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Short Communication

Genotype — Environmental interactions and phenotypic stability analyses of opium poppy (*Papaver somniferum* L.) for seed, opium and morphine content

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For the identification of improved genotype for commercial cultivation, the stability in the genotype for a given trait or set of traits across testing environments has always been emphasized [1-3]. Various statistical methods have been proposed to analyse the G × E interaction or yield stability [4-6]. Out of them, additive main effects and multiplicative interactions (AMMI) statistical model, which incorporates ANOVA main effects for genotypes and environments and multiplicative interaction effects obtained from a singular value decomposition of the matrix of residue, has been proclaimed superior to linear regression and principal component analysis models [7, 8]. The AMMI first separates the additive main effect from multiplicative variance and subsequently PCA is used to partition G × E deviation into different interaction principal component axes (ICPA) which can be tested for statistical significance through ANOVA [1].

Opium poppy (*Papaver somniferum* L.) is the crop of immense pharmaceutical importance since antiquity. In global market, India is one of the largest legal producer and exporter of opium products. To meet national and international demands of opium products, there is always a call to develop new and high yielding varieties. The newly developed varieties always need to test their adaptability and stability in different environments prior to their release for commercial cultivation. In the present investigation, 11 advance breeding materials have been evaluated over five environments to isolate the promising and stable genotypes based on their stability performance.

The materials used for present investigation comprised 11 advance and pure breeding lines of opium poppy obtained through various breeding programmes. The field experiments were carried out over five crop years (1999-2000 to 2003-2004) in a randomized block design (RBD) with three replications at the experimental field of National Botanical Research Institute, Lucknow, India. The plot size was 4.8 m^2 (having eight rows 25 cm apart). Plants were spaced 10 cm apart within rows. Standard cultural practices were followed throughout crop season. The middle six rows were used as harvest area of each plot for opium latex (mg/plant) and seed yield (g/plant). Morphine content (%) in dried opium samples was estimated following the method proposed by Pride and Stern [9]. Analysis of variance was undertaken for the combined analysis of variance across the test environment followed by stability analysis and AMMI's stability value (ASV) suggested by Zobel *et al.* [7], Hanson [9] and Purchase [10] respectively.

The result of combined analysis of variance and AMMI analysis showed that all the main as well as interaction effects were statistically significant for all traits (Table 1). The environment sum of squares for seed yield, opium yield and morphine content accounted 19%, 32% and 28%, respectively (Table 1). The sum of squares due to G × E ranged from 23% to 38%. The significant G × E variation for each trait validated further analysis of G × E interaction using AMMI model. For seed yield, the interaction contained 2% noise and 98% real structure with the relevant (target) variation 80% of the treatment sum of squares. For opium yield, the interaction contained 6% noise and 94% real structure with relevant variation of 66% of the treatment sum of square. In case of morphine content, the interaction contained 20% noise and 80% real structure with the relevant variation of 67%. Further, the G ×E was partitioned into three interaction principal component axes (IPCA) which were significant for all the traits. The IPCA I exhibited 55.64% of the G × E interaction sums of squares whereas IPCA II and IPCA III showed 30.68% and 11.29%, respectively for seed yield, the remaining being residual or noise. For opium yield the IPCA I, IPCA II and IPCA III explained 52.53%, 36.22% and 7.63% of interaction sum of squares comprising a

Table 1. ANOVA for combined and AMMI analysis for 11 genotypes and portion of sum of square (SS) attributed to environment, genotypes and genotype × environment (G × E) as a percentage of the total sums of squares remaining after removing sums of squares due to replications and errors in opium poppy.

Source	df	MS		
		Seed yield	Opium yield	Morphine content
Combined analysis				
Environments	4	25.107*	205.468**	6.457**
Rep (E)	10	6.40	5.83	1.03
Genotypes	10	23.058**	114.914**	4.126**
G × E	40	5.014**	14.726**	0.657**
Error	110	0.09	0.848	0.127
AMMI analysis				
Treatment	54	9.844**	47.408**	1.729**
Genotypes	10	23.058**	114.914**	4.126**
Environments	4	25.107**	205.468**	6.457**
G × E	40	5.014**	14.726**	0.657**
PCA I	13	8.570**	23.803**	0.976**
PCA II	11	5.595**	19.395**	0.734**
PCA III	9	2.516**	4.995**	0.366**
Residual	7	0.709**	3.045**	0.318*
Error	110	0.090	0.848	0.127
Total	164	3.302	16.179	0.654
			%SS	
Pooled error + Rep (E)		22	3	14
Remaining[a]		78	97	86
Environment (E)		19	32	28
Genotype (G)		43	45	44
G × E		38	23	28

*,**significant at 5% and 1% respectively

[a]The percentage of sums of squares remaining after that due to error and replication have been subtracted from the total sums of squares

total of 96.38% of G × E interaction sum of squares, while for morphine all the three IPCAs represented 48.28%, 30.71% and 12.53%, respectively with a total of 91.52% of G × E interaction sum of squares. The AMMI model explains that the genotypes characterized by mean higher than population mean and PCA scores near to zero, are considered adaptable to all environments. On the other hand genotypes with high mean value with large value of PCA scores are considered as having specific adaptations to environments.

The maximum opium yield was obtained from BR 330 (59.85 kg ha^{-1}) followed by BR 243 (58.91 kg ha^{-1}) and BR 238 (57.90 kg ha^{-1}). The maximum seed yield across the environments was found for BR 330(16.92 q ha^{-1}) followed by BR 328 (16.43 q ha^{-1}) and BR 333 (16.19 q ha^{-1}). The morphine content was noticed highest in genotype BR 328 (17.96%) (Table 3). According to IPCA I score, BR 333 was the most stable genotype followed by BR 243, BR 229 and BR 313 for opium yield (Table 2). It was interesting to note that when IPCA II was taken into consideration, the stability order of the genotypes changed which showed BR 229 and BR 335 as stable genotypes. It suggested that the two IPCAs have different values and meanings. This inconsistency was sorted out by calculating AMMI stability value (ASV) given by Purchase [10], which provides a balanced measurement between two IPCA cores. The ASV scores identified BR 229, BR 238, BR 333 and BR 243 as stable genotypes having mean value higher than population mean. The genotypes BR 238, BR 328 and BR 333 showed similar interaction patterns as they clustered together. The stability parameter (Di) [9], indicated that BR 243 as most stable genotype followed by BR 333, BR 328 and BR 229 since these had lower Di values and higher mean yield than population mean. Thus, the

Table 2. Mean seed yield, opium yield, morphine content (values in parenthesis denotes rankings), AMMI and other stability measurement for 11 genotypes of opium poppy tested over five environments

Genotypes	Mean (Rank)			Seed yield				Opium yield				Morphine content			
	Seed yield (q/ha)	Opium yield (kg/ha)	Morphine (%)	IPCAI	IPCAII	ASV	Di	IPCAI	IPCAII	ASV	Di	IPCAI	IPCAII	ASV	Di
1. BR 330	16.92(1)	59.85(1)	16.77(2)	0.20	–0.29	0.481	5.110	0.54	1.32	1.917	11.645	0.54	–0.04	0.728	1.175
2. BR 336	11.68(10)	47.12(10)	15.50(9)	–1.74	0.42	2.400	8.547	2.98	–1.19	4.317	8.191	–0.12	–0.49	0.678	1.689
3. BR 333	16.19(3)	57.03(5)	15.89(6)	–0.32	–0.12	0.458	5.109	0.14	–0.86	1.173	10.863	0.05	0.34	0.463	0.795
4. BR 335	13.47(6)	54.79(7)	16.22(5)	0.42	1.91	2.631	7.489	–2.04	–0.40	2.796	18.233	–0.64	–0.50	1.092	2.656
5. BR 328	16.43(2)	57.46(4)	17.96(1)	0.04	0.06	0.009	4.998	0.97	1.07	1.943	11.217	–0.19	–0.47	0.682	1.366
6. BR 229	15.67(4)	55.88(6)	15.75(8)	0.31	–0.73	1.067	5.217	–0.31	–0.06	0.424	10.105	–0.23	0.53	0.777	1.420
7. BR 238	13.29(7)	57.90(3)	14.79(10)	0.08	–0.77	1.042	6.943	–0.49	–0.66	1.106	12.225	0.23	0.23	0.438	1.612
8. BR 307	12.32(9)	51.27(9)	15.85(7)	–0.21	–1.40	1.903	9.568	–1.19	–0.98	2.069	15.212	–0.36	–0.80	1.180	2.392
9. BR 313	10.41(11)	45.21(11)	16.45(3)	–1.29	0.76	2.01	7.599	0.33	2.35	3.192	12.544	0.39	0.01	0.525	2.191
10. BR 291	13.06(8)	53.13(8)	16.36(4)	2.32	0.42	3.171	5.834	–1.9	0.74	1.887	16.136	1.25	0.18	1.697	2.176
11. BR 243	15.14(5)	58.91(2)	14.73(11)	0.17	–0.26	0.425	5.134	0.24	–1.37	1.868	11.727	–0.92	1.00	1.828	2.691

genotypes BR 333, BR 330 and BR 243 were found more adaptable and stable over environments for opium yield.

The genotypes BR 243, BR 333 and BR 330 indicated their stability over environments for seed yield. The genotypes BR 330, BR 328 and BR 333 had higher mean yield, IPCA I values close to zero and minimum interaction. The Di values indicated high sensitivity for BR 328, BR 330 and BR 243. The genotype BR 238 followed by BR 333, BR313 and BR 328 showed lower value of ASV for morphine content, which suggested that these genotypes might be stable over environments. The genotypes BR 333, BR 229 and BR 307 showed minimum interaction but have mean value lower than population mean.

It was concluded from the present study that the genotypes performed dissimilar stability across the gradient of environmental indices. The usefulness of AMMI model is conveniencingly proved based on the present study for detecting important sources of G × E effects. Three most stable genotypes *viz.*, BR 330, BR 333 and BR 243 were identified, which can be commercially utilized for obtaining the optimum yield potential.

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