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ELUCIDATIONS OF REVERSION, SEX EXPRESSION AND DETECTING PERFORMANCE OF HYBRID GCH 7 OVER ENVIRONMENTS IN CASTOR (*RICINUS COMMUNIS* L.)

A.M. Patel^{1*}, D.K. Patel², Y.N. Patel¹, J.R. Patel¹, T.A. Desai⁵, P.C. Patel⁴, H.N. Zala⁴ and K.N. Prajapati⁴, N.B. Patel⁴ and J.M. Patel³

¹Centre for Oilseeds Research, S. D. Agricultural University, Sardarkrushinagar -385 506, Gujarat, India

²Department of Seed technology, S. D. Agricultural University, Sardarkrushinagar -385 506, Gujarat, India

³Cotton Research Station, S. D. Agricultural University, Talod, Gujarat, India

⁴Department of Genetics and Plant breeding, C. P. Collage of Agriculture, S. D. Agricultural University, Sardarkrushinagar -385 506, Gujarat, India

⁵Polytechnic college, S. D. Agricultural University, Deesa, Gujarat, India

*Corresponding author: ankitp.patel224@sdau.edu.in

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ABSTRACT

The experiments was conducted during *Kharif* 2022 and *kharif* 2023 at the Centre for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar to study the identification of reversion, sex expression in the context of castor hybrid GCH-7 and performance across different environments for this hybrid was studied by evaluating four parents *i.e.*, SKP 84, SKP 84 (M), SKI 215 and SKI 215 (M) and their four hybrids *i.e.*, SKP 84 × SKI 215, SKP 84 × SKI 215 (M), SKP 84 (M) × SKI 215 and SKP 84 (M) × SKI 215 (M) over three environments. The result obtained from chi-square test for genetics on sex expression in castor revealed that different type of gene action *i.e.*, dominant epistasis type, recessive epistasis type and polymeric gene action were observed with non-significant chi-square test in four diverse cross among three different environment. The study of sex expression in F_1 's of four different crosses revealed more than 99 % of ISF type or true to type of plants in the cross I (SKP 84 × SKI 215). The higher number of monoecious plant was observed *i.e.*, 50% in cross II [SKP 84 × SKI 215 (M)] than in cross III [SKP 84 (M) × SKI 215] (37%) in all environments considered. While in cross IV [SKP 84 (M) × SKI 215 (M)], around 70% monoecious and 30% interspersed staminate flower type of plants were obtained in this cross over environments. The study of sex expression in F_1 's in response to environment revealed that the cross I (SKP 84 × SKI 215) produced low number of ISF on the primary, secondary and subsequent order of racemes than remaining crosses. Looking to the stability, the genotype SKP 84 × SKI 215 were found stable and widely adapted over all the environments for seed yield per plant.

Key words: Reversion, Sex expression, Monoecious, Interspersed, Epistasis and Stability

Introduction

Castor (*Ricinus communis* L.) serves as a crucial non-edible oilseed crop with significant industrial importance. It is part of the *Euphorbiaceae* family and represents a single genus and species with limited natural diversity but substantial morphological variability. Over the past few decades, castor oil and its derivatives have been utilized in the production of over 250 industrial goods, including lubricants, pharmaceuticals, cosmetics, paints,

and nylon threads. In the year 2024-25, India cultivated castor across 8.28 lakh hectares, resulting in a production of 15.88 lakh tonnes and a productivity rate of 1918 kg/ha (Anon, 2024a). Gujarat stands as the primary state for castor cultivation in India, contributing 75 percent of the total production. The state cultivated castor on 6.46 lakh hectares, yielding 14.75 lakh tonnes and a productivity rate of 2281 kg/ha (Anon, 2024b).

The majority of castor farmers in India and Gujarat

Appendix I: Meteorological data recorded during the year 2022-23 and 2023-24 at SKNagar, Gujarat:

Sr. No.	Month	Rainfall	Rainy days	Temperature (°C)		Relative humidity (%)	
				Min	Max	Morning	Evening
2022-23							
1	June-22	36.5	03	39.62	26.24	77.4	65.4
2	July-22	470.6	18	33.22	24.36	92.60	79.40
3	August22	739.0	14	31.86	23.89	89.32	82.48
4	September-22	100.0	04	34.07	23.24	78.46	68.30
5	October-22	0.0	0.0	35.38	17.78	64.80	51.00
6	November-22	0.0	0.0	33.04	12.46	58.56	49.20
7	December-22	0.0	0.0	29.77	9.09	62.51	47.84
8	January-23	28.5	2.0	25.80	7.52	65.84	42.80
9	February-23	0.0	0.0	33.53	12.60	65.80	43.00
10	March-23	23.5	4.0	35.90	17.52	72.31	59.00
2023-24							
1	June-23	291.00	08	36.18	25.46	88.82	70.82
2	July-23	414.10	14	34.10	26.26	93.90	84.06
3	August-23	3.0	01	32.43	24.53	91.00	76.50
4	September-23	194.0	05	34.15	24.63	84.43	66.80
5	October-23	0.0	0.0	35.44	19.88	73.60	59.12
6	November-23	51.0	01	32.45	15.10	76.85	69.23
7	December-23	0.0	0.0	28.23	11.90	74.10	64.35
8	January-24	0.0	0.0	27.18	9.70	68.56	44.90
9	February-24	31.0	1.0	29.88	13.00	74.28	44.25
10	March-24	35.00	17.03	35.00	17.03	70.23	38.10

utilize certified seeds for the well-liked hybrid GCH 7, which they obtain from GSSC, non-governmental organizations, agricultural universities, and other private companies. GCH 7's popularity stems from its ability to resist wilt and nematode complex, as well as its high seed yield, plentiful branching, and tolerance to both biotic and abiotic stresses. Although GCH 7 is widely recognized, farmers regularly express concerns about reversion and a higher male ratio in small portions of the primary raceme, with the majority of reversion occurring in secondary and subsequent racemes. The number of ISF varies significantly in the primary raceme and increases with each successive order of spikes up to quaternaries and pentanaries. To address reversion and a higher proportion of males in secondary and subsequent racemes, the current study involved the use of four parents along with their four F_1 hybrids as mentioned above in three diverse environments. The study was also important to identify the promising hybrid over environments for getting higher yield with the best environment for quality hybrid seed production in castor in order to reduce the rejection of seed lots.

Materials and Method

The experiments was conducted during *Kharif* 2022 and *Kharif* 2023 at the Centre for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat with aimed to investigate the

inheritance patterns of sex expression and the interaction between genotype $\times$ environment, as well as the stability parameters of different genotypes for various traits. The experimental materials included 8 genotypes, consisting of 4 parents (SKP 84, SKP 84 (M), SKI 215, and SKI 215 (M)) and their 4 hybrids (SKP 84 $\times$ SKI 215, SKP 84 $\times$ SKI 215 (M), SKP 84 (M) $\times$ SKI 215, and SKP 84 (M) $\times$ SKI 215 (M)), with each cross having six generations (P_1 , P_2 , F_1 , F_2 , B_1 , and B_2). The parents SKP-84 (SKI-1 $\times$ VP-1) and SKI 215 (SKI 8A $\times$ SA-2) were developed through hybridization followed by selection using pedigree breeding methods. While SKP 84 (M) and SKI 215 (M) were derived by selection from its original version *i.e.*, SKP 84 and SKI 215, respectively. In cross I (SKP 84 $\times$ SKI 215) both the parents are regular parents (true to types) as per the recommendations. While in cross IV [SKP 84 (M) $\times$ SKI 215 (M)] both the parents are monoecious type.

The genotypes were assessed using a compact family block design with three replications in three different environments: Early sown (E_1 - Second fortnight of July), Timely sown (E_2 - Second fortnight of August) and Late sown (E_3 - Second fortnight of September) by manipulating sowing dates. Each replication consisted of four cross blocks for each of the four crosses: one row for P_1 , P_2 , and F_1 and four rows for the F_2 generation.

Table 1: Soil characteristics of experimental plots at S.K. Nagar (Gujarat).

Sr. No.	Soil Parameter	S K Nagar
1.	Soil type	Sandy loam
2.	Soil depth	>300 cm (very deep)
3.	Available Soil N (kg/ha)	122 (Low)
4.	Available Soil P (kg/ha)	37.5 (Medium)
5.	Available Soil K (kg/ha)	226 (Medium)

Total 10 plants were accommodated in each row. The inter and intra row spacing was 120 cm and 60 cm, respectively. All the recommended agronomical practices and plant protection were measured.

The various thirteen quantitative characters were studied which include viz., number of monoecious plant, number of interspersed plant and number of pistillate plant for study of sex expression. While days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme (cm), number of node up to primary raceme, effective length of primary raceme (cm), number of capsule on primary raceme, number of effective branches per plant, seed yield per plant (g), 100-seed weight (g) and oil content (%) to study the stability analysis. Maximum and minimum temperatures were recorded (Appendix-1) and soil type and Nitrogen, Phosphorous and potassium status in the experimental plot (Table 1) was also estimated at each location to understand the role of temperature and nitrogen on pistillate expression.

Results and Discussion

Genetics of sex expression

Table 2: Genetic analysis of sex expression in segregating population of castor and test of goodness of fit to the expected ratio over environments for three different characters.

Name of crosses	Total Plants	No. of ISF Plants	Number of Monoecious plants	Number of pistillate Plants	Expected ratio	X ² value
Environment – I						
SKP 84 × SKI 215	120	99	12	9	12:03:01	6.063
SKP 84 × SKI 215 (M)	118	68	38	12	09:06:01	3.812
SKP 84 (M) × SKI 215	120	93	20	7	12:03:01	0.399
SKP 84 (M) × SKI 215 (M)	120	50	61	9	09:06:01	10.535
Environment – II						
SKP 84 × SKI 215	120	81.00	13.00	26.00	12:03:01	50.597
SKP 84 × SKI 215 (M)	120	64.00	30.00	26.00	09:03:04	3.196
SKP 84 (M) × SKI 215	120	72.00	20.00	28.00	09:03:04	0.726
SKP 84 (M) × SKI 215 (M)	120	42.00	53.00	25.00	09:06:01	51.859
Environment – III						
SKP 84 × SKI 215	120	93.00	10.00	17.00	12:03:01	19.074
SKP 84 × SKI 215 (M)	118	62.00	43.00	15.00	09:06:01	8.0191
SKP 84 (M) × SKI 215	120	100.00	11.00	9.00	12:03:01	7.248
SKP 84 (M) × SKI 215 (M)	120	45.00	50.00	25.00	09:06:01	48.855
ISF : Interspersed staminate flowers						

In the present study, a total of four crosses and 120 plants in each cross were evaluated three replications each of three environments to investigate the inheritance of sex expression. Cross I (SKP 84 × SKI 215) segregated at a ratio of 12:03:01 in all three environments examined. The segregation pattern of this cross indicates the presence of a dominant epistasis controlling sex expression (Table 2).

In the cross II [SKP 84 × SKI 215 (M)], the segregating population was segregated in both environment I (early sown) and environment III (late sown) at a ratio of 09:06:01. It was suggested that polymeric gene activity-controlled sex expression for this cross. In the environment II (timely sown), the F₂ population was segregated in the ratio 09:03:04, indicated that sex expression is under the control of recessive gene action (Table 2). The comparable result was also reported by Patel *et al.*, (2014), who reported a ratio of 09:06:01 for sex expression in castor.

The advanced populations of the cross III [SKP 84(M) × SKI 215] were divided into a ratio of 12:03:01 in environment I (early sowing) and in environment III (late sowing), indicating that sex expression for this cross was determined by dominant gene action. In the environment II, the F₂ population was split in a ratio of 09:03:04, indicating that recessive gene action determined the sex expression for this cross (Table 2).

In the cross IV, the F₂ generation was inherited in a ratio of 09:06:01 in all environments (Table 2). This revealed that a polymeric gene activity was responsible

Table 3: Study of sex expression in F_1 population.

Name of cross	Number of plants observed	Nature of sex expression	EI	EII	EIII
SKP 84 × SKI 215	89	Number of monoecious plants	0.0	0.0	0.0
		Percentage %	0.0	0.0	0.0
		Number of interspersed plants	10.0	9.7	9.7
		Percentage %	100.0	100.0	96.7
		Number of pistillate plants	0.0	0.0	0.3
		Percentage %	0.0	0.0	3.3
		Proportion of male on primary raceme	Low	Low	Low
		Proportion of male Secondary and onward raceme	Medium	Medium	Medium
SKP 84 × SKI 215 (M)	90	Number of monoecious plants	4.0	5.0	5.7
		Percentage %	40.0	50.0	56.7
		Number of interspersed plants	6.0	5.0	3.7
		Percentage %	60.0	50.0	36.7
		Number of pistillate plants	0.0	0.0	0.7
		Percentage %	0.0	0.0	6.7
		Proportion of male on primary raceme	Medium	Medium	Medium
		Proportion of male Secondary and onward raceme	High	High	Medium
SKP 84 (M) × SKI 215	86	Number of monoecious plants	4.3	3.7	2.3
		Percentage %	43.3	36.7	30.0
		Number of interspersed plants	5.7	6.3	6.3
		Percentage %	56.7	63.3	70.0
		Number of pistillate plants	0.0	0.0	0.0
		Percentage %	0.0	0.0	0.0
		Proportion of male on primary raceme	Medium	Medium	Medium
		Proportion of male Secondary and onward raceme	High	High	Medium
SKP 84 (M) × SKI 215 (M)	87	Number of monoecious plants	8.3	6.3	6.3
		Percentage %	83.3	70.5	63.3
		Number of interspersed plants	1.7	2.7	3.3
		Percentage %	16.7	29.5	33.3
		Number of pistillate plants	0.0	0.0	0.3
		Percentage %	0.0	0.0	3.3
		Proportion of male on primary raceme	High	High	Medium
		Proportion of male Secondary and onward raceme	High	High	High
Note: Low : < 10 number of males; Medium : 10-20 number of males and High : > 20 number of males. E ₁ : Environment – 1, E ₂ : Environment – 2, E ₃ : Environment-3.					

for controlling sex expression. The same results were presented by Patel *et al.*, (2014).

Study of sex expression in F_1 's

Cross I (SKP 84 × SKI 215) had the most plants (more than 99%) showing interspersed staminate flowers in all three environments. The cross between SKP 84 (M) × SKI 215 (M) (cross IV) produced greater part of monoecious plants in all three environments. Over environments, around 73 per cent monoecious and 27 per cent higher ISF plants were observed in this cross.

Cross II (SKP 84 × SKI 215 (M)) and cross III (SKP 84 (M) × SKI 215) had a one monoecious type of parent in the cross combination. These crosses resulted in different proportion of monoecious and ISF plants. The

inheritance of monoecious nature reflected in F_1 hybrid from the parents depends on the monoecious nature of parent that was acted as either male or female present in the cross combination.

Considering the performance of the cross II [SKP 84 × SKI 215 (M)] over the environments, the proportion of monoecious and ISF type was 50 per cent monoecious type of plants and 50 per cent ISF types. In early sown condition (E-I) for cross III (SKP 84 (M) × SKI 215), 43 per cent monoecious and 57 per cent interspersed type of plants were observed; 37 per cent monoecious and 63 per cent ISF plants were founds in E-II, while in E-III (late sown conditions) 30 and 70 per cent of monoecious and ISF type of plants were observed, respectively. Over

Table 4: Classification of genotypes based on stability parameters.

Characters	Stable and widely adapted to all environments		Stable and specifically adapted to the favorable environment		Stable and specifically adapted to the unfavorable environment	
Days to flowering of primary raceme	3 genotypes		0 genotype		0 genotype	
	Parents	-	Parents	-	Parents	-
	Hybrids	SKP 84 × SKI 215 SKP 84 (M) × SKI 215 SKP 84 (M) × SKI 215 (M)	Hybrids	-	Hybrids	-
Days to maturity of primary raceme	1 genotypes		2 genotype		0 genotype	
	Parents	-	Parents	SKI 215	Parents	-
	Hybrids	SKP 84 (M) × SKI 215	Hybrids	SKP 84 × SKI 215(M)	Hybrids	-
Plant height up to primary raceme (cm)	0 genotypes		0 genotype		0 genotype	
	Parents	-	Parents	-	Parents	-
	Hybrids	-	Hybrids	-	Hybrids	-
Number of node up to primary raceme	2 genotypes		0 genotype		3 genotype	
	Parents	-	Parents	-	Parents	SKI 215 (M)
	Hybrids	SKP 84 × SKI 215 SKP 84 (M) × SKI 215	Hybrids	-	Hybrids	SKP 84 × SKI 215(M) SKP 84 (M) × SKI 215(M)
Effective length of primary raceme (cm)	3 genotypes		0 genotype		1 genotype	
	Parents	SKI 215	Parents	-	Parents	-
	Hybrids	SKP 84 × SKI 215 SKP 84 × SKI 215(M)	Hybrids	-	Hybrids	SKP 84 (M) × SKI 215
Number of capsule on primary raceme	1 genotypes		0 genotype		1 genotype	
	Parents	-	Parents	-	Parents	-
	Hybrids	SKP 84 × SKI 215(M)	Hybrids	SKP 84 (M) × SKI 215	Hybrids	SKP 84 (M) × SKI 215
Number of effective branches per plant	1 genotypes		1 genotype		0 genotype	
	Parents	SKI 215 (M)	Parents	-	Parents	-
	Hybrids	-	Hybrids	SKP 84 × SKI 215(M)	Hybrids	-
Seed yield per plant (g)	3 genotypes		2 genotype		1 genotype	
	Parents	SKI 215	Parents	-	Parents	-
	Hybrids	SKP 84 × SKI 215 SKP 84 (M) × SKI 215	Hybrids	SKP 84 × SKI 215(M) SKP 84 (M) × SKI 215 (M)	Hybrids	-
100-Seed weight (g)	0 genotype		0 genotype		0 genotype	
	Parents	-	Parents	-	Parents	-
	Hybrids	-	Hybrids	-	Hybrids	-

Note: 1). $b_i = 1$, average stability and widely adapted to all environment; 2). $b_i > 1$ and significant; below average stability and increasing sensitivity to environmental changes and well adapted to favourable environment, 3). $b_i < 1$ and significant; above average stability with greater tolerance to environmental changes and genotype would have specific adaptability to poor environment.

the environment, 37 per cent monoecious and 63 per cent interspersed staminate flower types were recorded.

Looking to genotype × environment interaction study for the traits viz., number of interspersed staminate flower plant, number of monoecious plant and number of pistillate plant. There was non-significant variation was observed intended for the trait number of pistillate plant over the environments. Whereas, significant difference was noticed for remaining two traits viz., number of ISF plant (true to type GCH 7) and number of monoecious plants. The maximum interspersed type of plants were produced in the cross I (SKP 84 × SKI 215), followed by cross III [SKP 84 (M) × SKI 215], cross II [SKP 84 × SKI 215 (M)] and cross IV [SKP 84 (M) × SKI 215 (M)] (Supplementary Table 1).

Study of sex expression in F_1 's in response to environment

Crosses were sown on three different date in loamy sand soil with low N (122 kg/ha). Flowering initiation

was after 45 DAS.

Cross I (SKP 84 × SKI 215) had a low number of ISF in the primary raceme in all three environments, whereas an intermediate number of ISF was present in the secondary and subsequent racemes. The possible reason behind these might be due to male and female parents of this cross were true to type (Table 3) and the temperature at the time of flowering of the primary raceme was optimal, i.e., an average of 31-35°C during the months of August to October and less diurnal temperature. While slight higher male as compared the primary raceme were produced in secondary and onward racemes due to genetic nature of hybrid along with the higher difference between day and night temperatures during Oct.- Jan (Appendix-I).

In the cross II [SKP 84 × SKI 215 (M)] and the cross III [SKP 84 (M) × SKI 215], the ratio of male proportions in the primary and secondary & subsequent racemes was medium and high in environments I and II,

Supplementary Table 1: Treatment vs. Environment interaction over the environments for three different characters.

Sr. No.	Characters	Name of crosses	E ₁	E ₂	E ₃	Pooled
1	No. of Interspersed Plants	SKP 84 × SKI 215	10.0	9.7	9.7	9.8
		SKP 84 × SKI 215 (M)	6.0	5.0	3.7	4.9
		SKP 84 (M) × SKI 215	5.7	6.3	6.3	6.1
		SKP 84 (M) × SKI 215 (M)	1.7	2.7	3.3	2.6
		S.Em.±	0.51	0.70	0.51	0.33
		C.D. at 5%	1.76	2.42	1.76	0.99
		C.V.%	15.12	20.51	15.34	17.2
		E. CD @ 5%				NS
		E × T C.D. 5%				NS
2	No. of Monoecious plants	SKP 84 × SKI 215	0.0	0.0	0.0	0.0
		SKP 84 × SKI 215 (M)	4.0	5.0	5.7	4.9
		SKP 84 (M) × SKI 215	4.3	3.7	2.3	3.4
		SKP 84 (M) × SKI 215 (M)	8.3	6.3	6.3	7.0
		S.Em.±	0.51	0.62	0.32	0.29
		C.D. at 5%	1.76	2.13	1.10	0.85
		C.V.%	21.17	28.46	15.43	22.5
		E. CD @ 5%				NS
		E × T C.D. 5%				1.48
3	No. of pistillate Plants	SKP 84 × SKI 215	0.0	0.0	0.3	0.1
		SKP 84 × SKI 215 (M)	0.0	0.0	0.7	0.2
		SKP 84 (M) × SKI 215	0.0	0.0	0.3	0.1
		SKP 84 (M) × SKI 215 (M)	0.0	0.0	0.3	0.1
		S.Em.±	0.00	0.00	0.33	0.11
		C.D. at 5%	-	-	NS	NS
		C.V.%	-	-	138.56	240.0
		E. CD @ 5%				0.29
		E × T C.D. 5%				NS
E ₁ : Environment – 1, E ₂ : Environment – 2, E ₃ : Environment-3.; E.CD: Environmental critical difference. E × T C. D.: Environmental vs. Treatments critical difference.						

respectively. In the environment III, it was medium in the primary, secondary and subsequent racemes. The reason of medium male proportion in E-I and E-II in the primary raceme was due to genetic nature of parents and hybrid, optimal relative humidity and temperature during the month of August to October. The high male proportion in E-I and E-II in secondary and subsequent racemes was might be due to genetic nature of parents and hybrid and diurnal temperature during August to February (Appendix-I). The mean ISF proportion in primary, secondary and subsequent racemes in E-III was medium due to the genetic nature of parents & hybrid and decrease in temperature (Appendix-I).

The high proportion of ISF was evident in the primary, secondary and subsequent racemes in the cross IV [SKP 84 (M) × SKI 215 (M)] due to the fact that both parents in the cross combinations were monoecious. In contrast to environments-I and II, this ratio was intermediate in E-III in primary racemes due to temperature at < 33.0°C and moderately high relative humidity in the month of

November (Appendix-I).

The difference in number of ISFs in different pistillate lines might be due to different genetic nature of the plant, temperature and other environmental conditions *i.e.*, relative humidity and diurnal temperature. The result showed that the environmental influence on the occurrence of ISF in the primary, secondary and subsequent raceme was non-significant *i.e.*, the environmental influence on the occurrence of ISF in all racemes was lower. It might be hindrance of environmental effect in the crosses like SKP 84 × SKI 215 (M), SKP 84 (M) × SKI 215, and SKP 84 (M) × SKI 215 (M) due to the actuality that either one of the two or both parents in the cross combinations were monoecious. However, the cross SKP 84 × SKI 215 has less ISF on the primary and secondary racemes than SKP 84 × SKI 215 (M), SKP 84 (M) × SKI 215, and SKP 84 (M) × SKI 215 (M).

The parents with a low number of ISF have a lower chance of reflecting selfed progenies in the hybrids

Supplementary Table 2: Analysis of variance (mean square) for phenotypic stability for different characters in castor.

Source of variation	d.f.	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of node up to primary raceme	Effective length of primary raceme (cm)
Genotypes (G)	7	122.80**	207.24**	519.09**	19.48**	941.90**
Environments (E)	2	133.47**	965.25**	58.33	81.35**	771.88**
Genotypes $\times$ Environments (G $\times$ E)	14	4.71**	11.25**	41.56*	3.30**	32.34*
Environments + (G $\times$ E)	16	20.81**	130.50**	43.66*	13.05**	124.78**
Environments (Linear)	1	266.94**	1930.49**	116.66*	162.70**	1543.74**
G $\times$ E (Linear)	7	4.52**	15.88**	34.54	5.38**	32.22
Pooled Deviation	8	4.30**	5.79	42.52	1.06*	28.40
Pooled Error	42	1.31	2.77	20.25	0.40	15.22

Source of variation	d.f.	Number of capsule on primary raceme	Number of effective branches per plant	Seed yield per plant (g)	100-seed weight (g)	Oil Content (%)
Genotypes (G)	7	675.97**	31.44**	10832.98**	4.18**	1.32
Environments (E)	2	695.06**	21.50**	72338.21**	5.10**	0.23
Genotypes $\times$ Environments (G $\times$ E)	14	30.50**	1.36**	1180.94**	0.86*	0.82
Environments + (G $\times$ E)	16	113.57**	3.87**	10075.60**	1.39**	0.75
Environments (Linear)	1	1390.11**	42.99**	144676.40**	10.20**	0.45
G $\times$ E (Linear)	7	37.99**	0.63	1703.15**	1.17**	1.04
Pooled Deviation	8	20.14	1.82**	576.39	0.48	0.53
Pooled Error	42	10.81	0.29	364.64	0.37	0.73

themselves, which ultimately reflects the genetic purity of the hybrids. Thus, the hybrid SKP 84 $\times$ SKI 215 has higher genetic purity in all three environments than the other three crosses, viz., SKP 84 $\times$ SKI 215 (M), SKP 84 (M) $\times$ SKI 215 and SKP 84 (M) $\times$ SKI 215 (M).

Similar finding was supported by Zimmerman and Smith (1966), Ankineedu and Rao (1973), Patel *et al.*, (1986) and (1990), Lavanya (2002), Murthy (2003), Hegde *et al.*, (2003), Patel *et al.*, (2010) and Manjunatha *et al.*, (2023).

Genotype $\times$ Environment (G $\times$ E) interactions and stability analysis

Analysis of variance for phenotypic stability

Supplementary Table 3: Estimates of stability parameters of individual genotype for ten different characters.

Sr.	Genotypes	Days to flowering of primary raceme						Days to maturity of primary raceme					
		Pooled mean ($\bar{X}$)		b_i		S^2d_i		Pooled mean ($\bar{X}$)		b_i		S^2d_i	
1.	SKP 84	72.36	0.39	**	++	-0.61		145.04	0.55	**	++	-2.34	
2.	SKI 215	60.36	1.48	**		5.88	*	133.27	0.97	**		2.77	
3.	SKP 84 (M)	73.69	0.86	**		-1.07		145.45	0.70	**		12.19	*
4.	SKI 215 (M)	62.42	1.09			15.29	**	131.95	1.17	**	+	-1.26	
5.	SKP 84 $\times$ SKI 215	58.02	0.84	**		-0.44		125.71	1.19	**		8.74	*
6.	SKP 84 $\times$ SKI 215 (M)	58.64	0.70			4.35	*	125.29	1.19	**	+	-1.37	
7.	SKP 84 (M) $\times$ SKI 215	58.04	1.35	**		0.28		125.71	0.98	**		-2.72	
8.	SKP 84 (M) $\times$ SKI 215 (M)	59.98	1.29	**		0.20		128.80	1.26	**		8.11	*
Environmental mean		62.94						132.65					

Stability in performance of genotypes for economical characters is one of the desirable properties for selection or recommendation of new genotypes in plant breeding programme. The mean sum of square due to genotypes was found highly significant for all the characters except for oil content. Whereas, mean square due to genotypes $\times$ environments interactions were significant for all the characters except oil content, which revealed that genotypes interacted differently with array of environments for those characters.

The variance due to G $\times$ E (linear) was higher in magnitude as compared to G $\times$ E (non-linear) for all the traits under study except plant height up to primary raceme

Supplementary Table 3 Continue ...

Sr.	Genotypes	Plant height up to primary raceme (cm)						Number of node up to primary raceme					
		Pooled mean ($\bar{X}$)		b_i		S^2d_i		Pooled mean ($\bar{X}$)		b_i		S^2d_i	
1.	SKP 84	71.63	3.22			30.46		25.91	2.17	**	+	5.19	**
2.	SKI 215	90.96	-1.85			25.38		18.31	0.81	**		1.57	*
3.	SKP 84 (M)	64.42	0.59		++	29.91		22.80	1.26	**	++	-0.37	
4.	SKI 215 (M)	97.53	0.78		++	27.23		18.80	0.52	**	++	-0.39	
5.	SKP 84 × SKI 215	93.11	0.99	**		-18.61		19.49	0.77	**		-0.01	
6.	SKP 84 × SKI 215 (M)	97.20	2.18		++	66.83	*	19.71	0.84	**	++	-0.35	
7.	SKP 84 (M) × SKI 215	96.18	2.03			10.03		19.56	0.87	**		-0.16	
8.	SKP 84 (M) × SKI 215 (M)	98.69	0.066			6.86		19.69	0.77	**	++	-0.28	
Environmental mean		88.72						20.53					

Supplementary Table 3 Continue ...

Sr.	Genotypes	Effective length of primary raceme (cm)						Number of capsule on primary raceme					
		Pooled mean ($\bar{X}$)		b_i		S^2d_i		Pooled mean ($\bar{X}$)		b_i		S^2d_i	
1.	SKP 84	73.11	1.33	*		56.42	*	80.17	1.32	*		48.99	*
2.	SKI 215	54.09	1.05	**		-0.49		52.31	1.07	**		2.19	
3.	SKP 84 (M)	35.27	0.42	**	++	-10.80		32.96	0.36		+	0.86	
4.	SKI 215 (M)	28.24	0.32		+	4.76		30.20	0.49	**	++	-14.19	
5.	SKP 84 × SKI 215	65.07	1.33	**		7.43		71.62	1.21	*		54.88	*
6.	SKP 84 × SKI 215 (M)	54.78	1.23	**		0.89		60.98	0.79	*		12.31	
7.	SKP 84 (M) × SKI 215	55.09	0.72	**	+	-7.19		53.56	1.47	**	+	-5.83	
8.	SKP 84 (M) × SKI 215 (M)	41.80	1.61	**		23.59		41.73	1.29	**		6.17	
Environmental mean		50.93											

Supplementary Table 3 Continue ...

Sr.	Genotypes	Number of effective branches per plant						Seed yield per plant (g)					
		Pooled mean ($\bar{X}$)		b_i		S^2d_i		Pooled mean ($\bar{X}$)		b_i		S^2d_i	
1.	SKP 84	4.73	0.50			3.65	**	145.44	0.56	**	++	-128.39	
2.	SKI 215	12.73	1.04			1.69	**	270.20	0.99	**		48.43	
3.	SKP 84 (M)	5.67	0.62	**		-0.05		128.69	0.55	**	++	-351.31	
4.	SKI 215 (M)	13.20	0.91	**		0.10		244.87	0.91	**		1198.68	*
5.	SKP 84 × SKI 215	11.71	0.90			4.19	**	292.76	1.29	**		617.70	
6.	SKP 84 × SKI 215 (M)	11.00	1.48	**	++	-0.25		262.52	1.29	**	++	-363.77	
7.	SKP 84 (M) × SKI 215	12.02	1.36			3.05	**	261.26	1.19	**		921.91	
8.	SKP 84 (M) × SKI 215 (M)	11.36	1.20	**		-0.15	**	237.47	1.22	**	++	-249.23	
Environmental mean		10.30											

Supplementary Table 3 Continue ...

Sr.	Genotypes	100-seed weight (g)					
		Pooled mean ($\bar{X}$)		b_i		S^2d_i	
1.	SKP 84	29.90	0.03			0.65	
2.	SKI 215	30.26	1.62	*		0.25	
3.	SKP 84 (M)	28.69	1.93	**	++	-0.36	
4.	SKI 215 (M)	32.09	0.25			-0.05	*
5.	SKP 84 × SKI 215	30.50	1.02			0.18	
6.	SKP 84 × SKI 215 (M)	31.69	1.23			0.30	
7.	SKP 84 (M) × SKI 215	30.60	2.30	**	++	-0.37	
8.	SKP 84 (M) × SKI 215 (M)	32.09	-0.38		+	0.21	
Environmental mean		30.73					

and number of effective branches per plant. This indicated that major portion of interaction was predictable in nature. Only linear component of $G \times E$ interaction was significant for days to flowering of primary raceme, days to maturity of primary raceme, number of node up to primary raceme, number of capsule on primary raceme, seed yield per plant and 100-seed weight. This indicated that prediction of performance would be easy. (Supplementary Table 1).

Stability parameter

The character, which had significant $G \times E$ variances, stability parameters viz., deviation

from mean square (S^2d_i), regression coefficient (b_i) and mean (X_i) were estimated for each genotype separately and discussed here after.

For days to flowering three genotypes viz., SKP 84 $\times$ SKI 215, SKP 84 (M) $\times$ SKI 215, SKP 84 (M) $\times$ SKI 215 (M) had significant regression coefficient at $b_i = 0$, non-significant regression coefficient at unity ($b_i = 1$) and deviation from regression ($S^2d_i = 0$) and lower mean than the overall mean, which suggested that these genotypes were stable and widely adapted to all the environments for days to flowering of primary raceme (Table 4 and Supplementary Table. 2). While for days to maturity, two genotypes viz., SKI 215 and SKP 84 $\times$ SKI 215 (M) found promising (Table 4 and Supplementary table. 2). These results are in confirmation with Patel *et al.* (2010) and Patel *et al.*, (2011).

The cross SKP 84 $\times$ SKI 215 for plant height up to primary raceme and three genotypes viz., SKI 215 (M), SKP 84 $\times$ SKI 215 (M) and SKP 84 (M) $\times$ SKI 215 (M) showed significant regression coefficient at $b_i = 0$ and non-significant deviation from regression ($S^2d_i = 0$) (Table 4). These results were in agreement with the findings of Manivel and Hussain (1997), Chaudhari (2006) and Patel *et al.*, (2010). Three genotypes viz., SKI 215, SKP 84 $\times$ SKI 215 and SKP 84 $\times$ SKI 215 (M) had higher mean than the overall mean, significant regression coefficient at $b_i = 0$, non-significant regression coefficient at unity ($b_i = 1$) and non-significant deviation from regression ($S^2d_i = 0$), which suggested that these genotypes were stable and widely adapted to all the environments for effective length of primary raceme (Table 4 and Supplementary Table 2).

For number of capsules on primary raceme only two genotypes namely SKP 84 $\times$ SKI 215 (M) and SKP 84 (M) $\times$ SKI 215 had higher mean than the overall mean and stable across the environments (Table 4). While one genotype viz., SKI 215 (M) had non-significant deviation from regression ($S^2d_i = 0$), regression coefficient significant at $b_i = 0$ and non-significant at $b_i = 1$, hence, they were stable and well adapted to all the environments for number of effective raceme per plant (Table 4 and Supplementary Table 2)

On the basis of three stability parameters viz., mean (X), regression coefficient (b_i) and deviation from regression (S^2d_i) indicated that 03 genotypes SKI 215, SKP 84 $\times$ SKI 215 and SKP 84 (M) $\times$ SKI 215 were stable and widely adapted genotypes for seed yield per plant over all the environments (Table 4 and Supplementary Table 2). These genotypes also showed stable performance across the environments for the yield

attributing traits viz., days to flowering of primary raceme, days to maturity of primary raceme, number of node up to primary raceme, effective length of primary raceme and number of capsule on primary raceme.

Conclusions

With respect to monoecious or interspersed nature in F_1 generation, all the crosses showed different genetic ratio indicating involvement of epistatic gene effect in this trait. As epistatic type, the inheritance of sex expression would offer poor amenability to simple selection procedure. Based on the study of sex expression in F_1 's, more weight or value give to rough out the monoecious type of the male parent, i.e., SKI 215 (M), together with female plants that are monoecious, i.e., SKP 84 (M), which will certainly produce reversion or hybrids with higher male content in primary, secondary and further orders. It is clearly indicated that reversion or higher male ratio was more in hybrid due to monoecious nature of male parent i.e., SKI 215 (M). So, emphasis will give more to rough out monoecious type of male parents in hybrid seed production to get true to type of hybrid. The cross SKP 84 $\times$ SKI 215 produced less number of ISF on the primary, secondary and subsequent order of racemes than the crosses SKP 84 $\times$ SKI 215 (M), SKP 84 (M) $\times$ SKI 215 and SKP 84 (M) $\times$ SKI 215 (M). This clearly indicates that ISF production was depend not only on its genetic nature but also the maximum temperature and diurnal variation in temperature, relative humidity and monoeciousness of parents in the cross affected the male ratio in primary and secondary racemes. Looking to the stability parameters, this genotype i.e., SKP 84 $\times$ SKI 215 were found stable and widely adapted over all the environments for seed yield per plant. So, it could be concluded that parents viz., SKP 84, SKP 84 (M) and SKI 215 and were found promising and may be exploited in further breeding programmes.

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