



Genotype $\times$ Environment interaction: AMMI analysis of radish (*Raphanus sativus*) genotypes in different environments of Punjab

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ABSTRACT

The study entailed the determination of Genotype $\times$ Environment ($G \times E$) interaction through Additive Main effects and Multiplicative Interaction (AMMI) analysis to identify radish (*Raphanus sativus* L.) genotypes suitable for cultivation in the province of Punjab, India. Twelve newly developed advanced breeding lines of radish were sown on six different dates for two years, i.e. 2014-15 and 2015-2016, in a randomized complete block design, replicated thrice. The explicit analysis of the AMMI revealed pronounced performance differences among the genotypes due to environments, explained by high percentage of GEI through IPCA1 and IPCA2 (65.48 %-82.79%). The AMMI analysis clearly delineated the mega environments and provided information on the cultivars exhibiting enhanced performance in those mega-environments on the basis of stability, performance and genetic difference between genotypes and environments. Temperature and photoperiod were the major contributing factors in $G \times E$ interactions. RL-30 excelled across the environments in terms of root length, root weight, plant weight and total marketable yield whilst, RB-21 performed best under hostile environments (high – ve score on IPCA axis).

Key words: Adaptability, AMMI analysis, $G \times E$ interaction, Radish, Stability

Agro-climatic environment (cool and humid north to warm and dry south) and geographical terrain (sub mountainous to alluvial plains) of Punjab is quite heterogeneous. Short growing period of radish (*Raphanus sativus* L.) is well suited for multiple and intensive cropping system practised in the region throughout the year, provided correct choice is made in selection of variety (Dhaliwal and Klair 2008). However, over the last few years climatic disruptions in the form of extended summers and milder winters have rendered the productivity and quality of agricultural produce poor (Singh *et al.* 2019). Cultivated radish is broadly classified into two groups – European or temperate types and Asian or tropical types (Banga 1976). The tropical varieties have exhibited better adaptation to higher temperature, humidity and photoperiod (Ma *et al.* 2015 and Naseeruddin *et al.* 2014). The performance of superior genotypes in segregating generations becomes complicated due to $G \times E$ interactions across environments (Gauch 2013). Stability indices are based both on regression analysis or principal component analysis (Gauch 2006). The intrinsic benefit of Additive Main effects and Multiplicative Interaction (AMMI) to plant breeders lies in ability to the select stable and superior genotypes in advance generations

of hybridisation, by coalescing the additive main effects for $G \times E$ interaction with principal component analysis (Ariyo and Ayo 2000, Agyeman *et al.* 2015). Applications and advantages of the AMMI model in multi-location yield trials (MLTs) in various crops have been extensively reviewed by Dias and Krzanowski, (2006), Yan *et al.* (2009), Gauch, (2013), Rodrigues *et al.* (2014).

Sowing time in radish is greatly influenced by vegetative and reproductive growth periods and the balance between them ultimately affects root yield and quality. Major environmental factors influencing the root and shoot biomass are temperature (Abdel 2015), photoperiod (Lavanya *et al.* 2014) and light intensity (Rajasekar *et al.* 2013). Therefore, it becomes imperative to find stable genotypes complimenting the sowing time, in order to overcome both biotic and abiotic stress factors limiting productivity and quality in radish. The current experiment was undertaken to gauge the stability and adaptability of new breeding lines of radish generated through hybridisation between Asiatic (tropical) and European (temperate) types.

MATERIALS AND METHODS

Experimental site and climate: The investigation was conducted at Vegetable Research Farm of Punjab Agricultural University, Ludhiana, Punjab, India during 2015-2016 and 2016-2017. Ludhiana is situated at 30° 56" N latitude and 72° 52" E longitude, at an altitude of 247 m amsl. The experimental area is characterized by hot and dry

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summer during April- June followed by rainy season (July-August) and the winter period from November-February.

Experimental material and sowing time: Seventeen radish genotypes (Table 1) including 12 newly developed breeding lines and four checks, viz. Japanese White (temperate), Punjab Pasand, Pusa Chetki and Hisar Sweti (tropical) were sown on six sowing dates, i.e. 1st week of August (E1), 1st week of October (E2), 1st week of December (E3), 1st week of February (E4), 1st week of March (E5) and 1st week of April (E6).

Experimental design and agronomic practices: The experiment was laid out in a randomized complete block design (RCBD) with three replications. The size of each unit plot was 2.25 m × 4 m. A distance of 50 cm between two plots was maintained. Seed was sown on pre irrigated ridges kept 45 cm × 7.5 cm apart.

Data collection: Twenty plants were randomly selected from each genotype from each plot for recording of data for root length (cm), root weight (gm), plant weight (g). Root length was measured using a measuring tape from shoulder to the tail end. Root weight was obtained after removing the leaves and measured on a pan balance. Marketable root yield (kg/plot) was obtained from the periodic harvest of whole plot and excluded forked, twisted and undersized roots. For dry matter, 100g fresh root sample was cut into pieces and was put in a petri dish and sample was dried in oven at 65°C till constant weight was obtained. Weight of the dried sample was recorded in grams and calculated as percentage.

Statistical analysis: Analysis of variance across all environments was performed using statistical software Window STAT version 9.2 developed by INDOSTAT services, Hyderabad, India. The same software was used for analysis of yield and related data to produce AMMI bi plots depicting both main and interaction effects for genotypes as well as environments (Romagosa and Fox 1993). The AMMI's stability value (ASV) was calculated to rank genotypes in terms of stability (Purchase 1997) through Sum of squares (SS); interaction principal component analysis axes 1 and 2, i.e (IPCA1; AMMI 1) and IPCA2 (AMMI 2), respectively.

RESULTS AND DISCUSSION

The AMMI analysis utilized in this study was able to clearly distinguish performance of genotypes evaluated under specific as well as broader environments. Combined stability ANOVA for root length, root weight, plant weight, marketable root yield and dry matter content is presented in Table 2. It exhibited significant differences ($P \leq 0.05$ and $P \leq 0.01$) for genotype (G), environment (E) and $G \times E$, indicating the presence of genetic variation and possible selection of stable genotypes. The large sum of squares for environments pointed towards diverse environments, with differences among environmental means causing about variation in characters evaluated. Highly significant ($P \leq 0.01$) $G \times E$ interaction was indicative of performance differential of genotypes across environments. Contribution of two IPCA components 1 and 2 ranged from 65.48% (root

Table 1 Description of parents and genotypes

Genotype (Code)	Pedigree	Root colour and shape	Source
Punjab Safed (P1; G9)	Released cultivar, PAU Ludhiana	White, conical	PAU, Ludhiana*
Japanese White (P2; G8)	Released cultivar, PAU Ludhiana	White, semi stumped	IARI, New Delhi
Punjab Ageti (P3)	Released cultivar, PAU Ludhiana	Half red, conical	PAU, Ludhiana
Palak Muli (G1)	PS × JW	White, cylindrical	PAU, Ludhiana
RL 2210 Long (G2)	PS × JW	White, cylindrical	PAU, Ludhiana
RB-20 (G3)	PS × JW	White, semi stumped	PAU, Ludhiana
LSR-2 (G4)	PA × PS	Red, cylindrical	PAU, Ludhiana
RL-15 (G5)	PA × PS	White, semi stumped	PAU, Ludhiana
Selection-2 (G6)	PA × PS	White, conical	PAU, Ludhiana
RL-2210 (G7)	PS × JW	White, cylindrical	PAU, Ludhiana
Hisar Sweti (G10)	Check	White, semi stumped	HAU, Hisar
RL-30 (G11)	PS × JW	White, stumped	PAU, Ludhiana
RL-9-1 (G12)	PS × JW	White, conical	PAU, Ludhiana
Jamuni 2 (G13)	PA × PS	Purple at shoulder, conical	PAU, Ludhiana
Punjab Pasand (G14)	Check	White, cylindrical	PAU, Ludhiana
RL-31 (G15)	PS × JW	White, conical	PAU, Ludhiana
RB-21 (G16)	PS × JW	White, conical	PAU, Ludhiana
Pusa Chetki (G17)	Check	White, rat tail	IARI, New Delhi

*Parents (P): Punjab Safed (PS); Japanese White (JW) and Punjab Ageti (PA)

Table 2 ANOVA (pooled) under different environments

Trait	Source of variation	df	Sum of squares	Mean squares	Variance (%)	Cumulative variance (%)
Root length	Trials	101	2100.12	20.79**		
	Genotype (G)	16	660.22	41.26**		
	Environment (E)	5	748.15	149.63**		
	G×E	80	691.75	8.65**		
	PCA I	20	423.03	21.15**	61.15%	61.15%
	PCA II	18	149.66	8.31**	21.64%	82.79%
	Error	204	365.27	1.79		
	LSD		5%		1%	
	Genotype Gi – Gj		1.52		2.00	
	Environment Ei- Ej		0.91		1.21	
Root weight	Trials	101	599707.50	5937.70**		
	Genotypes	16	49572.31	3098.27*		
	Environments	5	452750.16	90550.03**		
	G×E Interaction	80	97385.03	1217.31**		
	PCA I	20	42641.02	2132.05**	43.79%	43.79%
	PCA II	18	21128.96	1173.83**	21.70%	65.48%
	Error	204	66311.23	325.06		
	LSD		5%		1%	
	Genotype Gi – Gj		20.52		27.06	
	Environment Ei - Ej		12.30		16.31	
Plant weight	Trials	101	2027138.50	20070.68**		
	Genotypes	16	220989.95	13811.87**		
	Environments	5	1581789.13	316357.84**		
	G×E Interaction	80	224359.38	2804.49**		
	PCA I	20	117653.40	5882.67**	52.44%	52.44%
	PCA II	18	47131.57	2618.42**	21.01%	73.45%
	Error	204	182276.75	893.51		
	LSD		5%		1%	
	Genotype Gi – Gj		34.02		44.87	
	Environment Ei - Ej		20.40		27.05	
Marketable root yield	Trials	101	27310.05	270.40**		
	Genotypes	16	3654.15	228.38*		
	Environments	5	16216.32	3243.26**		
	G × E Interaction	80	7439.58	92.99**		
	PCA I	20	3864.61	193.23**	51.95%	51.95%
	PCA II	18	1959.44	108.86**	26.34%	78.28%
	Error	204	995.62	4.88		
	LSD		CD 5%		CD 1%	
	Genotype Gi – Gj		2.51		3.31	
	Environment Ei - Ej		1.50		1.99	

Contd.

Table 2 (Concluded)

Trait	Source of variation	df	Sum of squares	Mean squares	Variance (%)	Cumulative variance (%)
Dry matter content	Trials	101	96.00	0.95*		
	Genotypes	16	17.70	1.11*		
	Environments	5	34.26	6.85**		
	G×E Interaction	80	44.04	0.55**		
	PCA I	20	21.71	1.09**	49.30%	49.30%
	PCA II	18	12.58	0.70**	28.55%	77.85%
	Error	204	2.97	0.01		
	LSD		5%			1%
	Genotype Gi – Gj		0.13			0.18
	Environment Ei -Ej		0.08			0.10

Horticultural parameters

weight) to as high as 82.79% for root length. In AMMI 1 bi-plot, stability was inferred from the ordinate axis, with scores adjacent to the zero considered as the stable genotypes and environments. Nevertheless, the genotype with high mean performance and large value of IPCA scores were considered as having specific adaptability to a particular environment. AMMI 2 bi-plot illustrates a polygon connecting the genotypes that are furthest from the bi-plot point of origin having the highest vectors in their respective directions. The genotypes lying within the polygon are less sensitive to environmental interactions in each sector, thereby more stable (Agyeman *et al.* 2015).

Root length: Among newly developed genotypes, RL-30 (G11) and RB 21 (G16) produced longest roots (Fig 1a) and showed wider adaptability, whereas Pusa Chetki and Japanese White (both checks) produced shortest roots. Key to high root yield in radish lies in the identification of genotypes complimenting a specific sowing time (Dhaliwal

and Klair 2008, Alam *et al.* 2010). Personal interactions with radish growers' and consumers' of the region emphasized that radish ideotype should have a root length of 12-15 inches, diameter 1-1.5 inches and high root: plant ratio. Sarkar *et al.* (1978) recorded longest roots when photo period was less than 9 hours, whilst Kabir *et al.* (2013) produced longer roots in October-November as compared to December sown crop. The genotypes derived from 1st cross (tropical × temperate) were better adapted across all environments as compared to 2nd cross, probably due larger buffering capacity owing to their diverse pedigree.

In AMMI 2 biplot (Fig 1b), three check cultivars Punjab Pasand (G14), Japanese White (G8), Pusa Chetki (G17), and one newly tested genotype RL 2210 Long (G2), were extreme genotypes and produced a greatest contribution to the G × E interaction. Hisar Sweti (G10) and RL-9-1 (G12) were closest to the origin of both IPCAs and thus highly stable across all environments. Genotype RL-15 (G5) had

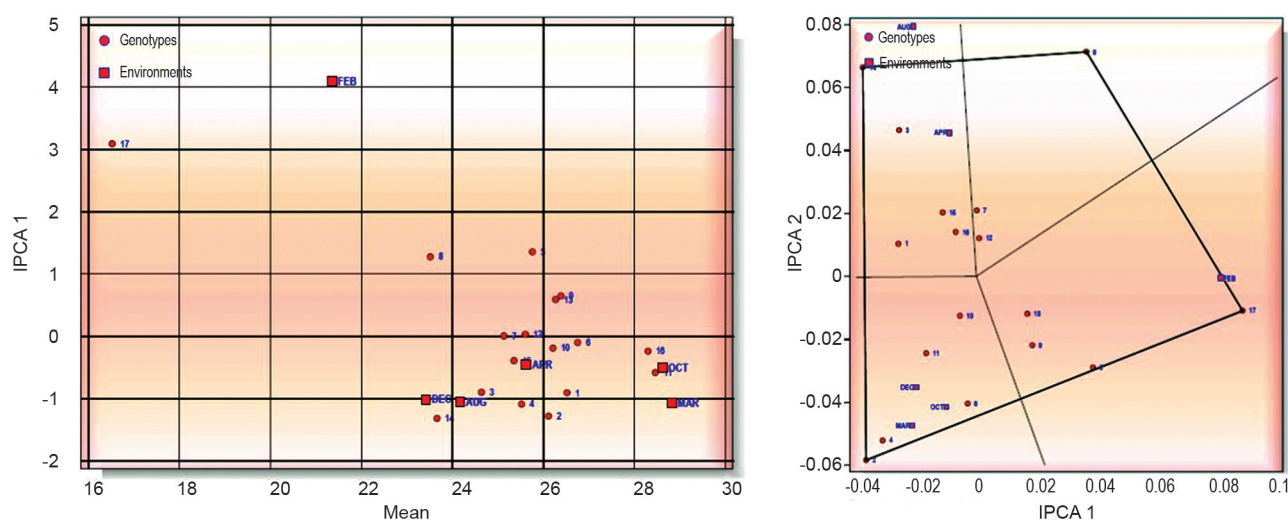


Fig 1 (a) AMMI 1 and (b) AMMI 2 bi-plot for root length.

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In AMMI 2 biplot, three check cultivars Punjab Pasand (G14), Japanese White (G8), Pusa Chetki (G17), and one newly tested genotype RL 2210 Long (G2), were extreme genotypes and produced a greatest contribution to the $G \times E$ interaction. Hisar Sweti (G10) and RL-9-1 (G12) were closest to the origin of both IPCAs and thus highly stable across all environments. Genotype RL-15 (G5) had the highest positive interaction with environment and also had higher root length than mean indicated its suitability for favourable environment because of higher genotypic sensitivity. RL 2210 Long (G2) had the highest negative interaction with environment and also higher root length than mean indicated its greater resistance to environmental changes. Findings of the present study were in consonance with those of Sharma *et al.* (2002).

Root weight: AMMI 1 biplot (Fig 2a), Selection-2 (G6), RB-21 (G16), RL-9-1 (G12), and RL-15 (G5) were extreme genotypes and produced a greatest contribution to the $G \times E$ interaction. Six mega environments were distinguished for root weight (Fig 2b). Environment August and March incorporated in one mega environment and December and October integrated in one mega environment, while environment February and April built-in singly in different mega environments. The genotype RB-21 (G16) showed better adaptation to environment December and October. RL-30 (G11), RL-2210 Long (G2), RL-9-1 (G12) and RB-20 (G3) performed better in high temperature months of August and March. In radish crop improvement programs, focus should be on desirable correlations to increase root mass, irrespective of the nature of correlations (Kaur *et al.* 2017, Mallikarjunarao *et al.* 2015). RL-30 (G11) gave highest plant weight, whereas it was lowest in Punjab Pasand. October sown crop had maximum plant weight and February minimum. From AMMI 1 biplot (Fig 3b), RL-2210 (G7), RL-31 (G15), RB-20 (G3), RL-15 (G5) and RL-9-1 (G12),

were most stable genotypes. August and October sowing times had positive interaction with genotypes, while April, March, February and December had adverse interaction. Selection-2 (G6), RB-21 (G16), RL-30 (G11), Palak Muli (G1), RL - 9- 1 (G12), RL 2210 Long (G2) and RL-15 (G5) were extreme genotypes (Fig 2b). Warde and Gonge (2004) observed better root: shoot ratio in milder temperatures as compared to high and low temperature extremes. For example, leaf number and size may contribute positively to overall plant weight but may reduce commercially more valuable root: plant ratio, which is undesirable from growers' point of view. Adverse environmental conditions lead to more foliage weight but accumulate less assimilates in roots (Sirtautas *et al.* 2011).

Marketable yield: RL-30 (G11) gave maximum marketable yield followed by LSR-2 (G4). Among the environments October sown crop gave highest yield whereas, it was lowest in February. Under high temperature conditions genotypes suffered due to pithiness, forking and internal blackening, whereas under low temperature conditions roots were undersized and twisted, both leading to lower marketable root yield. Genotypes recording higher marketable yield were corresponded by low amount of splitting, forking cracking etc., in different seasons indicating the genetic strength to perform under adverse effects of environment fluctuations (Rawat *et al.* 2014). The AMMI 1 bi-plot (Fig 3a), revealed RL-30 (G11) exhibited greater adaptability because of higher marketable yield as compared to other genotypes. LSR-2 (G4) gave best performance under unfavourable environments (largest -ve score on IPCA axis, more marketable yield). RB-21 (G16) and RL-15 (G5) responded well to favourable environments (highest score on IPCA axis; largest positive interaction with the environment. High percentage of GEI explained by IPCA1 and IPCA2 (65.48% to 82.79%) indicated that the AMMI bi-plot of the two axes amply verged on to the environment focussed data. The genotypes at the vertex of each polygon out performed in the particular environment falling within the

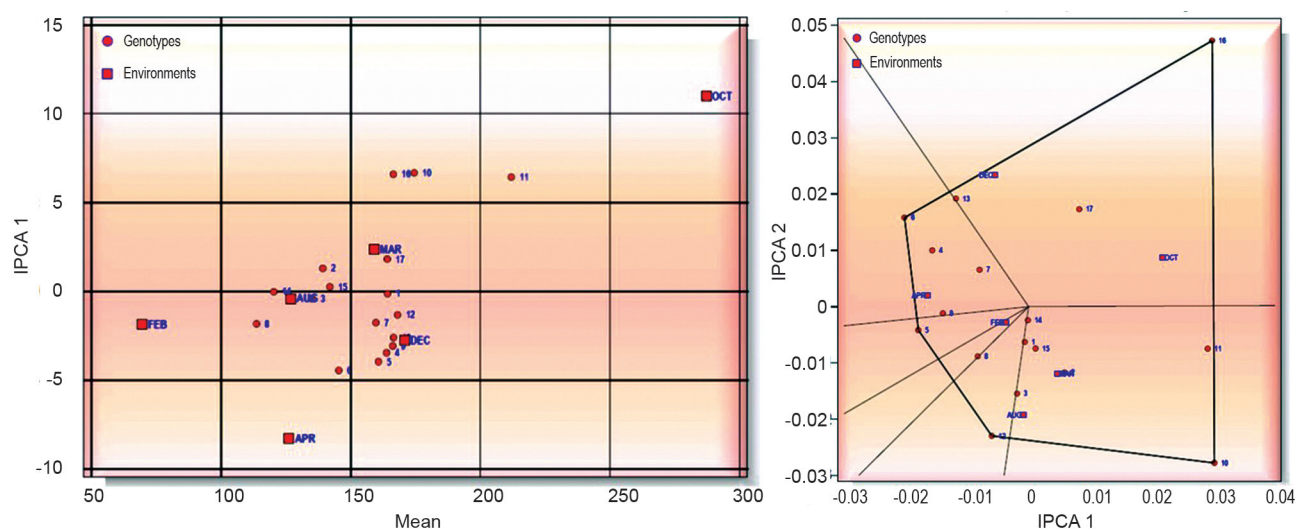


Fig 2 (a) AMMI 1 and (b) AMMI 2 bi-plot for root weight.

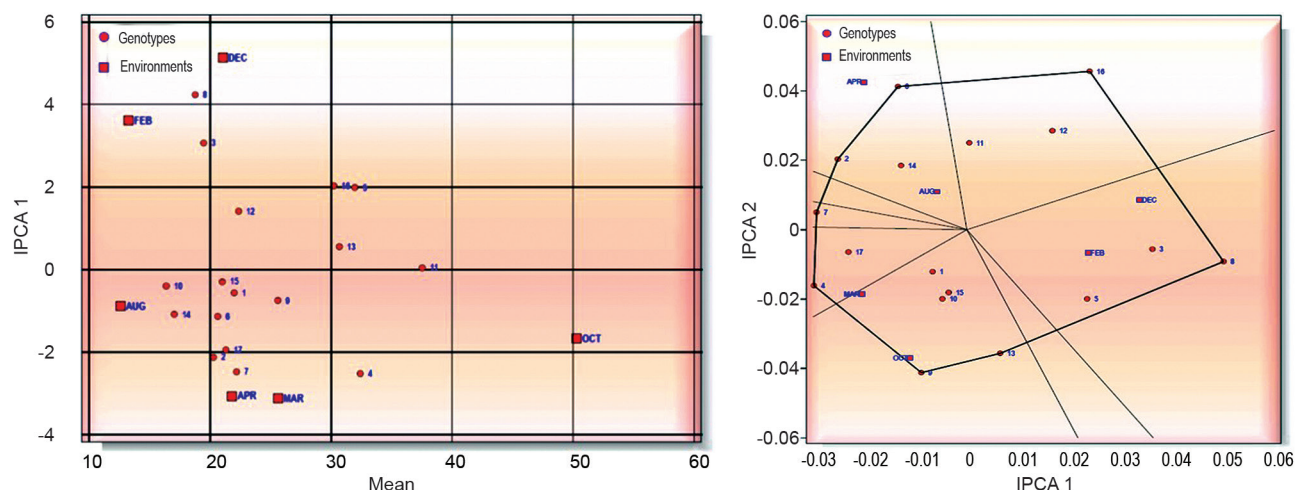


Fig 3 (a) AMMI 1 and (b) AMMI 2 bi-plot for marketable yield.

bi-plot sectors (Yan and Tinker 2006). G9, G8, G16, G6, G2, G13, G7 and G4 were extreme genotypes and produced a greatest contribution to the $G \times E$ interaction (Fig 3b).

Dry matter content: Maximum dry matter was obtained in RB-21 (G16) while, Pusa Chetki scored lowest on dry matter content. Among the environments maximum dry matter was observed in April and lowest in December sown crop. Dry matter content increased with rise in temperature and day length which can be credited to higher production and translocation of photosynthates to the roots (Sarkar *et al.* 1978). Schreiner *et al.* (2002) inferred that quality characters such as dry matter content and glucosinolates depended on the seasonal climatic conditions like temperature and irradiation. G16 and G4 had the highest dry matter. Genotype RB-21 was most adaptable to hostile environments (high –ve score on IPCA axis) while, LSR-2 (G4) had the largest positive score on the IPCA axis exposed its greater sensitivity to environmental changes. Pusa Chetki fared poorest in dry matter content across the environments. October and December were most unfavourable while August was most favourable environment for selecting genotypes for dry matter content. Genotypes Selection-2 (G6), LSR-2 (G4), Palak Muli (G1), RL-31 (G15) and RB -21 (G16) that were furthest from the bi plot point of origin. Genotype Palak Muli was best in environment February, whereas RB-21 was good performer in April and March genotype.

From the present investigation, RL-30 was identified as the best all round genotype across the environments followed by RB-21 except in April. Among the environments, October followed by March, found to be most discriminating and representative environments for testing the genotypes for wider adaptability. RL-2210, LSR-2 were standout performers in higher temperature regimes (August, March and April), whereas RL-30, RB-21, and RB-20 were best suited from October-December period.

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