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Stability Analysis of Different Chilli Hybrids (*Capsicum annuum* L.) for Their Yield and Yield Attributing Traits

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Authors' contributions

This work was carried out in collaboration between all authors. Author HR designed, conducted and executed the field experiment. Author TBP guided in recording the observations. Author DV conducted field level emasculation and collected floral biology of the crop. Author JK performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Chilli, an important vegetable crop in India. It is sensitive to environmental variations and climate change. An investigation was carried out to assess the stability of 25 test hybrids along with three commercial check varieties across different locations. Pooled analysis of variance showed the presence of significant genetic variability among the hybrids for all the characters studied. Variance due to hybrid × environment interaction was non-significant for red fruit yield plant^{-1}, number of fruits plant^{-1}, average fruit length (cm), fruit weight and fruit width except green fruit yield plant^{-1}. Considering all the stability parameters, CMS10A x Byadgikaddi for fruit weight and fruit width, CMS10A × Gouribidanur for green fruit yield plant^{-1}, CMS10A x LCA 206 for red fruit yield plant^{-1} and CMS8A × Byadgidabbi for number of fruits were exhibited below average stability and these

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were specifically adopted to unfavorable locations. The test Hybrids, CMS6A × Tiwari for average fruit weight, CMS9A × LCA 206 for the character fruit width were well adopted to all environments. CMS10A × Gouribidanur proved to be the best yielding hybrid, having higher yield level than the check and were also stable for most of the characters as evident from their non-significant s^2di values.

Keywords: Capsicum annuum L.; stability, genotype × environments; fruit yield and adaptability.

1. INTRODUCTION

Chilli (*Capsicum annuum* L.) is one of the most important solanaceous vegetable crops grown for variegated use of its fruits both in green and ripe stages. It is the second largest commodity after black pepper (*Piper nigrum* L.) in the international spice trade. Chilli has its unique place in Asian diet as a spice as well as vegetable. The area under Chilli in India is about 774870 Hectars with annual production of 1492140 Metric tones [1].

Capsaicinoids are important in the food and pharmaceutical industries. For this reason, a number of researchers are engaged in improving their production be it by manipulating chili plant cultivation conditions, chemical synthesis, enzymatic synthesis or alternative methods such as cell or tissue culture. To date, research has shown that capsaicinoids, and capsaicin in particular, have a wide variety of biological and physiological activities which provide them functions such as antioxidants, anticarcinogenics, promotion of energy metabolism and suppression of fat accumulation and anti-inflammatories. However, the potential applications of these molecules are limited by the irritation caused by their pungency; this has driven the search for and characterization of analogous molecules without inherent and undesirable effects [2].

Chilli, being sensitive to environmental variations exhibits large fluctuations in yield. Phenotypically stable genotypes (varieties/ hybrids) are of great importance, because environmental condition varies from season to season. Phenotypic expression of the genotype is variable when grown in different environments. It is observed that genotype × environment (G × E) interaction is widely present and contributes substantially to the non-realization of expected gain from selection [3].

Partitioning of growing environments to reduce genotype × environment (G × E) interaction is challenging especially in regions where climatic variation is large. Therefore, evaluation of cultivars by stability parameters across multi-environments is important to identify the consistent performing and high yielding cultivars [4]. Stable genotypes are particularly of great importance in Chilli growing areas of Karnataka, where the crop is grown in varied environmental conditions. It is difficult to expect a hybrid to be stable in its performance from one environment to another, because of uncertain magnitude and distribution of rainfall. Multi environmental testing of genotypes provides an opportunity to plant breeders to identify the adaptability of a genotype to a particular environment and also stability of the genotypes over different environments. Although a number of varieties have been recommended for cultivation, yet the information on stability is lacking across agro-climate conditions of south Karnataka. Hence, the present investigation was carried out to identify high yielding stable genotypes of chilli for cultivation at this region through stability analysis.

2. MATERIALS AND METHODS

Proven hybrid lines from Department of Genetics and plant breeding UAS, GKVK Bengaluru were procured for the study. Five lines were crossed with five testers in Line × Tester mating design to synthesize twenty-five F_1s (Table 1). The 25 crosses so synthesised and three commercial checks *viz*., KBCH-1, Arka Haritha and Arka Meghana were evaluated during *kharif* 2014 at three different environments viz., experimental plots of Balajigapade (Chikkaballapur), Department of Horticulture, 'K' block and Department of Genetics and Plant Breeding (GPB), University of Agricultural sciences (UAS). Gandhi Krishi Vignana Kendra (GKVK), Bengaluru. The experiments were laid out in Randomized Complete Block Design (RCBD) with two replications. Each genotype was grown in a single row of five-meter length consisting of 12 plants per row with a spacing of 0.40 m between plants within a row and 0.75 meter between rows. All the recommended package of practices was followed to grow the good crop.

Table 1. List of test hybrids and check hybrids used for experiment

Sl. No	Hybrids
1	CMS6A × Gouribidanur
2	CMS 6A × Tiwari
3	CMS 6A × Byadgi kaddi
4	CMS 6A × Byadgi dabbi
5	CMS 6A ×LCA 206
6	CMS 7A ×Gouribidanur
7	CMS 7A × Tiwari
8	CMS 7A × Byadgi kaddi
9	CMS 7A × Byadgi dabbi
10	CMS 7A ×LCA 206
11	CMS 8A × Gouribidanur
12	CMS 8A × Tiwari
13	CMS 8A × Byadgi kaddi
14	CMS 8A × Byadgi dabbi
15	CMS 8A ×LCA 206
16	CMS 9A × Gouribidanur
17	CMS 9A × Tiwari
18	CMS 9A × Byadgi kaddi
19	CMS 9A × Byadgi dabbi
20	CMS 9A ×LCA 206
21	CMS 10A × Gouribidanur
22	CMS 10A × Tiwari
23	CMS 10A × Byadgi kaddi
24	CMS 10A × Byadgi dabbi
25	CMS 10A ×LCA 206
26	KBCH-1
27	Arka Haritha
28	Arka Meghana

Five representative plants in each genotype (hybrids and check) were tagged at random from each replication for recording of observations on the following traits.

1. **Green fruit yield plant^{-1} (g):** Fresh green fruits over all pickings from five plants was weighed and expressed as grams plant^{-1}.
2. **Red fruit yield plant^{-1} (g):** Weight of dry fruits over all pickings from other five-labeled plants was recorded and expressed as grams plant^{-1}.
3. **Fruits plant^{-1}:** Total number of green fruits over all pickings were counted and expressed on per plant basis.
4. **Average fruit length (cm):** The length of ten fruits were measured from the tip to the base excluding the pedicel and expressed as a mean of ten fruits in centimeters.
5. **Average fruit weight (g):** The weight of 10 randomly chosen fruits were recorded in grams and expressed as the mean.
6. **Fruit width (cm):** The ten fruits chosen for estimating fruit length were measured at their maximum width and expressed as centimeters per fruit.

Genotypes were assessed for stability of performance over environments in accordance with method described by Eberhart and Russel [5].

3. RESULTS

Pooled analysis of variance (Tables 2) showed that the mean sum of squares (MSS) due to hybrids and environments for all the characters *viz.,* green fruit yield plant^{-1}, red fruit yield plant^{-1}, fruits plant^{-1}, average fruit length, average fruit weight, fruit width were highly significant. Further, it could be observed that variance due to hybrid × environment interaction was non-significant for all the characters except green fruit yield plant^{-1}. MSS due to hybrids × environment (linear) was non-significant for all the characters under study except green fruit yield plant^{-1}. However, variance due to pooled deviation was significant for all the productive traits across three environments.

3.1 Stability Parameters

The test hybrid, CMS10A × Byadgikaddi exhibited higher mean with unit regression co-efficient (b_i>1) and the deviation non-significantly different from zero (S^2_{di} = 0) for average fruit weight and fruit width (Table 3c). Similarly, the hybrid, CMS10A × Gouribidanur for green fruit yield plant^{-1}, CMS10A × LCA 206 for red fruit yield plant^{-1} and CMS8A x Byadgidabbi for number of fruits exhibited high mean with unit regression co-efficient (b_i>1) and the deviation non-significantly different from zero (S^2_{di} = 0) (Table 3a). The test Hybrids, CMS 6A × Tiwari for the character average fruit weight and CMS 9A × LCA 206 for the character fruit width were exhibited nearer to unit regression co-efficient and non-significant deviation from regression. Further, CMS10A × Gouribidanur has higher yield level than the check and unit regression coefficient for most of the characters under study.

Table 2. ANOVA for fruit yield and its component traits

Source of variance	df	Green fruit yield plant¯1 (g)	Red fruit yield plant¯1 (g)	Fruits plant^{-1}	Average fruit length (cm)	Average fruit weight (g)	Average fruit width (cm)
Rep within environment	3	8031.33	59.58	774.30	0.02	0.24	0.008
Hybrids	27	30430.24**	1611.30*	2463.41 **	10.35**	3.46**	0.06**
Environment + (Hybrids x Environment)	56	15450.02	1222.39	711.52	0.86	0.13	0.01**
Environments	2	43692.14*	9656.72**	3635.90 **	4.82**	1.05**	0.19**
Hybrids x Environment	54	14404.01	910.01	603.21	0.71	0.10	0.003
Environments (Lin.)	1	87384.30**	19313.44**	7271.78**	9.65**	2.11 **	0.39**
Hybrids x Environment (Lin.)	27	19646.98*	936.94	768.27	0.66	0.03	0.002
Pooled Deviation	28	8833.87**	851.53**	422.50**	0.74***	0.16**	0.003
Pooled Error	81	770.34	48.74	66.13	0.046	0.01	0.003

** Significant @P = 0.05 and ** Significant @P = 0.01*

Table 3a. Stability parameters for green fruit yield plant^{-1} and red fruit yield plant^{-1}

Hybrids	Green fruit yield plant¯1 (g)			Red fruit yield plant¯1 (g)		
	Mean	bi	S^2di	Mean	bi	S^2di
CMS6A × Gouribidanur	532.4	-3.27**	-1026.91	140.1	2.996	653.47**
CMS 6A × Tiwari	461.3	-4.83**	-1023.68	71.76	0.383	-37.62
CMS 6A × Byadgikaddi	390.2	-0.55**	-1029.58	70.96	1.726	184.14*
CMS 6A × Byadgidabbi	316.7	-0.001**	-1029.66	88.6	0.00**	-49.13
CMS 6A × LCA 206	295.7	0.07	-973.17	109.01	-0.637	6849.29**
CMS 7A × Gouribidanur	351.6	4.23**	-1025.08	102.47	0.153*	-47.3
CMS 7A × Tiwari	386.2	-0.57**	-1029.58	76.21	0.856	8.25
CMS 7A × Byadgikaddi	647.4	-3.67**	-1026.2	120.37	2.411	405.80**
CMS 7A × Byadgidabbi	357.2	3.24**	-1026.96	87.01	0.971	24.62
CMS 7A × LCA 206	380.6	1.44	3864.91*	82.48	1.122	1971.47**
CMS 8A × Gouribidanur	570.9	2.54	13556.61**	93.96	-0.306	1.3105*
CMS 8A × Tiwari	294.9	1.53	11451.01**	76.44	0.357	1297.70**
CMS 8A × Byadgikaddi	295.8	4.02**	-1025.51	123.14	2.533	453.05**
CMS 8A × Byadgidabbi	333.6	3.61**	-1026.32	91.7	2.129	305.72**
CMS 8A × LCA 206	414	2.91	3968.93*	82.48	1.122	1971.47**
CMS 9A × Gouribidanur	381	-0.49	72802.22**	84.17	1.412	288.05*

Hybrids	Green fruit yield plant¯1 (g)			Red fruit yield plant¯1 (g)		
	Mean	bi	S^2di	Mean	bi	S^2di
CMS 9A × Tiwari	263.7	0.73*	-1029.52	90.45	2.435	414.85**
CMS 9A × Byadgikaddi	472	0.04**	-1029.66	59.61	-0.532	-26.99
CMS 9A × Byadgidabbi	316.7	-0.001**	-1029.66	59.06	2.61	484.12**
CMS 9A × LCA 206	341.6	2.98	430.26	85.44	2.012	2231.76**
CMS 10A × Gouribidanur	458.6	0.78	-768.92	101.76	-0.829	4381.55**
CMS 10A × Tiwari	453.4	4.36	1918.15	123.14	0.883	146.78*
CMS 10A × Byadgikaddi	295.8	4.02**	-1025.51	123.14	2.533	453.05**
CMS 10A × Byadgidabbi	226.7	-1.36**	-1029.19	64.39	1.565	142.48
CMS 10A × LCA 206	490.1	4.59	13426.03**	113.41	1.078	-43.65
KBCH-1	487.1	1.39	-989.11	121.63	-0.361	78.44
ArkaHaritha	307.9	1.12	11006.17**	93.04	- 0.125**	-48.97
ArkaMeghana	287.9	-0.9	4237.83*	141.41	-0.501	-26.37
Mean	386.1			95.62		
SEm ±	66.5			20.63		

** Significant @ p= 0.05 **significant @ p= 0.01*

Table 3b. Stability parameters for number of fruits plant^{-1} and average fruit length (cm)

Hybrids	Number of fruits plant^{-1}			Average fruit length (cm)		
	Mean	bi	S^2di	Mean	bi	S^2di
CMS6A × Gouribidanur	92.12	-0.88*	-89.25	9.78	0.21	0.27**
CMS 6A × Tiwari	47.23	-0.13**	-91.37	10.17	0.21	0.27**
CMS 6A × Byadgikaddi	67.26	-0.39*	-90.98	11.69	0.21	0.27**
CMS 6A × Byadgidabbi	73.39	-0.64*	-90.26	14.19	0.21	0.27**
CMS 6A × LCA 206	52.68	0.39	108.24	9.76	0.00**	-0.04
CMS 7A × Gouribidanur	91.31	3.1	-64.5	9.27	0.21	0.27**
CMS 7A × Tiwari	92.67	3.12	-64.07	8.86	0.21	0.27**
CMS 7A × Byadgikaddi	110.5	-1.83*	-82.03	13.23	-0.97	6.38**
CMS 7A × Byadgidabbi	106.63	3.58	-55.402	13.51	0.21	0.27**
CMS 7A × LCA 206	96.33	2.72	525.09*	11.13	3.58	1.54***
CMS 8A × Gouribidanur	144.37	1.83	3406.79**	9.44	1.18	-0.04
CMS 8A × Tiwari	67.9	1.01	1008.80**	10.25	2.5	0.41**
CMS 8A × Byadgikaddi	64.68	1.63	-83.98	10.64	0.21	0.27**

Hybrids	Number of fruits plant^{-1}			Average fruit length (cm)		
	Mean	bi	S^2di	Mean	bi	S^2di
CMS 8A × Byadgidabbi	91.04	1.51	-84.97	12.39	0.21	0.27**
CMS 8A × LCA 206	96.33	2.72	525.09*	11.13	3.58	1.54**
CMS 9A × Gouribidanur	78.27	-0.78	2140.86**	10.47	4.13	2.39**
CMS 9A × Tiwari	63.07	0.02**	-91.42	8.62	0.21	0.27**
CMS 9A × Byadgikaddi	63.47	1.09	-88.08	11.75	0.21	0.27**
CMS 9A × Byadgidabbi	73.39	-0.64*	-90.26	14.19	0.21	0.27**
CMS 9A × LCA 206	82.35	3.13*	-89.65	10.33	1.25*	-0.04
CMS 10A × Gouribidanur	116.91	-1.3	1462.01**	10.14	3.08	0.93**
CMS 10A × Tiwari	149.27	3.17	822.37**	9.79	2.19	0.21*
CMS 10A × Byadgikaddi	64.68	1.63	-83.98	10.64	0.21	0.27**
CMS 10A × Byadgidabbi	71.97	-1.42*	-85.74	13.59	0.21	0.27**
CMS 10A × LCA 206	145.82	3.47	841.19**	11	3.3	1.19**
KBCH-1	115.96	0.38	-75.05	6.92	0.39	0.52**
ArkaHaritha	69.51	2.26	-80.91	8.97	0.84	0.36**
ArkaMeghana	42.63	-0.79*	-88.43	7.77	-0.12	0.26*
Mean	86.85			10.7		
SEm ±	14.53			0.6		

** significant @ p= 0.05 **significant @ p= 0.01*

Table 3c. Stability parameters for average fruit weight and fruit width

Hybrids	Average Fruit weight (g)			Fruit width (cm)		
	Mean	bi	S^2di	Mean	bi	S^2di
CMS6A X Gouribidanur	4.74	1.45	-0.01	1.26	1.03	-0.003
CMS 6A X Tiwari	5.05	0.99	-0.01	1.36	1.03	-0.003
CMS6A × Gouribidanur	5.57	1.33	-0.01	1.37	1.03	-0.003
CMS 6A × Tiwari	4.57	1.33	-0.01	1.08	1.03	-0.003
CMS 6A × Byadgikaddi	3.38	0.00**	-0.01	1.07	0.00**	-0.003
CMS 6A × Byadgidabbi	3.81	1.33	-0.01	1.07	1.03	-0.003
CMS 6A × LCA 206	2.57	0.47	-0.01	1.11	1.03	-0.003
CMS 7A × Gouribidanur	5.66	-0.44	-0.01	1.21	1.13	-0.003
CMS 7A × Tiwari	3.00	1.22	-0.01	0.98	1.03	-0.003
CMS 7A × Byadgikaddi	4.17	0.23	0.44**	1.07	0.88	-0.002

Hybrids	Average Fruit weight (g)			Fruit width (cm)		
	Mean	bi	S^2di	Mean	bi	S^2di
CMS 7A × Byadgidabbi	4.32	0.25	0.66**	1.18	-0.1	0.07**
CMS 7A × LCA 206	4.34	0.7	0.38**	1.14	0.78	-0.0007
CMS 8A × Gouribidanur	5.32	1.04	-0.01	1.22	1.03	-0.003
CMS 8A × Tiwari	4.18	1.27	-0.01	1.02	1.03	-0.003
CMS 8A × Byadgikaddi	4.17	0.23	0.44	1.06	0.88	-0.002
CMS 8A × Byadgidabbi	4.71	1.28	-0.01	1.22	1.56	0.01*
CMS 8A × LCA 206	4.34	1.45	-0.008	1.23	1.03	-0.003
CMS 9A × Gouribidanur	5.72	1.56	-0.007	1.29	1.03	-0.003
CMS 9A × Tiwari	4.57	1.33	-0.01	1.08	1.03	-0.003
CMS 9A × Byadgikaddi	3.68	1.11	0.032	1.11	1.01	-0.003
CMS 9A × Byadgidabbi	4.23	2.73	2.02**	0.95	1.04	-0.003
CMS 9A × LCA 206	3.02	1.66	0.20**	0.96	1.13	-0.002
CMS 10A × Gouribidanur	5.32	1.04	-0.01	1.22	1.03	-0.003
CMS 10A × Tiwari	2.82	1.27	-0.01	0.69	1.03	-0.003
CMS 10A × Byadgikaddi	3.44	1.09	0.03	0.93	0.93	-0.003
KBCH-1	4.27	1.32	-0.01	0.95	1.3	-0.003
ArkaHaritha	3.57	0.42	0.05	0.96	2.34	-0.003
ArkaMeghana	7.67	0.22	-0.01	1.23	0.59	-0.003
Mean	4.36			1.11		
SEm ±	0.28			0.04		

** significant @ p= 0.05 **significant @ p= 0.01*

Table 4. List of hybrid with good performance based on stability parameters for yield components

Stability parameter	High responsive hybrids
Green fruit yield plant^{-1}	CMS 10A × Gouribidanur
Red fruit yield plant^{-1}	CMS 10A× LCA206
Number of fruits plant^{-1}	CMS 7A × Gouribidanur, CMS 7A × Tiwari, CMS 7A × Byadgidabbi and CMS 8A × Byadgidabbi
Average fruit length (cm)	8A × Gouribidanur
Average fruit weight (g)	CMS 6A× Gouribidanur, CMS 6A× Tiwari, CMS 6A× Byadgikaddi, CMS 6A× Byadgidabbi, CMS 8A× Byadgikaddi, CMS 9A× Gouribidanur, CMS 9A× Byadgikaddi, CMS 9A× Byadgidabbi and CMS 10A× Byadgikaddi.
Fruit width (cm)	CMS 6A× Gourbidanur, CMS 6A × Tiwari, CMS 6A × Byadgikaddi, CMS 7A × Tiwari, CMS 7A × Byadgikaddi, CMS 8A × Byadgikaddi, CMS 9A × Byadgidabbi, CMS 9A × Tiwari, CMS 9A × Byadgikaddi,CMS 9A × LCA206 and CMS 10A × Byadgikaddi.

4. DISCUSSION

Pooled ANOVA reveals that the significant difference between the effect of genotype and environment was present in the current study. Significant environment mean square indicated that the differential effect of environment affected the performance of the genotypes. Significance of variance due to hybrids x environment (linear) was evident for green fruit yield plant^{-1} while it was non-significant for all other productive traits among three environments thus indicating the hybrids responded differentially to change in environments. Hence, other testing sites are needed or the environments in locations need to be controlled [6]. Further, variances due to pooled deviation was significant for all the productive traits across three environments indicated that the unpredictable partition formed the major part of G × E interaction that the genotypes tested differed considerably in their stability characters.

According to Eberhart and Russell [5] a genotype is considered stable in performance if it has high mean performance, unit regression coefficient, least deviation from regression. Cultivar with a regression value above one was considered unstable with higher sensitivity to environmental change. It is good for specific adaptation in high yielding environment. Regression coefficient below one indicates that the cultivar is relatively stable with greater resistance to environmental change.

Among was hybrids, CMS10A × Byadgikaddi specifically adapted to unfavorable environment for the productive traits viz., average fruit weight and fruit width. Similarly, CMS10A × Gouribidanur for green fruit yield plant^{-1}, CMS10A × LCA 206 for red fruit yield plant^{-1} and CMS8A × Byadgidabbi for number of fruits were having below average stability Hence, specifically adapted to unfavorable locations for the respective traits. The test Hybrids, CMS 6A × Tiwari (for average fruit weight) and CMS 9A × LCA 206 (for fruit width) were adapted to all environments for respective traits (Table 3c). But, CMS10A × Byadagidabbi was poorly adapted to all the environments for the productive traits viz., red fruit yield, average fruits plant^{-1}. The hybrid, CMS 10A × LCA 206 for green fruit yield, red fruit yield, average fruits plant^{-1} and average fruits length and CMS10A × Gouribidanur for green fruit yield, red fruit yield and average fruits plant^{-1} were specifically adopted to favorable and unfavorable environments respectively. CMS10A × Gouribidanur proved to be the best yielding genotype among 25 test hybrids and it was stable for most of the characters as evident from their non-significant s^2di values (Table 4) Chowdhury et al. [7], Senapati and Sarkar [8], Nehru et al. [9] and Tembhurne and Rao [10] also obtained similar results for investigating characters.

5. CONCLUSION

The stability analysis study revealed that, additive environmental variance was found to be considerable magnitude as indicated by the significance of variance due to environment at différent locations. Among the three locations studied the 'K' block, Department of Genetics and Plant Breeding (GPB) (E_3) was found to be the most suitable location for most of the characters especially to obtain yield and its component traits. The present investigation revealed that the test hybrid CMS10A × Gouribidanur was found promising and highly adaptable different across environments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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