x PMPR-14	55.56	0.48*	-3.29	81.78	0.13	-3.35
55	PMPF-3 x PMPR-14	55.22	0.40	-2.80	81.44	0.40	-2.86
56	PMPF-4 x PMPR-14	56.89	-0.21	-2.85	84.11	-0.60	-2.13
57	PMPF-1 x PMPR-15	51.22	-2.26	-1.70	78.44	-2.37	-1.90
58	PMPF-2 x PMPR-15	55.89	0.40	-2.80	79.78	0.58	-3.14
59	PMPF-3 x PMPR-15	52.89	0.61**	-3.33	80.44	0.26	-3.17
60	PMPF-4 x PMPR-15	54.22	-1.78	-2.18	78.11	-2.13	-3.12
61	PMPR-1	65.56	-1.51	-0.89	92.11	-2.18	-2.40
62	PMPR-2	60.89	-0.45	0.14	88.11	-1.02	0.78
63	PMPR-3	65.56	-0.69	-2.52	92.44	-0.92	-2.18
64	PMPR-4	65.22	1.79	4.00	92.11	1.37	0.61
65	PMPR-5	63.89	-0.86	-2.06	90.11	-0.79	-1.57
66	PMPR-6	65.22	3.81**	-3.11	92.11	3.93**	-3.11
67	PMPR-7	65.22	1.15	-2.30	92.44	1.16	-2.33
68	PMPR-8	66.22	1.40**	-3.31	93.44	1.45**	-3.40
69	PMPR-9	62.22	1.69	0.64	90.11	1.69	0.71
70	PMPR-10	60.89	1.94*	-2.65	89.11	2.48**	-2.96
71	PMPR-11	58.89	-0.07	-2.45	86.11	0.03	-2.01
72	PMPR-12	56.89	0.92**	-3.33	88.11	0.95**	-3.41
73	PMPR-13	67.56	0.71	-2.77	94.11	0.93	-0.41
74	PMPR-14	60.22	0.58	-3.08	85.78	0.26	-3.17
75	PMPR-15	55.56	-0.51	-2.87	93.44	-0.18	-3.36
76	PMPF-1	65.56	0.64	-0.47	91.78	0.61	-0.50
77	PMPF-2	64.89	0.33	-0.53	89.44	0.16	-1.36
78	PMPF-3	64.89	2.96	-0.78	90.11	2.74*	-2.05
79	PMPF-4	64.22	2.55**	-2.59	89.44	2.61*	-2.57
80	PA9385 (checks)	53.56	2.92	0.95	80.44	2.72	4.56
81	9444 (checks)	54.89	0.20	-1.29	82.78	-0.21	0.11
82	86M20 (checks)	57.56	0.92**	-3.33	81.44	0.55	-2.97
83	86M22 (checks)	53.22	-1.16	-2.10	82.11	-1.24	-2.24

Table 4. Stability for plant height and productive tillers per plant

		Plant height			Productive tillers per plant		
S.No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
1	PMPF-1 x PMPR-1	194.91	1.28**	-65.14	1.34	1.87	5.37**
2	PMPF-2 x PMPR-1	179.41	1.02**	-73.35	1.24	0.78	1.25**
3	PMPF-3 x PMPR-1	179.79	0.09	0.20	1.24	0.57*	0.15*
4	PMPF-4 x PMPR-1	198.33	1.10**	-62.74	1.95	1.46	2.91**
5	PMPF-1 x PMPR-2	201.90	0.24	66.46	1.96	0.81	6.45**
6	PMPF-2 x PMPR-2	201.07	1.26**	-71.46	2.08	2.31**	0.00
7	PMPF-3 x PMPR-2	124.25	0.05	15.67	1.24	1.89	5.44**
8	PMPF-4 x PMPR-2	207.76	1.55**	-72.99	2.04	2.26	7.73**
9	PMPF-1 x PMPR-3	104.86	1.12**	-67.90	1.04	0.93	1.73**
10	PMPF-2 x PMPR-3	186.46	0.98**	-58.18	1.57	0.81	6.45**
11	PMPF-3 x PMPR-3	205.71	1.26**	-71.46	2.03	2.31**	0.00
12	PMPF-4 x PMPR-3	202.73	0.94**	-71.40	1.78	0.34	3.12**
13	PMPF-1 x PMPR-4	161.30	1.00**	-71.58	1.57	0.29	0.12
14	PMPF-2 x PMPR-4	191.94	1.01**	-72.44	1.90	0.78	1.61**
15	PMPF-3 x PMPR-4	198.12	1.18**	-68.29	1.92	1.31	2.48**
16	PMPF-4 x PMPR-4	198.79	1.28**	-65.14	1.90	1.87	5.37**
17	PMPF-1 x PMPR-5	173.97	0.02	-15.36	1.73	0.49	1.30**
18	PMPF-2 x PMPR-5	167.06	0.30**	-74.79	1.64	0.30	0.17*
19	PMPF-3 x PMPR-5	205.51	1.02**	-72.17	2.04	2.26	7.73**
20	PMPF-4 x PMPR-5	206.27	1.11**	-75.51	2.03	0.93	1.73**

		Plant height			Productive tillers per plant		
S.No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
21	PMPF-1 x PMPR-6	193.90	1.01**	-62.70	1.65	0.35	6.71**
22	PMPF-2 x PMPR-6	203.93	0.69	27.66	2.04	0.40	0.61**
23	PMPF-3 x PMPR-6	147.12	0.29	-18.75	1.64	-0.42	1.25**
24	PMPF-4 x PMPR-6	176.46	1.06**	-75.67	1.70	0.27	1.38
25	PMPF-1 x PMPR-7	148.22	1.02**	-73.26	1.10	0.12	0.28**
26	PMPF-2 x PMPR-7	194.79	1.08**	-73.84	1.90	0.86**	0.02
27	PMPF-3 x PMPR-7	188.72	1.11**	-75.51	1.64	0.93	1.73**
28	PMPF-4 x PMPR-7	188.19	0.96**	103.04	1.97	0.81	6.45**
29	PMPF-1 x PMPR-8	177.85	1.10**	-62.74	1.30	1.46	2.91**
30	PMPF-2 x PMPR-8	172.00	1.10**	-62.74	1.17	1.46	2.91**
31	PMPF-3 x PMPR-8	166.60	-0.88	271.05*	1.02	0.54	3.33**
32	PMPF-4 x PMPR-8	151.16	1.10**	-62.74	0.97	1.46	2.91**
33	PMPF-1 x PMPR-9	154.07	1.10**	-62.74	0.93	1.46	2.91**
34	PMPF-2 x PMPR-9	191.43	2.69**	262.54*	2.04	1.46	2.91**
35	PMPF-3 x PMPR-9	173.95	-0.49	49.72	1.44	1.46	2.91**
36	PMPF-4 x PMPR-9	163.12	1.10**	-62.74	1.15	1.46	2.91**
37	PMPF-1 x PMPR-10	144.53	1.14**	-68.83	1.12	1.60**	1.10**
38	PMPF-2 x PMPR-10	127.15	1.08**	-75.52	0.95	1.02**	0.07
39	PMPF-3 x PMPR-10	158.55	1.28**	-65.08	1.24	1.89	5.44**
40	PMPF-4 x PMPR-10	148.39	1.34**	-63.15	1.27	2.26	7.73**
41	PMPF-1 x PMPR-11	205.00	1.12**	-67.90	1.83	0.93	1.73**
42	PMPF-2 x PMPR-11	181.46	0.92**	-62.67	1.44	0.35	6.71**
43	PMPF-3 x PMPR-11	204.17	1.02**	-68.87	1.92	0.40	0.61**
44	PMPF-4 x PMPR-11	168.12	0.92**	-56.11	1.57	-0.42	1.25
45	PMPF-1 x PMPR-12	202.67	1.02**	-63.36	1.86	0.27	1.38**
46	PMPF-2 x PMPR-12	198.12	0.94**	-75.43	2.01	0.12	0.28**
47	PMPF-3 x PMPR-12	159.27	1.07**	74.88	1.50	0.86**	0.02
48	PMPF-4 x PMPR-12	199.91	1.03**	-75.56	1.88	0.69**	0.00
49	PMPF-1 x PMPR-13	197.03	1.00**	-71.58	1.94	0.29	0.12
50	PMPF-2 x PMPR-13	188.12	1.15**	-75.00	1.73	1.49**	0.00
51	PMPF-3 x PMPR-13	170.93	1.08**	-57.19	1.59	0.54	3.33**
52	PMPF-4 x PMPR-13	221.16	1.10**	-62.74	2.28	1.46	2.91**
53	PMPF-1 x PMPR-14	171.00	1.10**	-62.74	1.37	1.46	2.91**
54	PMPF-2 x PMPR-14	201.46	1.09**	-75.55	2.01	0.54	3.33**
55	PMPF-3 x PMPR-14	190.00	1.10**	-62.74	1.97	1.46	2.91**
56	PMPF-4 x PMPR-14	192.82	2.81**	306.15*	1.96	1.75*	2.83**
57	PMPF-1 x PMPR-15	185.93	2.81**	306.70*	1.85	1.72	2.83**
58	PMPF-2 x PMPR-15	196.27	1.14**	-68.83	1.89	1.60**	1.10**
59	PMPF-3 x PMPR-15	178.12	1.08**	-75.52	1.17	1.02**	0.07
60	PMPF-4 x PMPR-15	201.33	1.28**	-65.08	1.99	1.89	5.44**
61	PMPR-1	149.79	1.34**	-63.15	1.50	2.26	7.73**
62	PMPR-2	141.46	1.12**	-67.90	1.21	0.93	1.73**
63	PMPR-3	153.12	0.92**	-62.67	1.26	0.35	6.71**
64	PMPR-4	163.12	1.02**	68.87	1.30	0.40	0.61**
65	PMPR-5	136.46	0.92**	-56.11	1.44	-0.42	1.25**
66	PMPR-6	128.12	1.02**	-63.36	1.44	0.27	1.38**
67	PMPR-7	149.79	0.94**	-75.43	1.46	0.12	0.28
68	PMPR-8	164.79	1.07**	-74.88	1.47	0.86**	0.02
69	PMPR-9	141.46	1.03**	-75.56	1.60	0.69**	0.00
70	PMPR-10	171.20	1.00**	-71.58	1.46	0.29	0.12
71	PMPR-11	123.12	1.15**	-75.00	1.56	1.49**	0.00
72	PMPR-12	164.79	1.08**	-57.19	1.38	0.54	3.33**
73	PMPR-13	159.79	1.10**	-62.74	1.44	1.46	2.91**
74	PMPR-14	126.46	1.10**	-62.74	1.30	1.46	2.91**
75	PMPR-15	174.79	1.01**	-72.44	1.50	0.78	1.61**

		Plant height			Productive tillers per plant		
S.No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
76	PMPF-1	107.93	0.13	78.64	0.90	1.13	2.43**
77	PMPF-2	96.93	0.23	92.04	1.17	1.70	5.30**
78	PMPF-3	113.44	-0.02	-8.70	1.00	0.60	1.28**
79	PMPF-4	112.53	-0.03	19.99	0.90	0.39	0.17*
80	PA9385 (checks)	174.30	1.34**	-63.15	1.43	2.26	7.73**
81	9444 (checks)	183.12	1.12**	-67.90	1.57	0.93	1.73**
82	86M20 (checks)	144.99	0.92**	-62.67	1.10	0.35	6.71**
83	86M22 (checks)	181.56	1.02**	-68.87	1.33	0.40	0.61**

3.1 Analysis of Variance and Environmental Indices

The analysis of variance for stability as per the Eberhart and Russell (1966) model revealed highly significant differences among genotypes (G) for all the traits studied, indicating the presence of substantial genetic variability. Environmental effects (E) were also significant for most traits such as days to 50% flowering, plant height, panicle traits, micronutrient content, and yield parameters, suggesting strong environmental influence on trait expression.

Table 5. Stability for panicle length and panicle girth

		Panicle length			Panicle girth		
S. No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
1	PMPF-1 x PMPR-1	22.43	1.53**	11.59**	1.68	1.85	1.20**
2	PMPF-2 x PMPR-1	24.37	0.83**	0.33	2.05	0.76	0.12*
3	PMPF-3 x PMPR-1	24.43	0.80**	-2.06	2.51	0.58**	3.04**
4	PMPF-4 x PMPR-1	25.10	2.20**	38.18**	2.64	1.37	6.34**
5	PMPF-1 x PMPR-2	26.43	2.06*	55.88**	2.56	0.76	0.06
6	PMPF-2 x PMPR-2	26.77	1.53**	0.56	2.39	2.19**	5.05**
7	PMPF-3 x PMPR-2	22.23	1.53**	11.69**	2.12	1.86	7.09**
8	PMPF-4 x PMPR-2	29.53	1.71**	14.86**	2.66	2.21	1.74**
9	PMPF-1 x PMPR-3	15.23	1.07**	6.56*	1.18	0.96	6.34**
10	PMPF-2 x PMPR-3	24.37	0.75	16.16**	2.06	0.76	0.06
11	PMPF-3 x PMPR-3	25.04	1.53**	0.56	2.67	2.19**	2.91**
12	PMPF-4 x PMPR-3	29.77	0.61*	2.95	2.44	0.34	0.18*
13	PMPF-1 x PMPR-4	21.22	0.74**	1.75	1.47	0.35	1.55**
14	PMPF-2 x PMPR-4	24.35	0.82**	1.28	2.51	0.76	2.38**
15	PMPF-3 x PMPR-4	25.05	1.24**	6.80*	2.39	1.31	4.99**
16	PMPF-4 x PMPR-4	26.93	1.53**	11.59**	2.60	1.85	1.19**
17	PMPF-1 x PMPR-5	20.82	-0.29	0.29	1.78	0.25	0.12*
18	PMPF-2 x PMPR-5	21.47	-0.51	9.35	2.09	0.24	7.10**
19	PMPF-3 x PMPR-5	26.52	0.99**	-0.25	2.67	2.08	1.74**
20	PMPF-4 x PMPR-5	27.03	0.90**	-2.03	2.65	0.92	6.39**
21	PMPF-1 x PMPR-6	27.30	0.81*	11.20*	2.36	0.34	0.70**
22	PMPF-2 x PMPR-6	29.44	0.94**	-1.86	2.74	0.46	1.56**
23	PMPF-3 x PMPR-6	19.17	0.79**	-1.92	1.78	-0.29	1.54**
24	PMPF-4 x PMPR-6	25.45	0.93**	-2.06	2.40	0.35	0.20*
25	PMPF-1 x PMPR-7	17.08	0.84**	0.41	2.07	0.17	0.03
26	PMPF-2 x PMPR-7	26.00	1.02**	-0.49	2.61	0.87**	1.74**
27	PMPF-3 x PMPR-7	26.68	1.07**	-1.99	2.61	0.96	6.34**
28	PMPF-4 x PMPR-7	27.95	0.91*	12.90**	2.50	0.76	3.04**
29	PMPF-1 x PMPR-8	24.47	1.07**	9.97*	2.12	1.37	3.04**
30	PMPF-2 x PMPR-8	20.50	1.07**	9.97*	2.22	1.37	3.48**
31	PMPF-3 x PMPR-8	16.37	1.01**	-1.85	1.57	0.61	3.04**
32	PMPF-4 x PMPR-8	20.73	1.07**	9.97*	1.52	1.37	3.04**
33	PMPF-1 x PMPR-9	18.50	1.07**	9.97*	1.95	1.37	3.04**

		Panicle length			Panicle girth		
S. No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
34	PMPF-2 x PMPR-9	28.41	1.07**	9.97*	2.69	1.37	3.04**
35	PMPF-3 x PMPR-9	18.03	1.07**	9.97*	1.89	1.37	3.04**
36	PMPF-4 x PMPR-9	16.87	1.07**	9.97*	1.52	1.37	1.22**
37	PMPF-1 x PMPR-10	20.41	1.18**	3.77	1.88	1.52**	0.07
38	PMPF-2 x PMPR-10	20.17	0.99**	-1.96	1.72	1.00**	5.05**
39	PMPF-3 x PMPR-10	20.03	1.53**	11.69**	1.57	1.86	7.09**
40	PMPF-4 x PMPR-10	16.47	1.71**	14.86**	1.55	2.21	1.74**
41	PMPF-1 x PMPR-11	27.14	1.07**	6.56*	2.72	0.96	6.39**
42	PMPF-2 x PMPR-11	23.05	0.56	12.50**	2.28	0.34	0.70**
43	PMPF-3 x PMPR-11	26.53	0.82**	4.63	2.80	0.46	1.56**
44	PMPF-4 x PMPR-11	21.70	0.51	15.59**	2.57	-0.29	1.54**
45	PMPF-1 x PMPR-12	26.23	0.79*	10.01*	2.61	0.35	0.20*
46	PMPF-2 x PMPR-12	27.10	0.61**	-1.95	2.51	0.17	0.03
47	PMPF-3 x PMPR-12	22.23	0.97**	-1.13	2.31	0.87**	-0.01
48	PMPF-4 x PMPR-12	26.93	0.87**	-1.95	2.54	0.70**	0.18*
49	PMPF-1 x PMPR-13	27.00	0.74**	1.75	2.58	0.35	0.02
50	PMPF-2 x PMPR-13	26.40	1.19**	-1.69	2.52	1.44**	3.48**
51	PMPF-3 x PMPR-13	23.93	0.95	17.03**	1.95	0.61	3.04**
52	PMPF-4 x PMPR-13	31.17	1.07**	9.97*	2.88	1.37	3.04**
53	PMPF-1 x PMPR-14	25.67	1.07**	9.97*	1.70	1.37	3.48**
54	PMPF-2 x PMPR-14	28.13	1.01**	-1.85	2.70	0.61	3.06**
55	PMPF-3 x PMPR-14	25.99	1.07**	9.97*	2.21	1.88*	3.06**
56	PMPF-4 x PMPR-14	28.03	1.47**	18.09**	2.38	1.72*	3.05**
57	PMPF-1 x PMPR-15	27.67	1.24**	13.15**	2.79	1.50	1.22**
58	PMPF-2 x PMPR-15	28.07	1.18**	3.77	2.69	1.57**	0.07
59	PMPF-3 x PMPR-15	17.32	0.99**	-1.96	1.81	1.00**	5.05**
60	PMPF-4 x PMPR-15	27.13	1.53**	11.69**	2.71	1.86	7.09**
61	PMPR-1	21.83	1.71**	14.86**	2.51	2.21	1.74**
62	PMPR-2	21.53	1.07**	6.56*	2.50	0.96	6.39**
63	PMPR-3	22.63	0.56	12.50**	2.61	0.34	0.70**
64	PMPR-4	20.73	0.82**	4.63	1.94	0.46	1.56**
65	PMPR-5	16.03	0.51	15.59**	2.34	-0.29	1.54**
66	PMPR-6	20.33	0.79*	10.01*	2.35	0.35	0.20*
67	PMPR-7	20.50	0.61**	-1.95	2.41	0.17	0.03
68	PMPR-8	20.13	0.97**	-1.13	2.19	0.87**	-0.01
69	PMPR-9	16.27	0.87**	-1.95	2.17	0.70**	0.18*
70	PMPR-10	18.63	0.74**	1.75	2.42	0.35	0.02
71	PMPR-11	18.00	1.19**	-1.69	2.49	1.44**	3.48**
72	PMPR-12	19.50	0.95	17.03**	2.47	0.61	3.04**
73	PMPR-13	20.83	1.07**	9.97*	2.35	1.37	3.04**
74	PMPR-14	20.03	1.07**	9.97*	2.52	1.37	1.55**
75	PMPR-15	23.00	0.82**	1.28	2.57	0.76	2.38**
76	PMPF-1	13.03	0.54	20.68**	1.80	1.31	4.99**
77	PMPF-2	15.06	1.08*	21.37**	1.46	1.85	1.20**
78	PMPF-3	15.36	0.65**	-0.90	1.89	0.76	0.12*
79	PMPF-4	13.67	0.28	0.23	1.99	0.58**	7.09**
80	PA9385 (checks)	21.67	1.71**	14.86**	2.12	2.21	1.74**
81	9444 (checks)	25.14	1.07**	6.56*	2.29	0.96	6.39**
82	86M20 (checks)	21.50	0.56	12.50**	1.72	0.34	0.70**
83	86M22 (checks)	22.57	0.82**	4.63	2.44	0.46	1.20**

The genotype × environment (G × E) interaction was significant for traits like plant height, panicle length, harvest index, 1000-grain weight, fodder yield, and grain yield per plant, indicating differential responses of genotypes across environments. Further partitioning showed that both linear (G × E (L)) and non-linear components (pooled deviation) contributed significantly for several traits, highlighting the complexity of

genotype performance across environments. The result is in agreement with earlier reports by Ramamoorthi et al. (1996), Manga (2001), Bikash et al. (2013), Patel et al. (2019) and Sodhaparmar et al. (2023).

The positive and negative value of the environmental index indicates the favourable and unfavourable situations, respectively for each character (De et al., 1992 and Sodhaparmar et al., 2023). Environmental indices indicated that Palanpur was generally favorable for grain yield and fodder yield, while Tharad exhibited negative indices for most traits, suggesting it as a relatively less favourable environment. Deesa enhanced stature, harvest index and Fe/Zn content.

Table 6. Stability for 1000 grain weight (g) and Harvest Index (H.I.) (%)

		Harvest index			1000-grain weight		
S. No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
1	PMPF-1 x PMPR-1	29.08	1.20*	1.36	8.96	2.14*	0.56**
2	PMPF-2 x PMPR-1	27.11	0.77	-3.91	7.18	0.72**	-0.01
3	PMPF-3 x PMPR-1	29.65	-0.16	3.75	8.91	1.89**	0.31**
4	PMPF-4 x PMPR-1	27.49	0.96	-2.23	9.16	1.89**	0.31**
5	PMPF-1 x PMPR-2	31.88	1.62*	3.25	8.13	1.89**	0.31**
6	PMPF-2 x PMPR-2	31.31	1.27	-4.30	9.60	2.96	1.74**
7	PMPF-3 x PMPR-2	27.04	1.20*	1.41	8.18	1.26**	-0.02
8	PMPF-4 x PMPR-2	33.68	1.33**	3.07	8.92	2.32*	0.76**
9	PMPF-1 x PMPR-3	18.17	0.88	-1.43	7.32	1.73**	0.19*
10	PMPF-2 x PMPR-3	27.12	0.74	-0.06	8.54	1.89**	0.31**
11	PMPF-3 x PMPR-3	30.73	1.27	-4.30	9.38	1.89**	0.31**
12	PMPF-4 x PMPR-3	30.34	0.61	-3.00	9.19	1.89**	0.31**
13	PMPF-1 x PMPR-4	23.99	0.66	-3.35	7.10	1.39**	0.02
14	PMPF-2 x PMPR-4	28.33	0.76	-3.69	8.99	1.59**	0.11
15	PMPF-3 x PMPR-4	31.27	1.39**	-1.96	8.09	0.56	0.04
16	PMPF-4 x PMPR-4	29.48	1.20*	1.36	9.30	2.21*	0.63**
17	PMPF-1 x PMPR-5	25.29	0.09	4.33	8.20	0.35	0.14
18	PMPF-2 x PMPR-5	25.91	0.26	4.15	7.32	-1.47	2.8**
19	PMPF-3 x PMPR-5	29.48	0.35	3.39	9.38	0.47	0.08
20	PMPF-4 x PMPR-5	32.42	1.27**	-4.34	9.50	1.27**	-0.02
21	PMPF-1 x PMPR-6	28.82	1.69**	-4.30	8.89	1.41**	0.03
22	PMPF-2 x PMPR-6	30.89	2.19*	-2.00	9.25	1.95*	0.37**
23	PMPF-3 x PMPR-6	26.64	0.90	15.30	6.87	-0.26	0.69**
24	PMPF-4 x PMPR-6	29.11	1.01	-3.15	8.32	0.54	0.05
25	PMPF-1 x PMPR-7	23.07	1.63**	-4.28	7.07	-0.19	0.61**
26	PMPF-2 x PMPR-7	28.29	1.18	-3.79	7.14	0.35	0.15*
27	PMPF-3 x PMPR-7	28.74	0.96	-2.23	7.26	-0.46	0.95**
28	PMPF-4 x PMPR-7	31.23	0.86	-2.23	7.20	0.42	0.11
29	PMPF-1 x PMPR-8	25.59	0.96	-2.23	8.00	0.57	0.03
30	PMPF-2 x PMPR-8	23.68	0.77	-2.23	7.40	0.71**	-0.01
31	PMPF-3 x PMPR-8	19.32	0.96	-2.23	7.34	-0.58	1.11**
32	PMPF-4 x PMPR-8	21.80	0.96	-2.23	8.35	0.82**	-0.04
33	PMPF-1 x PMPR-9	24.26	0.96	-2.23	7.11	-0.20	0.62**
34	PMPF-2 x PMPR-9	29.80	2.14**	1.27	8.82	2.74	1.36**
35	PMPF-3 x PMPR-9	27.15	0.45	-3.22	7.90	1.21**	-0.03
36	PMPF-4 x PMPR-9	22.42	0.96	-2.23	7.05	-1.09	1.99**
37	PMPF-1 x PMPR-10	23.72	1.49**	-2.85	7.10	1.44**	0.04
38	PMPF-2 x PMPR-10	22.67	1.04	-4.34	6.43	0.26	0.21*
39	PMPF-3 x PMPR-10	22.64	1.09	1.85	6.80	0.16	0.28*
40	PMPF-4 x PMPR-10	21.07	1.33**	3.07	5.89	0.16	0.28*
41	PMPF-1 x PMPR-11	29.88	0.88	-1.43	9.28	1.56**	0.09
42	PMPF-2 x PMPR-11	26.13	0.60	-0.45	9.18	1.86**	0.29**
43	PMPF-3 x PMPR-11	30.93	0.70	-2.49	9.58	1.94*	0.36**
44	PMPF-4 x PMPR-11	28.01	0.46	-0.54	7.31	0.16	0.28*

		Harvest index			1000-grain weight		
S. No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
45	PMPF-1 x PMPR-12	27.39	1.66**	-3.31	8.76	2.87	1.58**
46	PMPF-2 x PMPR-12	27.75	2.29**	-2.86	8.56	3.16	2.12**
47	PMPF-3 x PMPR-12	23.63	1.36**	-4.29	6.75	0.16	0.28*
48	PMPF-4 x PMPR-12	25.07	1.82**	-4.07	6.98	1.89**	0.31**
49	PMPF-1 x PMPR-13	28.74	0.66	-3.35	8.56	1.89**	0.31**
50	PMPF-2 x PMPR-13	29.86	1.01	-4.35	9.09	1.89**	0.31**
51	PMPF-3 x PMPR-13	23.49	0.78	1.09	7.27	-0.38	0.84**
52	PMPF-4 x PMPR-13	35.39	1.78**	0.03	10.17	2.07*	0.49**
53	PMPF-1 x PMPR-14	22.28	0.96	-2.23	8.63	2.16*	0.57**
54	PMPF-2 x PMPR-14	29.45	2.45**	2.49	9.04	2.50*	1**
55	PMPF-3 x PMPR-14	31.94	0.96	-2.23	9.47	1.89**	0.31**
56	PMPF-4 x PMPR-14	30.48	2.33**	2.00	9.31	1.89**	0.31**
57	PMPF-1 x PMPR-15	30.65	2.13**	1.25	9.20	3.53	2.92**
58	PMPF-2 x PMPR-15	28.44	1.13	-3.46	9.02	2.42*	0.89**
59	PMPF-3 x PMPR-15	25.04	-0.15	-3.66	6.83	-0.29	0.72**
60	PMPF-4 x PMPR-15	30.96	1.72**	-0.34	9.35	2.03*	0.44**
61	PMPR-1	21.23	1.33**	3.07	6.79	1.89**	0.31**
62	PMPR-2	26.10	0.88	-1.43	7.97	1.08**	-0.05
63	PMPR-3	23.90	0.60	-0.45	8.18	1.29**	-0.01
64	PMPR-4	25.22	0.70	-2.49	6.65	-0.72	1.32**
65	PMPR-5	23.95	0.46	-0.54	7.31	-0.02	0.43**
66	PMPR-6	21.23	0.86	-1.66	6.87	0.88**	-0.05
67	PMPR-7	22.74	0.58	-4.34	6.27	-1.35	2.52**
68	PMPR-8	24.81	0.83	-3.92	6.23	-0.59	1.13**
69	PMPR-9	21.03	0.77	-4.27	7.58	0.88**	-0.05
70	PMPR-10	25.06	0.66	-3.35	6.91	-0.69	1.28**
71	PMPR-11	23.61	1.01	-4.35	7.78	0.88**	-0.05
72	PMPR-12	22.16	0.78	1.09	6.66	-0.33	0.77**
73	PMPR-13	23.99	0.96	-2.23	6.60	-0.32	0.76**
74	PMPR-14	22.26	0.96	-2.23	7.48	0.88**	-0.05
75	PMPR-15	26.78	0.76	-3.69	8.09	1.65**	0.14
76	PMPF-1	14.52	0.04	2.39	4.70	-1.70	3.35**
77	PMPF-2	16.38	0.48	4.34	5.66	-0.16	0.58**
78	PMPF-3	15.99	-0.01	-4.35	6.56	0.88**	-0.05
79	PMPF-4	14.70	-0.20	-3.70	4.91	-1.22	2.24**
80	PA9385 (checks)	28.65	1.33**	3.07	7.97	0.63*	0.01
81	9444 (checks)	26.91	0.88	-1.43	8.66	1.83**	0.27*
82	86M20 (checks)	22.93	0.60	-0.45	7.64	1.46**	0.05
83	86M22 (checks)	26.41	0.70	-2.49	8.84	1.94*	0.36**

Table 7. Stability for iron content (ppm) and zinc content (ppm)

		Iron content			Zinc content		
S.No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
1	PMPF-1 x PMPR-1	75.38	1.96**	49.80	26.18	0.80*	-4.54
2	PMPF-2 x PMPR-1	52.99	0.27	-7.95	24.03	1.09**	-8.51
3	PMPF-3 x PMPR-1	51.49	2.07**	-4.58	21.53	0.95**	-8.65
4	PMPF-4 x PMPR-1	70.91	-0.03	67.34*	27.20	1.28**	-9.90
5	PMPF-1 x PMPR-2	60.83	0.86**	-17.52	26.37	1.29**	-6.08
6	PMPF-2 x PMPR-2	57.49	2.28*	106.87**	18.60	1.23**	-7.40
7	PMPF-3 x PMPR-2	57.46	1.46**	24.28	20.20	0.80*	-4.41
8	PMPF-4 x PMPR-2	69.55	1.27*	44.04	23.70	0.81	0.30
9	PMPF-1 x PMPR-3	65.88	1.61**	-13.01	18.37	0.77**	-10.08
10	PMPF-2 x PMPR-3	62.46	0.28	-13.99	16.83	1.29**	-6.08
11	PMPF-3 x PMPR-3	49.63	0.03	-17.94	30.12	1.23**	-7.40

		Iron content			Zinc content		
S.No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
12	PMPF-4 x PMPR-3	58.65	0.06	65.03*	21.22	1.10**	-4.66
13	PMPF-1 x PMPR-4	66.39	0.90**	-5.72	13.83	0.79**	-8.71
14	PMPF-2 x PMPR-4	52.09	0.70**	-18.29	27.30	1.11**	-8.29
15	PMPF-3 x PMPR-4	52.49	1.22	44.42	21.92	0.80**	-9.06
16	PMPF-4 x PMPR-4	68.64	2.36**	25.50	23.15	0.80*	-4.54
17	PMPF-1 x PMPR-5	63.53	0.61	168.14**	20.25	0.52	37.03*
18	PMPF-2 x PMPR-5	54.29	-0.46	17.40	16.04	0.72	2.01
19	PMPF-3 x PMPR-5	56.36	0.78	8.09	21.57	1.19	39.34*
20	PMPF-4 x PMPR-5	49.63	2.20**	89.15*	25.89	0.88**	-8.28
21	PMPF-1 x PMPR-6	71.96	1.37**	-9.09	34.97	1.21**	-2.47
22	PMPF-2 x PMPR-6	57.86	1.15**	-15.49	24.28	0.75**	-9.52
23	PMPF-3 x PMPR-6	46.60	1.91	285.11	18.70	0.56	-6.46
24	PMPF-4 x PMPR-6	49.66	1.97**	16.75	22.35	0.68**	-9.54
25	PMPF-1 x PMPR-7	62.63	0.09	-18.09	18.17	0.89**	-6.12
26	PMPF-2 x PMPR-7	42.53	1.84**	-18.44	13.80	0.91**	-10.03
27	PMPF-3 x PMPR-7	47.96	1.60**	-17.31	23.13	0.77**	-10.08
28	PMPF-4 x PMPR-7	52.59	3.04**	-18.43	22.15	1.29**	-6.08
29	PMPF-1 x PMPR-8	56.77	0.82*	8.25	18.02	1.28**	-9.90
30	PMPF-2 x PMPR-8	37.69	-0.14	-15.50	18.19	1.28**	-9.90
31	PMPF-3 x PMPR-8	48.19	0.08	-4.73	26.39	0.64**	-10.19
32	PMPF-4 x PMPR-8	67.24	1.00	23.67	18.90	1.28**	-9.90
33	PMPF-1 x PMPR-9	56.09	0.76**	-16.65	13.73	1.28**	-9.90
34	PMPF-2 x PMPR-9	46.49	0.45	23.70	23.00	1.28**	-9.90
35	PMPF-3 x PMPR-9	50.46	2.02*	79.06*	21.90	1.28**	-9.90
36	PMPF-4 x PMPR-9	56.09	1.03**	-9.49	18.87	1.28**	-9.90
37	PMPF-1 x PMPR-10	54.06	0.59	16.82	20.23	1.22**	-10.18
38	PMPF-2 x PMPR-10	46.13	1.73	128.00**	18.83	1.02**	-9.97
39	PMPF-3 x PMPR-10	42.59	1.46**	-16.61	16.73	0.80*	-4.41
40	PMPF-4 x PMPR-10	52.09	0.14**	-18.31	15.10	0.81	0.30
41	PMPF-1 x PMPR-11	61.23	0.60**	-12.41	26.60	1.84	108.33**
42	PMPF-2 x PMPR-11	53.59	0.59**	-17.49	13.73	1.21**	-2.47
43	PMPF-3 x PMPR-11	49.59	1.42*	55.59*	21.57	0.75**	-9.52
44	PMPF-4 x PMPR-11	58.07	2.09**	-6.18	17.03	0.56	-6.46
45	PMPF-1 x PMPR-12	65.14	0.68**	-18.37	30.82	0.68**	-9.54
46	PMPF-2 x PMPR-12	56.33	0.56**	-16.33	16.87	0.89**	-6.12
47	PMPF-3 x PMPR-12	56.00	1.32**	-10.53	21.83	0.91**	-10.03
48	PMPF-4 x PMPR-12	59.16	-0.02	101.90**	27.77	0.94**	-9.35
49	PMPF-1 x PMPR-13	59.74	0.34	162.39**	23.87	0.79**	-8.71
50	PMPF-2 x PMPR-13	55.84	1.24**	9.71	25.39	1.08**	-10.05
51	PMPF-3 x PMPR-13	48.40	0.46**	-17.51	27.47	0.64**	-10.19
52	PMPF-4 x PMPR-13	64.34	0.72	11.87	30.12	2.68	165.01**
53	PMPF-1 x PMPR-14	39.79	0.57	46.42	20.53	1.28**	-9.90
54	PMPF-2 x PMPR-14	42.90	0.66	17.52	15.67	0.64**	-10.19
55	PMPF-3 x PMPR-14	37.41	0.10	-17.57	14.81	1.28**	-9.90
56	PMPF-4 x PMPR-14	70.69	1.32**	-7.97	28.90	1.28**	-9.90
57	PMPF-1 x PMPR-15	55.63	0.64**	-15.89	22.92	1.85*	15.17
58	PMPF-2 x PMPR-15	46.59	0.63	8.52	17.12	1.45**	-4.85
59	PMPF-3 x PMPR-15	51.16	0.69**	-12.16	19.75	0.63	7.99
60	PMPF-4 x PMPR-15	61.36	0.98**	-9.94	25.39	0.70**	-8.36
61	PMPR-1	61.96	0.94**	-18.13	32.25	0.81	0.30
62	PMPR-2	67.07	1.87**	24.53	26.02	0.77**	-10.08
63	PMPR-3	46.56	1.22**	4.44	28.00	1.21**	-2.47
64	PMPR-4	67.87	2.00**	27.09	23.05	0.75**	-9.52
65	PMPR-5	64.61	-0.02	-17.81	20.33	0.56	-6.46
66	PMPR-6	47.73	0.37	-10.51	22.13	0.68**	-9.54

		Iron content			Zinc content		
S.No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
67	PMPR-7	49.33	1.97**	45.29	21.73	0.89**	-6.12
68	PMPR-8	46.29	1.90**	-6.81	18.87	0.91**	-10.03
69	PMPR-9	53.13	1.03	62.85	20.93	0.94**	-9.35
70	PMPR-10	43.53	0.77**	-5.86	22.87	0.79**	-8.71
71	PMPR-11	46.29	0.36	111.18**	18.93	1.08**	-10.05
72	PMPR-12	47.49	1.73	115.78**	19.63	0.64**	-10.19
73	PMPR-13	50.49	-0.64	15.53	30.97	1.28**	-9.90
74	PMPR-14	60.06	0.24	42.31	30.30	1.28**	-9.90
75	PMPR-15	66.24	0.27	88.79*	32.65	1.11**	-8.29
76	PMPF-1	48.76	0.82**	-8.05	16.03	0.80**	-9.06
77	PMPF-2	60.99	0.46*	-10.84	18.10	0.80*	-4.54
78	PMPF-3	60.91	0.09	-1.95	16.00	1.09**	-8.51
79	PMPF-4	39.43	1.31	90.23*	13.75	0.95**	-8.65
80	PA9385 (checks)	51.33	1.47**	3.41	15.43	0.81	0.30
81	9444 (checks)	46.16	2.07**	-18.04	15.65	0.77**	-10.08
82	86M20 (checks)	54.16	1.03**	-5.32	22.10	1.21**	-2.47
83	86M22 (checks)	40.63	0.93**	-16.87	20.41	0.75**	-9.52

3.2 Stability Parameters

Eberhart and Russell (1966) suggested the ideal genotype as one which has a high mean ($\bar{X}$), unit regression co-efficient (bi = 1) and the least deviation from regression (S2di = 0). On the basis of stability parameters, genotypes with near-unity regression coefficients, higher mean values, and non-significant departures from linear regression were deemed appropriate and acceptable for favourable environmental conditions. While genotypes with a higher mean, a regression coefficient less than one, or negative and non-significant deviations from linear regression were considered responsive and suited for unfavourable environmental conditions.

Table 8. Stability for grain yield per plant (g) and fodder yield per plant (g)

		Fodder yield per plant			Grain yield per plant		
S. No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
1	PMPF-1 x PMPR-1	79.37	1.06**	-30.24	21.28	1.04**	-2.66
2	PMPF-2 x PMPR-1	79.01	1.06**	-30.24	20.31	0.97**	-2.71
3	PMPF-3 x PMPR-1	84.65	1.06**	-30.24	21.35	0.97**	-2.71
4	PMPF-4 x PMPR-1	89.75	1.06**	-30.24	22.43	1.22**	-0.61
5	PMPF-1 x PMPR-2	88.20	1.76**	-7.71	23.20	1.41**	4.48
6	PMPF-2 x PMPR-2	82.19	1.06**	-30.24	23.50	1.32**	1.77
7	PMPF-3 x PMPR-2	80.61	0.79**	-28.69	20.79	0.97**	-2.71
8	PMPF-4 x PMPR-2	89.96	1.43**	-23.10	25.20	1.44**	5.66
9	PMPF-1 x PMPR-3	76.50	1.06**	-30.24	13.76	0.68**	1.78
10	PMPF-2 x PMPR-3	82.72	0.55*	-22.49	21.02	0.93**	-2.62
11	PMPF-3 x PMPR-3	91.76	1.06**	-30.24	24.87	1.11**	-2.20
12	PMPF-4 x PMPR-3	89.70	0.61**	-24.44	23.14	1.26**	0.14
13	PMPF-1 x PMPR-4	81.46	1.06**	-30.24	18.02	0.97**	-2.71
14	PMPF-2 x PMPR-4	88.30	0.51*	-20.76	22.27	0.97**	-2.71
15	PMPF-3 x PMPR-4	84.19	0.88**	-29.80	22.56	0.97**	-2.71
16	PMPF-4 x PMPR-4	84.10	0.83**	-29.20	22.81	0.22	1.16
17	PMPF-1 x PMPR-5	87.56	-0.54	62.71	20.65	0.63**	3.17
18	PMPF-2 x PMPR-5	88.96	0.04	6.06	21.12	0.58*	4.74
19	PMPF-3 x PMPR-5	100.03	0.38	-15.40	25.67	-0.86**	1.90
20	PMPF-4 x PMPR-5	93.28	0.43	-17.63	25.93	-0.89**	2.23
21	PMPF-1 x PMPR-6	86.70	0.75**	-27.91	22.35	-0.97**	2.71
22	PMPF-2 x PMPR-6	84.29	0.52*	-21.22	24.70	1.27**	0.48
23	PMPF-3 x PMPR-6	88.82	0.45	-18.69	23.11	-0.68**	1.78
24	PMPF-4 x PMPR-6	84.62	0.93**	-30.15	22.09	1.06**	-2.59

		Fodder yield per plant			Grain yield per plant		
S. No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
25	PMPF-1 x PMPR-7	78.99	1.19**	-28.94	18.17	0.97**	-2.71
26	PMPF-2 x PMPR-7	90.19	1.06**	-30.24	22.93	1.12**	-2.16
27	PMPF-3 x PMPR-7	90.05	0.79**	-28.56	22.79	0.87**	-1.98
28	PMPF-4 x PMPR-7	90.95	1.06**	-30.24	23.36	1.08**	-2.45
29	PMPF-1 x PMPR-8	82.10	0.22	-6.56	21.38	0.81**	-1.25
30	PMPF-2 x PMPR-8	82.21	0.47	-19.41	18.75	0.66**	2.25
31	PMPF-3 x PMPR-8	81.70	0.27	-9.39	18.12	0.37	14.52*
32	PMPF-4 x PMPR-8	80.49	0.78**	-28.46	18.17	0.62**	3.32
33	PMPF-1 x PMPR-9	77.33	1.06**	-30.24	18.30	0.97**	-2.71
34	PMPF-2 x PMPR-9	90.97	1.33**	-26.20	24.60	1.44**	5.41
35	PMPF-3 x PMPR-9	83.05	-0.12	18.49	21.38	0.66**	2.27
36	PMPF-4 x PMPR-9	78.10	1.33**	-25.97	17.31	0.92**	-2.45
37	PMPF-1 x PMPR-10	75.58	1.48**	-21.26	17.61	1.03**	-2.70
38	PMPF-2 x PMPR-10	79.17	1.40**	-24.18	17.01	0.97**	-2.71
39	PMPF-3 x PMPR-10	79.11	1.06**	-30.24	18.73	0.97**	-2.71
40	PMPF-4 x PMPR-10	80.24	1.40**	-24.14	16.82	0.97**	-2.71
41	PMPF-1 x PMPR-11	92.97	0.81**	-28.95	24.63	-0.56**	6.14
42	PMPF-2 x PMPR-11	83.40	0.73**	-27.41	22.11	0.97**	-2.71
43	PMPF-3 x PMPR-11	84.35	0.55*	-22.41	24.59	-0.64	7.91
44	PMPF-4 x PMPR-11	80.82	0.58**	-23.40	21.89	0.97**	-2.71
45	PMPF-1 x PMPR-12	83.95	1.85**	-1.86	21.55	1.39**	3.96
46	PMPF-2 x PMPR-12	83.59	2.09**	16.33	20.70	1.52**	8.94*
47	PMPF-3 x PMPR-12	78.93	1.34**	-25.85	18.48	1.11**	-2.26
48	PMPF-4 x PMPR-12	84.87	2.41**	48.04	20.21	1.34**	2.29
49	PMPF-1 x PMPR-13	87.76	1.06**	-30.24	22.41	1.17**	-1.45
50	PMPF-2 x PMPR-13	89.68	1.06**	-30.24	22.67	0.97**	-2.71
51	PMPF-3 x PMPR-13	81.85	0.17	-3.40	21.35	0.78**	-0.59
52	PMPF-4 x PMPR-13	95.00	1.06**	-30.24	31.02	1.42**	4.76
53	PMPF-1 x PMPR-14	82.44	1.21**	-28.69	20.29	1.11**	-2.19
54	PMPF-2 x PMPR-14	88.23	1.77**	-6.94	24.15	1.43**	5.34
55	PMPF-3 x PMPR-14	85.68	0.10	1.36	25.26	0.99**	-2.74
56	PMPF-4 x PMPR-14	93.53	1.06**	-30.24	26.86	1.42**	4.80
57	PMPF-1 x PMPR-15	89.37	2.02**	10.31	25.15	1.54**	9.63*
58	PMPF-2 x PMPR-15	94.62	2.08**	15.18	25.87	1.19**	-1.21
59	PMPF-3 x PMPR-15	83.39	1.33**	-26.13	20.50	0.67**	2.06
60	PMPF-4 x PMPR-15	91.04	1.17**	-29.25	25.32	1.27**	0.42
61	PMPR-1	74.83	1.06**	-30.24	19.45	1.02**	-2.73
62	PMPR-2	77.26	1.06**	-30.24	19.81	1.04**	-2.69
63	PMPR-3	76.82	1.06**	-30.24	20.02	0.97**	-2.71
64	PMPR-4	75.24	1.06**	-30.24	20.81	0.97**	-2.71
65	PMPR-5	73.33	1.06**	-30.24	20.79	0.95**	-2.65
66	PMPR-6	76.53	1.06**	-30.24	17.81	1.03**	-2.71
67	PMPR-7	79.26	1.06**	-30.24	19.39	1.00**	-2.74
68	PMPR-8	68.06	0.98**	-29.46	19.25	0.90**	-2.35
69	PMPR-9	75.27	1.11**	-29.47	20.41	0.98**	-2.73
70	PMPR-10	75.67	1.07**	-29.00	20.71	0.97**	-2.71
71	PMPR-11	76.80	1.04**	-30.29	19.75	0.97**	-2.71
72	PMPR-12	77.07	1.04**	-30.29	18.97	0.91**	-2.38
73	PMPR-13	71.44	1.13**	-29.82	20.40	0.99**	-2.74
74	PMPR-14	78.48	1.11**	-20.06	17.67	0.95**	-2.64
75	PMPR-15	79.52	1.04**	-30.29	20.04	1.16**	-1.66
76	PMPF-1	63.36	1.04**	-30.29	8.59	0.40	12.56*
77	PMPF-2	68.12	1.22**	-30.32	9.35	0.56*	5.73
78	PMPF-3	65.18	1.33**	-30.35	9.83	0.59*	4.66
79	PMPF-4	64.66	1.04**	-26.10	9.84	0.50	8.17*

		Fodder yield per plant			Grain yield per plant		
S. No.	**Genotype**	**Mean**	**bi**	**S^2di**	**Mean**	**bi**	**S^2di**
80	PA9385 (checks)	85.19	1.04**	-28.78	21.71	0.97**	-2.71
81	9444 (checks)	81.78	1.40**	-30.36	22.14	1.04**	-2.67
82	86M20 (checks)	81.71	1.46**	-22.16	17.62	0.97**	-2.71
83	86M22 (checks)	86.40	1.38**	-24.84	22.34	1.08**	-2.46

3.3 Phenological Traits

3.3.1 Days to 50% Flowering

Days to 50% flowering exhibited moderate variability, with mean values ranging from 50.89 days (PMPF-4 × PMPR-5) to 67.56 days (PMPR-13). Several genotypes exhibited non-significant S^2di values indicates stable performance.

Among parents, PMPR-9 (62.22 days), PMPR-4 (65.22 days) showed non-significant S^2di and bi ≈ 1. Similarly, crosses such as PMPF-1 x PMPR-9 (53.56 days), PMPF-2 x PMPR-8 (53.86 days), PMPF-2 x PMPR-5 (53.86 days) and PMPF-4 x PMPR-2 (52.89 days), depicted similar outcome, which implies that these parents and crosses had general adaptability i.e., high stability with desirable earliness.
However, PMPR-2 (65.56 days) and PMPF-4 x PMPR-5 (50.86 days) showed bi <1 and non-significant S^2di, therefore these genotypes had resistance to environment changes and perform best in unfavourable environments.

3.3.2 Days to Maturity

Days to maturity followed similar trends, with values ranging from 76.44 days (PMPF-3 × PMPR-3) to 94.11 days (PMPR-13). Stable parents included PMPR-9 (90.11 days), PMPR-4 (92.11 days) for all environmental conditions. In contrast, parent PMPR-2 (88.11 days) perform better in unfavourable environment.
Among hybrids, PMPF-1 × PMPR-9 (79.78 days), PMPF-2 × PMPR-8 (79.78 days) and PMPF-4 × PMPR-2 (77.78 days), exhibited stable performance with consistent maturity across environments. However, hybrids such as PMPF-2 × PMPR-1 (81.44 days), PMPF-3 × PMPR-4 (81.44 days), PMPF-3 × PMPR-1 (81.11 days), PMPF-2 × PMPR-3 (81.11 days), PMPF-2 × PMPR-4 (79.44 days), PMPF-4 × PMPR-3 (78.44 days), PMPF-3 × PMPR-3 (76.44 days) showed bi >1. In contrast, PMPF-4 × PMPR-5 (76.78 days) showed bi<1 indicating better performance under unfavourable conditions.

3.4 Growth Attributes

3.4.1 Plant Height

Plant height showed wide variation ranging from 104.86 cm (PMPF-1 × PMPR-3) to 221.16 cm (PMPF-4 × PMPR-13). A large number of genotypes exhibited either negative or significant S^2di. However, hybrids namely, PMPF-1 × PMPR-2 (201.90 cm), PMPF-3 × PMPR-9 (173.95 cm), PMPF-3 × PMPR-1 (179.79 cm), PMPF-3 × PMPR-2 (124.25 cm) and parents namely, PMPF-4 (112.53 cm), PMPF-1 (107.93 cm), PMPF-2 (96.93 cm) showed bi <1 and non-significant S^2di, which implied that these parents perform better under unfavourable environment.

Hybrids namely, PMPF-2 × PMPR-6 (203.93 cm), PMPF-4 × PMPR-7 (188.19 cm), PMPF-3 × PMPR-12 (159.27 cm) and parent PMPR-4 (163.12 cm) bi ≈ 1 and non-significant S^2di. Productive tillers per plant.

Genotypes with bi ≈ 1 and non-significant S^2di was reported in PMPF-2 × PMPR-7 (1.90), PMPF-4 × PMPR-12 (1.88), PMPF-2 × PMPR-13 (1.73), PMPF-3 × PMPR-12 (1.50), PMPF-3 × PMPR-15 (1.17) and PMPF-2 × PMPR-10 (0.95) among hybrids and PMPR-9 (1.60), PMPR-11 (1.56), PMPR-8 (1.47) among parents.

Hybrids viz., PMPF-1 × PMPR-13 (1.94), followed by PMPF-4 × PMPR-6 (1.70), PMPF-1 × PMPR-4 (1.57), PMPF-4 × PMPR-11 (1.57) and parents viz., PMPR-7 (1.46), PMPR-10 (1.46) having bi <1 and non-significant S^2di.

3.5 Panicle Characters

3.5.1 Panicle Length

Panicle length ranged from 15.23 cm (PMPF-1 × PMPR-3) to 31.17 cm (PMPF-4 × PMPR-13). Hybrids such as PMPF-2 × PMPR-1 (24.37 cm), PMPF-2 × PMPR-2 (26.77 cm), PMPF-3 × PMPR-3 (25.04 cm), PMPF-4 × PMPR-3 (29.77 cm), PMPF-1 × PMPR-4 (21.22 cm), PMPF-2 × PMPR-4 (24.35 cm), PMPF-1 × PMPR-7 (17.08 cm), PMPF-1 × PMPR-10 (20.41 cm), PMPF-3 × PMPR-11 (26.53 cm), PMPF-1 × PMPR-13 (27.00 cm), PMPF-2 × PMPR-15 (28.07 cm) and parents such as PMPR-4 (20.73 cm), PMPR-10 (18.63 cm), PMPR-15 (23.00 cm) and 86M22 check (22.57 cm) had bi ≈ 1 and non-significant S^2di.

In contrast, PMPR-4 (13.67 cm), PMPF-1 × PMPR-5 (20.82 cm) and PMPF-2 × PMPR-5 (21.47 cm), showed bi <1 and non-significant S^2di.

3.5.2 Panicle Girth

Genotypes with bi ≈ 1 and non-significant S^2di was reported in PMPF-1 × PMPR-2 (2.56 cm), PMPF-2 × PMPR-15 (2.69 cm), PMPF-1 × PMPR-10 (1.88 cm), and PMPF-2 × PMPR-3 (2.06 cm), for panicle girth. In contrast, among hybrids namely, PMPF-1 × PMPR-7 (2.07 cm), PMPF-2 × PMPR-12 (2.51 cm), PMPF-1 × PMPR-13 (2.58 cm) and among parents PMPR-7 (2.41 cm) and PMPR-10 (2.42 cm) showed bi <1 and non-significant S^2di. These genotypes performed better in unfavourable conditions.

3.6 Grain Yield Components

3.6.1 1000-grain Weight

The trait varied from 5.89 g (PMPF-4 × PMPR-10) to 10.17 g (PMPF-4 × PMPR-13). High-performing genotypes with bi ≈ 1 and non-significant S^2di are PMPF-3 × PMPR-5 (9.38 g), PMPF-1 × PMPR-11 (9.28 g), PMPF-2 × PMPR-4 (8.99 g), PMPF-1 × PMPR-6 (8.89 g), PMPF-4 × PMPR-6 (8.32 g), PMPF-1 × PMPR-5 (8.20 g), PMPF-3 × PMPR-4 (8.09 g), PMPF-1 × PMPR-8 (8.00 g), PMPF-4 × PMPR-7 (7.20 g), PMPF-1 × PMPR-10 (7.10 g), and PMPF-1 × PMPR-4 (7.10 g), among hybrids; PMPR-15 (8.09 g) among parents; and PA9385 (7.97 g), 86M20 (7.64 g) among checks. These genotypes performed better in varied environment conditions.

3.6.2 Harvest Index

Harvest index ranged from 14.52% (PMPF-1) to 35.39% (PMPF-4 × PMPR-13). High-performing genotypes with bi ≈ 1 and non-significant S^2di are PMPF-1 × PMPR-1 (29.08%), PMPF-1 × PMPR-2 (31.88%), PMPF-3 × PMPR-2 (27.04%), PMPF-4 × PMPR-2 (33.68%), PMPF-3 × PMPR-6 (26.64%), PMPF-3 × PMPR-10 (22.64%), PMPF-3 × PMPR-13 (23.49%), PMPF-4 × PMPR-13 (35.39%) among hybrids; PMPR-1 (21.23%), PMPR-12 (22.16%), PMPF-2 (16.38%) among parents; PA9385 (28.65%) among checks.

In contrast, PMPF-1 × PMPR-5 (25.29%), PMPF-2 × PMPR-5 (25.91%), PMPF-3 × PMPR-5 (29.48%), PMPF-3 × PMPR-1 (29.65%) among hybrids, PMPF-1 (14.52%), PMPF-1 (14.52%) among parents showed bi <1 which implies their better performance under unfavourable conditions.

3.7 Micronutrient Content

3.7.1 Iron (Fe) Content

Iron content ranged widely from 37.41 ppm to 75.38 ppm. Stable and high-performing genotypes included PMPF-1 × PMPR-1 (75.38 ppm) and PMPF-4 × PMPR-1 (70.91 ppm). Hybrids having bi ≈ 1 and non-significant S^2di are PMPF-1 × PMPR-1 (75.38 ppm), followed by PMPF-4 × PMPR-2 (69.55 ppm), PMPF-4 × PMPR-8 (67.24 ppm), PMPF-4 × PMPR-13 (64.34 ppm), PMPF-3 × PMPR-2 (57.46 ppm), PMPF-1 × PMPR-8 (56.77 ppm), PMPF-3 × PMPR-5 (56.36 ppm), PMPF-2 × PMPR-13 (55.84 ppm), PMPF-1 × PMPR-10 (54.06 ppm), PMPF-3 × PMPR-4 (52.49 ppm), PMPF-4 × PMPR-6 (49.66 ppm), PMPF-3 × PMPR-6 (46.60 ppm),

PMPF-2 × PMPR-15 (46.59 ppm), PMPF-2 × PMPR-9 (46.49 ppm), PMPF-2 × PMPR-14 (42.90 ppm) and PMPF-1 × PMPR-14 (39.79 ppm). Similarly, PMPR-2 (67.07 ppm), PMPR-9 (53.13 ppm), PMPR-7 (49.33 ppm), PMPR-3 (46.56 ppm) among parents and PA9385 (51.33 ppm) among checks showed bi ≈ 1 and non-significant S^2di. These genotypes gave stable performance across the environments.

In contrary, hybrid such as PMPF-2 × PMPR-5 had 54.29 ppm iron content and parents such PMPR-14 (60.06 ppm) and PMPR-13 (50.49 ppm) showed bi <1 in addition to non-significant S^2di, indicating their better performance under stressful conditions.

3.7.2 Zinc (Zn) Content

Zinc content ranged from 13.80 ppm to 34.97 ppm. Most genotypes exhibited bi ≈ 1 and negative S^2di. While S^2di is technically a variance and theoretically should be non-negative, in practice, it is often negative when the true value is zero or very close to zero. However, some hybrids depicted bi ≈ 1 and non-significant S^2di (non-negative) values, such as PMPF-4 × PMPR-2 (23.70 ppm), PMPF-3 × PMPR-15 (19.75 ppm), PMPF-2 × PMPR-5 (16.04 ppm), PMPF-4 × PMPR-10 (15.10 ppm). Similarly, PMPR-1(32.25 ppm) among parents and PA9385 (15.43 ppm) among checks showed bi ≈ 1 and non-significant S^2di, indicating that these genotypes gave stable performance across the environment.

3.8 Yield Performance and Stability

3.8.1 Grain yield per plant

Grain yield exhibited substantial variability and significant G × E interaction. Genotypes with positive and non-significant S^2di values demonstrated stability and suitability for wide adaptation, such as PMPF-4 × PMPR-13 (31.02 g), followed by PMPF-4 × PMPR-14 (26.86 g), PMPF-4 × PMPR-15 (25.32), PMPF-4 × PMPR-2 (25.20 g), PMPF-2 × PMPR-6 (24.70 g), PMPF-2 × PMPR-9 (24.60 g), PMPF-2 × PMPR-14 (24.15 g), PMPF-2 × PMPR-2 (23.50 g), PMPF-1 × PMPR-2 (23.20 g), PMPF-3 × PMPR-6 (23.11 g), PMPF-1 × PMPR-12 (21.55 g), PMPF-3 × PMPR-9 (21.38 g), PMPF-2 × PMPR-5 (21.12 g), PMPF-1 × PMPR-5 (20.65 g), PMPF-3 × PMPR-15 (20.50 g), PMPF-4 × PMPR-12 (20.21 g), PMPF-2 × PMPR-8 (18.75 g), PMPF-4 × PMPR-8 (18.17 g), PMPF-1 × PMPR-3 (13.76 g) among hybrids and PMPF-3 (9.83 g), PMPF-2 (9.35 g) among parents.
In contrary, hybrid such as PMPF-4 × PMPR-4 (22.81 g), PMPF-3 × PMPR-6 (23.11 g), PMPF-3 × PMPR-5 (25.67 g), PMPF-4 × PMPR-5 (25.93 g), PMPF-1 × PMPR-6 (22.35 g), PMPF-1 × PMPR-11 (24.63 g) and PMPF-3 × PMPR-11 (24.59 g) showed bi <1 in addition to non-significant S^2di, indicating their better performance under stressful conditions.

3.8.2 Fodder yield per plant

Fodder yield ranged widely, with PMPR-15 emerging as the highest yielder. Most of the genotypes exhibited extreme negative S^2di values or significant S^2di values. Although few hybrids showed non-negative and non-significant values such as PMPF-2 × PMPR-5 (88.96 g) and PMPF-3 × PMPR-14 (85.68 g) having bi ≈ 1 i.e. stable performance across the environments and PMPF-1 × PMPR-5 (87.56 g) and PMPF-3 × PMPR-9 (83.05 g) showed bi <1 indicating better performance under stress.

Overall, the results indicated that both grain and fodder yield were influenced by environmental factors, but several genotypes exhibited stable performance across locations.

Findings were in accordance with reports of Dadarwal et al. (2018), Katariya et al. (2019), Sodhaparmar et al. (2023), Sagar et al. (2024) and Gokulakrishnan et al. (2025). Further, the performance for micronutrient stability was found to be similar to the result obtained by Sathyavathi et al. (2015) and Singhal et al. (2024).

4. Conclusion

Overall, PMPF-4 × PMPR-13 was identified as the best-performing hybrid in favorable for grain yield, whereas PMPF-1 × PMPR-1 for iron and PMPF-4 × PMPR-2, PMPF-3 × PMPR-15 for zinc content showed stable and desirable performance across environments, making them promising genotypes for both productivity and micronutrient improvement.

The genotypes that can be described as better performing under unfavourable environments include: PMPR-2 for days to 50% flowering, PMPF-4 × PMPR-5 for days to 50% flowering and maturity, PMPF-2 × PMPR-5 and PMPF-3 × PMPR-9 for fodder yield, and PMPF-4 × PMPR-5 for yield stability under stress.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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Supplementary

Supplementary Table 1. Weather data during crop season (March 2024 – June 2024)

S. No	Meteorological Standard Weeks	Temperature (°C)		Relative Humidity (%)		Wind Velocity	Total rainfall	Rainy Days
		Maximum	Minimum	Maximum	Minimum	(Km/h)	(mm)	(No.)
Deesa, Gujarat								
1.	15.3.24 to 21.3.24	25.10	16.50	29.52	19.42	7.36	0	0
2.	22.3.24 to 28.3.24	28.70	16.21	38.42	27.52	8.11	0	0
3.	29.3.24 to 4.4.24	31.25	18.34	39.22	29.11	8.29	1.5	2
4.	5.4.24 to 11.4.24	32.10	19.44	45.28	26.42	11.52	0	0
5.	12.4.24 to 18.4.24	35.42	21.26	47.68	37.44	10.58	0	0
6.	19.4.24 to 25.4.24	36.10	25.42	55.42	51.82	9.25	0	0
7.	26.4.24 to 2.5.24	37.20	27.25	57.18	50.42	9.77	3.20	2
8.	3.5.24 to 9.5.24	39.44	28.66	61.56	57.58	8.11	0	0
9.	10.5.24 to 16.5.24	41.55	29.32	68.42	51.25	8.36	0	0
10.	17.5.24 to 23.5.24	46.30	29.60	63.00	43.20	7.30	0	0
11.	24.5.24 to 30.5.24	43.80	27.80	57.00	39.80	8.10	7.00	2
12.	31.5.24 to 6.6.24	44.50	29.80	54.30	33.50	7.20	0	0
Tharad, Gujarat								
1.	15.3.24 to 21.3.24	24.30	16.20	30.22	19.42	7.86	0	0
2.	22.3.24 to 28.3.24	29.40	15.11	37.12	28.32	8.31	0	0
3.	29.3.24 to 4.4.24	32.15	18.74	40.44	29.42	8.79	0	0
4.	5.4.24 to 11.4.24	36.30	20.14	48.61	26.42	11.62	0	0
5.	12.4.24 to 18.4.24	35.42	20.16	47.68	30.44	10.78	0	0
6.	19.4.24 to 25.4.24	36.10	24.92	54.42	53.82	9.35	0	0
7.	26.4.24 to 2.5.24	37.70	27.25	55.18	57.42	10.37	3.60	3
8.	3.5.24 to 9.5.24	39.84	28.16	65.46	58.18	8.21	0	0
9.	10.5.24 to 16.5.24	40.55	27.42	68.42	53.35	8.86	0	0
10.	17.5.24 to 23.5.24	43.30	26.70	68.00	44.10	8.10	0	0
11.	24.5.24 to 30.5.24	43.80	28.10	72.00	40.70	8.30	7.77	4
12.	31.5.24 to 6.6.24	44.10	30.80	74.30	34.80	8.10	0	0
Palanpur, Gujarat								
1.	15.3.24 to 21.3.24	25.82	17.57	31.08	20.36	7.29	0	0
2.	22.3.24 to 28.3.24	29.42	17.28	39.98	28.46	8.04	0	0
3.	29.3.24 to 4.4.24	31.97	19.41	40.78	30.05	8.22	0.3	1
4.	5.4.24 to 11.4.24	32.82	20.51	46.84	27.36	11.45	0	0
5.	12.4.24 to 18.4.24	36.14	22.33	49.24	38.38	10.51	0	0
6.	19.4.24 to 25.4.24	36.82	26.49	56.98	52.76	9.18	0	0
7.	26.4.24 to 2.5.24	37.92	28.32	58.74	51.36	9.7	4.10	3
8.	3.5.24 to 9.5.24	40.16	29.73	63.12	58.52	8.04	0	0
9.	10.5.24 to 16.5.24	42.27	30.39	69.98	52.19	8.29	0	0
10.	17.5.24 to 23.5.24	47.02	30.67	64.56	44.14	7.23	0	0
11.	24.5.24 to 30.5.24	44.52	28.87	58.56	40.74	8.03	6.80	4
12.	31.5.24 to 6.6.24	45.22	30.87	55.86	34.44	7.13	0	0

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