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Identification of superior lines and cross combinations of King chilli (*Capsicum chinense*) for suitablity in north-eastern hill region

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ABSTRACT

The improvement of yield and quality traits in King chilli (*Capsicum chinense* Jacq.) is a major objective in breeding programmes, particularly due to the ever increasing demand of this chilli species because of high capsaicin content. However, the complex inheritance of these traits and limited information on suitable parental combinations pose challenges in developing superior hybrids. The present study estimated the combining ability effects for identifying the lines and cross combinations, superior in terms of yield, its contributing traits and quality parameters. The variances for general combining ability (GCA) and specific combining ability (SCA) were highly significant reflecting the role of additive and non-additive gene effects in the expression of traits studied. More prominent additive gene effects were also observed as indicated by relatively higher magnitude of variance for GCA for the yield, contributing and quality traits studied. The lines RCML11 and RCNL1 were observed to be the best general combiners for yield, while RCML6 for earliness; RCML2 and RCML4 for capsaicin content. Cross combinations, viz. RCML-9 × RCNL-1; RCML-11 × RCNL-1, RCML-6 × RCML-11 and RCML-3 × RCML-9 were identified as promising combinations with respect to yield and capsaicin content. The promising parents and cross combinations identified in the present study can be effectively utilised in hybrid breeding programmes to develop high-yielding and quality-enhanced King chilli hybrids with broader agronomic adaptability.

Keywords: Combining ability, GCA, King chilli, SCA

The north-eastern region of India comprising of the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura is located between 22–29.3ºN and 89.7–97.8ºE representing 8% of the total geographical area of the country. The agro-climatic conditions of the region are favourable for cultivation of wide range of horticultural crops including King chilli (*Capsicum chinense* Jacq.). This region is bestowed with variant strains of King chilli with wide variation (Devi *et al.* 2025). It is mainly cultivated in Nagaland, Assam, Arunachal Pradesh, Manipur and Meghalaya (Verma *et al.* 2018) and is one of the most pungent, known for its spiciness (Oney *et al.* 2021). The pungency in all chilli species is attributed by a secondary metabolite called capsaicin (Lu *et al.* 2020). Capsaicin is present in the placenta of fruit and possesses diverse pharmacological properties (Ghosh *et al.* 2024). Besides, it is rich in antioxidants and inhibit the progression of chronic diseases such as muscular degeneration, cardiovascular diseases and cancer (Husen *et al.* 2023, Komala *et al.* 2023).

King chilli has a huge potential both for fresh consumption in national market as well as high value low volume products such as capsaicin and oleoresin extraction for global market. During the peak season, this chilli costs about ₹500–800/kg which rises up to ₹1,300–1,500 in the off-season (Devi *et al.* 2025). Commercialisation of the crop has already started in the past few years which is a good source of income for local farmers but most of the earlier research in King chilli is mostly confined to its pharmacological importance. There is limited information on hybridisation and genetic improvement for yield and quality traits. Systematic efforts to identify promising lines and cross combinations for developing suitable hybrids with efforts to understand the genetic basis of combining ability for important traits will help the breeder for future successful breeding programmes. For a successful hybridisation programme, parents should be selected not only on the basis of their diversity but also on the basis of their combining ability (Pathania *et al.* 2024). Thus, the present study aimed to assess combining ability effects and to identify superior parental lines and cross combinations for yield and quality

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traits, particularly capsaicin content, for their potential use in King chilli breeding programmes.

MATERIALS AND METHODS

The present experiment was carried out during 2022–2024 at Horticulture Farm, ICAR-Research Complex for North Eastern Hill Region, Umiam (25°41'N, 91°54'E; at an elevation of 850 m amsl), Meghalaya. The location had subtropical climate with an average annual rainfall of 150–250 cm. The experimental material comprised of eight promising lines, viz. RCML-3, RCML-5, RCML-6, RCML-9, RCML-11, RCNL-1, RCNL-2 and RCNL-4 (Table 1). These lines were crossed in diallel fashion following Griffing (1956) Model 1, Method 2. All the cross combinations along with the parents were evaluated for combining ability study during year 1 (Y1) 2022–23 and year 2 (Y2) 2023–24 in a randomised complete block design (RCBD) with three replications. The crop was grown on 20 cm raised bed having 90 cm width. Each bed consisted of two rows of 1.5 m length accommodating 8 plants/genotype of each entry. The plants were spaced at 90 cm × 90 cm. Four randomly taken plants of each genotype were used for recording data on days to 50% flowering, days to first harvest, marketable yield/plant (g), marketable fruits/plant, average fruit weight (g), shelf life, ascorbic acid content, antioxidant activity (umg AAE/g) and capsaicin (%). The ascorbic acid contents and antioxidant activity were estimated as per standard method described by Ranganna (1979) and DPPH (2, 2-Diphenyl-1-picrylhydrazyl) free radical scavenging assay, respectively. The capsaicin was estimated using Shimadzu Double Beam Spectrophotometer as per Balasubramaniam *et al.* (1982). For the diallel analysis Method 2 (excluding reciprocal), Model 1 (fixed effect model) as per by Griffing (1956) was adopted. The data were subjected for combining ability analysis using SPSS software.

RESULTS AND DISCUSSION

The analysis of variances for combining ability in each individual years and pooled over environments (Table 2) showed that mean sum of squares due to general combining ability (GCA) for all the traits studied were significant across environments. Except for days to first harvest across environments and antioxidant activity in Y2, the mean sum of squares due to specific combining ability (SCA) for all the traits was also significant. The result indicated the existence of genetic variability for parents and their cross combinations. Earlier study by Sahid *et al.* (2020) also revealed significant variance between the GCA and SCA for yield component and capsaicin content in chilli pepper. The mean sum of squares due to GCA × environment interaction were significant for all the traits studied except days to 50% flowering, days to first harvest, shelflife and antioxidant activity, whereas mean square due to SCA × environment interaction were significant for all the traits studied except days to first harvest, average fruit weight, shelf life and antioxidant activity. Involvement of both additive and non-additive types of gene action for the expression of these traits is reflected by the highly significant variation due to GCA and SCA. Significant GCA × environment and SCA × environment interactions also indicated that the expression of these traits was influenced by environmental conditions. The presence of both additive and non-additive gene effects suggested that heterosis breeding along with selection in later generations would be effective strategies for their improvement. Sharma *et al.* (2022) also reported importance of additive and non-additive gene in the expression of those traits in capsicum. Istiqlal *et al.* (2018) also reported significant difference in GCA and SCA analysis of variance for average weight/plant, fruit diameter and fruit length in chilli.

Estimates of GCA effects: The efficiency of a line or cross combinations as a parent in breeding programme can be understood by knowing the nature and magnitude of combining ability effects. It is revealed from Table 3 that among parents, RCML-6 was found to be the best as it showed good GCA consistently across the environments for days to 50% flowering and marketable fruits/plant. Besides, RCML-6 was also a good combiner for other traits,

Table 1 Characteristics of parents used in crossing (Royal Horticulture chart)

S. no.	Parent	Colour			Fruit	
		Immature stage	Half mature stage	Fully ripe stage	Surface	Shape
1.	RCML-3	Strong yellow Green B 144	Strong yellow Green B 144	Moderate brown C 2000	Wrinkled	Triangular
2.	RCML-5	Moderate olive green A 137	Vivid reddish orange A 30	Vivid red B 45	wrinkled	Elongated
3.	RCML-6	Brilliant yellowish orange B 142	Vivid reddish orange A 43	Vivid red A 44	wrinkled	Triangular
4.	RCML-9	Strong green C N134	Vivid reddish orange C 44	Vivid red A 44	wrinkled	Triangular
5.	RCML-11	Light yellowish green A 134	Vivid reddish orange C 44	Vivid red A 44	wrinkled	Blocky
6.	RCNL-1	Moderate olive green A 137	Vivid reddish orange A 30	Vivid red A 44	wrinkled	Triangular
7.	RCNL-2	Brilliant yellowish orange B 142	Vivid reddish orange A 43	Vivid reddish orange B 44	wrinkled	Triangular
8.	RCNL-4	Moderate olive green A 137	Vivid reddish orange A 30	Vivid red B 45	wrinkled	Blocky

Table 2 Analysis of variances in King chilli for combining ability

Source of variation	→	GCA	SCA	Error	Environment	GCA × environment	SCA × environment	Pooled error
Traits	df→	7	28	70	1	7	28	140
Days to 50% flowering	Y1	35.821*	2.270*	0.614	-	-	-	-
	Y2	28.167*	3.872*	2.611	-	-	-	-
	Pooled	63.739*	3.117*	-	289.724*	1.250	3.214*	2.113
Days to first harvest	Y1	40.170*	8.520	6.546	-	-	-	-
	Y2	30.022*	5.436	4.180	-	-	-	-
	Pooled	72.157*	7.483	-	143.308*	7.045	6.573	6.218
Marketable yield/ plant (g)	Y1	0.128*	0.056*	0.006	-	-	-	-
	Y2	0.045*	0.026*	0.007	-	-	-	-
	Pooled	0.148*	0.067*	-	1.191*	0.025*	0.024*	0.006
Marketable fruits/ plant	Y1	135.467*	18.390*	1.524	-	-	-	-
	Y2	47.142*	8.102*	1.128	-	-	-	-
	Pooled	154.345*	13.812*	-	240.120*	28.285*	12.571*	1.832
Average Fruit weight (g)	Y1	224.012*	23.147*	2.630	-	-	-	-
	Y2	174.281*	20.628*	4.604	-	-	-	-
	Pooled	308.150*	40.116*	-	120.776*	10.254*	3.660	4.615
Shelf life	Y1	0.367*	0.108*					
	Y2	0.381*	0.102*	0.037	-	-	-	-
	Pooled	0.822*	0.284*	-	0.167*	0.026	0.026	0.044
Antioxidant activity (umg AAE/g)	Y1	0.275*	0.107*	0.027	-	-	-	-
	Y2	0.177*	0.068	0.054	-	-	-	-
	Pooled	0.483*	0.142*	-	0.105*	0.058	0.035	0.041
Ascorbic acid (mg/100 g)	Y1	2.818*	11.281*	0.656	-	-	-	-
	Y2	15.411*	10.102*	0.687	-	-	-	-
	Pooled	10.635*	12.460*	-	0.760	7.593*	7.843*	0.566
Capsaicin (%)	Y1	0.021v	0.006*	0.0002	-	-	-	-
	Y2	0.010*	0.006*	0.0003	-	-	-	-
	Pooled	0.026*	0.010*	-	0.056*	0.004*	0.003*	0.0004

*Significant at 5% level of significance; GCA, General combining ability; SCA, Specific combining ability; Y1, Year 2022–23; Y2, Year 2023–24; df, Degree of freedom.

viz. days to first harvest, marketable yield/plant, ascorbic acid and capsaicin (%) in pooled data over environments. RCML-11 was observed to be the second best parent with significant desirable GCA effects for marketable yield/plant, average fruit weight and shelf life across environments and ascorbic acid in Y2 and pooled data over environment. Another line RCNL-1 was also found to be promising as parent with good GCA for marketable yield/plant and average fruit weight across environments, besides it also showed significant desirable GCA effects for antioxidant activity in Y1 and pooled environment. For capsaicin content, RCNL-1 and RCNL-4 were promising with good GCA across environment. Best overall and trait specific parents are listed in Table 4. These promising lines could be utilised in future breeding programme for further genetic improvement in King chilli. It was also observed from the study that no single parent is a good combiner for all the traits studied. This showed that each parent has their unique advantage in utilisation for improvement of specific desired traits. High GCA effects of different parents for fruit yield and component traits in capsicum was reported by earlier researchers i.e. Singh and Chaudhary (2005), Chadchan (2008), Prasath and Ponnuswami (2008), Singh and Pan (2009), Yadahalli *et al.* (2017) for yield and component traits, Rushiraj *et al.* (2023) for ascorbic acid and capsaicin content and Syukur *et al.* (2024) for antioxidant activity.

Estimates of SCA effects: From the SCA effects (Table 5), it could be seen that a total of 10 cross combinations each in Y1 and Y2 and 11 cross combinations in pooled environment showed significant positive SCA effects for the most important economic trait i.e. marketable yield/plant. Amongst them, best five crosses were RCML-11 × RCNL-1, RCML-6 × RCML-11, RCML-9 × RCNL-1, RCML-9 × RCML-11and RCML-5 × RCNL-4 in pooled environment

Table 3 General combining ability (GCA) effects of parents for different traits in King chilli

Traits	lines→	RCML-3	RCML-5	RCML-6	RCML-9	RCML-11	RCNL-1	RCNL-2	RCNL-4	SE(gi) ±	CD (gi)
Days to 50% flowering	Y1	2.11*	-1.01*	-2.51*	1.07*	2.93*	-0.11	-1.65*	-0.89*	0.24	0.49
	Y2	2.01*	-1.43*	-1.42*	0.82	2.89*	-0.44	-1.22*	-1.18*	0.56	1.13
	Pooled	2.11*	-1.22*	-1.96*	0.93*	2.91*	-0.28	-1.42*	-1.02*	0.30	0.61
Days to first harvest	Y1	2.77*	-1.86*	-3.01*	0.07	3.51*	-0.07	-1.34	-0.14	0.80	1.62
	Y2	2.23*	-1.15	-0.82	1.34*	2.19*	-0.26	-2.46*	-1.16	0.66	1.33
	Pooled	2.71*	-1.51*	-1.91*	0.71	2.85*	-0.15	-1.89*	-0.65	0.52	1.05
Marketable yield/plant (g)	Y1	0.01	-0.11*	0.13*	-0.03	0.12*	0.11*	-0.11*	-0.12*	0.01	0.04
	Y2	-0.10*	-0.05*	0.02	0.01	0.11*	0.06*	-0.05*	-0.01	0.01	0.03
	Pooled	-0.03*	-0.08*	0.08*	-0.01	0.11*	0.10*	-0.08*	-0.06*	0.01	0.02
Marketable fruits/plant	Y1	-0.87*	-1.08*	8.85*	-2.00*	0.70	0.17	-3.12*	-2.58*	0.47	0.93
	Y2	-2.73*	-0.15	4.79*	-0.22	-0.01	-1.09*	-1.01*	0.55	0.32	0.64
	Pooled	-1.81*	-0.62*	6.83*	-1.11*	0.34	-0.44	-2.06*	-1.01*	0.28	0.56
Average fruit weight (g)	Y1	1.43*	-3.51*	-9.49*	1.15*	4.58*	5.89*	0.85	-1.05	0.56	1.13
	Y2	1.08	-2.21*	-7.41*	2.56*	4.76*	5.31*	-1.17	-2.84*	0.70	1.40
	Pooled	1.21*	-2.86*	-8.41*	1.85*	4.68*	5.60*	-0.13	-1.95*	0.44	0.90
Shelf life	Y1	0.17*	0.11	-0.16*	0.11	0.28*	0.02	-0.22*	-0.32*	0.06	0.13
	Y2	0.17*	0.17*	-0.26*	0.03	0.33*	-0.07	-0.14*	-0.23*	0.06	0.12
	Pooled	0.17*	0.14*	-0.21*	0.07	0.31*	-0.01	-0.17*	-0.28*	0.04	0.09
Antioxidant activity (umg AAE/g)	Y1	0.20*	0.11*	0.04	0.18*	-0.07	-0.37*	-0.09	-0.01	0.05	0.11
	Y2	0.21*	0.12	0.11	-0.02	0.07	-0.28*	-0.11	-0.10	0.07	0.14
	Pooled	0.21*	0.12*	0.07	0.07	0.00	-0.32*	-0.09*	-0.05	0.04	0.08
Ascorbic acid (mg/100 g)	Y1	1.01*	-0.94*	0.03	-0.06	0.04	0.20	-0.04	-0.23	0.25	0.50
	Y2	-0.35	-0.84*	1.28*	1.68*	1.45*	-0.54*	-1.47*	-1.20*	0.25	0.52
	Pooled	0.32	-0.90*	0.65*	0.79*	0.75*	-0.16	-0.75*	-0.72*	0.17	0.36
Capsaicin (%)	Y1	-0.04*	-0.05*	0.06*	-0.02*	-0.03*	0.03*	0.02*	0.03*	0.01	0.01
	Y2	-0.01*	-0.04*	0.01	-0.02*	-0.01*	0.01	0.03*	0.04*	0.01	0.01
	Pooled	-0.02*	-0.05*	0.03*	-0.02*	-0.02*	0.01*	0.02*	0.03*	0.003	0.01

*Significant at 5% level of significance; Y1, Year 2022–23; Y2, Year 2023–24.

and were common across environments. For marketable fruits/plant, the cross combination RCML-5 × RCNL-2 showed good SCA effects across environment and can be considered good combiner for this trait. For average fruit weight, the cross combinations, viz. RCML-3 × RCML-5, RCML-3 × RCML-6 and RCML-5 × RCML-6 exhibited significant positive SCA effects across environments. For days to 50% flowering, RCML-5 × RCNL-4 and RCML-9 × RCNL-2 showed significant negative SCA effects across environment indicating their good specific combining ability. It implies to the earliness, which is a favourable trait in our breeding programme. The cross combinations RCML-6 × RCNL-1, RCML-9 × RCML-11 and RCML-9 × RCNL-4 in Y1; RCML-3 × RCNL-2 in Y2 also showed significant negative SCA effects. The variable SCA effects with the change of seasons both in nature and magnitude observed might be attributed to the environmental effects and genetic background of lines. Further calculation of the SCA effects of the cross combinations for days to first harvest in each year and pooled environment were not carried out due to

Table 4 Overall best general combiners (across traits) and trait specific combiners

Best general combiners	Traits
Overall	
RCML-6	Earliness, marketable yield/plant and capsaicin content
RCML-11	Marketable yield/plant, average fruit weight and shelf life
RCNL-1	Marketable fruit yield and average fruit weight
Trait specific	
RCML-3	Antioxidant activity and shelf life
RCML-9	Ascorbic acid
RCNL-2, RCNL-6	Earliness
RCNL-1, RCNL-6 and RCNL-4	Capsaicin

Table 5 Specific combining ability (SCA) effects for yield and related traits in King chilli

Crosses	Days to 50% flowering			Marketable yield/plant (g)			Marketable fruits/plant			Average fruit weight (g)			Shelf life		
	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled
RCML-3 × RCML-5	0.70	-1.01	-0.15	0.02	0.12*	0.07	-1.84	-0.02	-0.89	6.57*	5.63*	6.18*	-0.15	-0.28	-0.22*
RCML-3 × RCML-6	-0.45	3.17	1.31	0.17*	0.01	0.14*	0.14	-3.49*	-1.63	6.87*	6.82*	6.84*	0.14	0.24	0.16
RCML-3 × RCML-9	-0.72	1.57	0.37	-0.12	0.10	-0.01	-2.14	1.17	-0.41	1.09	0.73	1.00	-0.02	0.19	0.12
RCML-3 × RCML-11	-1.25	1.83	0.23	0.08	0.00	0.04	0.25	-0.02	0.15	1.82	1.61	1.72	0.26	-0.01	0.15
RCML-3 × RCNL-1	0.13	1.53	0.78	-0.12*	0.01	-0.11*	-4.87*	0.14	-2.29*	0.74	2.13	1.43	0.10	-0.17	-0.06
RCML-3 × RCNL-2	1.35	-4.14*	-1.33	0.10	-0.11	-0.01	4.21*	-0.26	1.89*	-4.53*	-4.76*	-4.64*	-0.08	0.19	-0.01
RCML-3 × RCNL-4	-0.72	-2.18	-1.41	-0.02	-0.06	-0.04	1.34	0.47	1.02	-3.59*	-4.83*	-4.32*	0.23	0.22	0.23*
RCML-5 × RCML-6	0.43	1.09	0.65	0.17*	0.12*	0.15*	1.00	-0.12	0.32	6.10*	4.41*	5.21*	-0.15	-0.18	-0.13
RCML-5 × RCML-9	-1.15	2.01	0.38	-0.11	0.01	-0.04	-2.24	-1.21	-1.73*	1.02	1.39	1.17	0.42*	0.38*	0.41*
RCML-5 × RCML-11	-0.68	-1.81	-1.21	0.11	-0.08	0.01	2.73	-1.51	0.52	-1.36	-0.65	-1.08	0.10	-0.31*	-0.15
RCML-5 × RCNL-1	0.70	0.67	0.62	0.01	0.10	0.05	-0.58	0.42	-0.04	0.31	2.39	1.35	-0.12	-0.12	-0.11
RCML-5 × RCNL-2	-0.05	1.18	0.47	0.18*	0.14*	0.15*	3.00*	3.51*	3.21*	1.81	-0.65	0.47	-0.23	-0.15	-0.17
RCML-5 × RCNL-4	-1.82*	-2.38	-2.15*	0.12*	0.14*	0.18*	3.73*	1.35	2.55*	2.36	2.67	2.41	0.06	0.14	0.15
RCML-6 × RCML-9	-1.32	-1.45	-1.33	0.01	0.11	0.06	1.69	3.51*	2.57*	-2.35	-4.31*	-3.33*	0.64*	0.38*	0.51*
RCML-6 × RCML-11	1.80*	-2.85	-0.46	0.18*	0.11*	0.19*	2.62	4.19*	3.41*	0.49	1.53	1.09	-0.23	-0.15	-0.15
RCML-6 × RCNL-1	-2.12*	1.63	-0.17	0.00	-0.27*	-0.17*	2.81	-6.25*	-1.63	-7.05*	-6.49*	-6.74*	0.61*	0.36*	0.49*
RCML-6 × RCNL-2	-0.88	0.73	-0.01	-0.17*	0.02	-0.07	-3.53*	-0.11	-1.78*	-3.07	0.49	-1.39	-0.26	-0.31*	-0.29*
RCML-6 × RCNL-4	-0.65	0.78	0.07	-0.15*	-0.10*	-0.12*	-5.32*	-5.56*	-5.44*	-2.05	1.37	-0.23	0.01	0.01	0.02
RCML-9 × RCML-11	-1.78*	-1.45	-1.56	0.27*	0.17*	0.14*	2.54	1.25	1.89*	7.43*	3.29	5.56*	0.03	0.37*	0.16
RCML-9 × RCNL-1	1.60*	-1.41	0.03	0.34*	0.11*	0.22*	7.14*	0.62	3.88*	1.04	7.13*	4.06*	0.14	0.26	0.19
RCML-9 × RCNL-2	-3.82*	-4.31*	-4.11*	0.12*	0.08	0.15*	4.11*	0.79	2.39*	1.43	1.15	1.26	0.64*	0.53*	0.59*
RCML-9 × RCNL-4	-1.58*	2.11	0.20	0.15	-0.01	0.05	3.43*	-2.01*	0.66	-0.79	2.48	0.75	0.39	0.15	0.14
RCML-11 × RCNL-1	-0.58	-1.81	-1.15	0.24*	0.25*	0.28*	10.56*	1.86	6.21*	3.14	7.48*	5.29*	0.24	0.28	0.26*
RCML-11 × RCNL-2	-1.02	1.15	0.07	-0.15*	0.10	-0.03	-4.03*	1.56	-1.25	1.86	2.12	2.04	0.27	0.29	0.28*
RCML-11 × RCNL-4	-1.12	2.37	0.57	0.00	0.26*	0.12*	0.29	5.57*	3.06*	-2.02	-0.35	-1.15	-0.37*	-0.44*	-0.39*
RCNL-1 × RCNL-2	0.03	0.43	0.18	-0.01	0.14*	0.06	-2.76	3.39*	0.22	5.78*	-0.35	2.63	0.12	0.11	0.15
RCNL-1 × RCNL-4	-1.38	1.73	0.12	0.02	-0.07	-0.02	-2.47	-1.06	-1.77*	7.02*	-0.12	3.36*	0.11	0.03	0.11
RCNL-2 × RCNL-4	0.50	0.82	0.62	0.13*	0.01	0.12*	2.14	-1.09	0.39	6.32*	4.10	5.17*	-0.02	0.03	0.00
SE(Sij) ±	0.76	1.64	0.84	0.06	0.06	0.04	1.36	1.01	0.79	1.66	2.15	1.28	0.13	0.11	0.13
SE(Sij-Sik) ±	1.12	2.47	1.30	0.10	0.10	0.06	2.15	1.39	1.23	2.48	3.11	2.05	0.24	0.20	0.13
SE(Sij-Skl) ±	1.06	2.33	1.22	0.10	0.08	0.06	2.04	1.32	1.15	2.35	3.01	1.85	0.22	0.19	0.12
CD(Sij)	1.52	3.37	1.82	0.14	0.12	0.09	2.84	2.01	1.69	3.39	4.23	2.67	0.35	0.31	0.21
CD(Sij-Sik)	2.25	5.14	2.70	0.11	0.19	0.14	4.24	2.89	2.54	5.14	6.28	4.09	0.57	0.49	0.35
CD(Sij-Skl)	2.12	4.75	2.54	0.11	0.16	0.13	4.07	2.72	2.39	4.78	6.01	3.76	0.51	0.46	0.33

*Significant at 5% level of significance; Y1, Year 2022–23; Y2, Year 2023–24; SE, Standard error; CD, Critical difference.

Table 6 Specific combining ability (SCA) effects for antioxidant activity, ascorbic acid and capsaicin in King chilli

Crosses	Antioxidant activity (µmg AAE/g)			Ascorbic acid (mg/100 g)			Capsaicin (%)		
	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled
RCML-3 × RCML-5	-0.12	-	-0.23*	6.23*	3.51*	4.83*	0.02	0.01	0.01*
RCML-3 × RCML-6	0.22*	-	0.29*	-4.50*	0.64	-1.87*	0.01	-0.02	-0.01
RCML-3 × RCML-9	-0.11	-	-0.03	-0.44	-1.48	-1.01	0.07*	0.10*	0.08*
RCML-3 × RCML-11	0.32*	-	0.19	2.11*	-1.29	0.33	0.02	0.04	0.03*
RCML-3 × RCNL-1	-0.05	-	-0.06	5.25*	1.45	3.31*	-0.02	0.06*	0.01*
RCML-3 × RCNL-2	-0.36*	-	-0.33*	-2.85*	-4.68*	-3.73*	-0.04	0.06*	0.01
RCML-3 × RCNL-4	-0.11	-	0.00	-8.11*	2.65*	-2.66*	-0.06*	0.01	-0.02*
RCML-5 × RCML-6	-0.03	-	0.01	1.46	3.74*	2.56*	-0.03	0.03	0.00
RCML-5 × RCML-9	-0.12	-	-0.14	-4.53*	0.99	-1.74*	0.05*	0.10*	0.07*
RCML-5 × RCML-11	0.10	-	0.13	-0.76	1.02	0.07	0.05*	0.01	0.03*
RCML-5 × RCNL-1	0.17	-	0.21*	-4.52*	-4.21*	-4.32*	-0.02	-0.01	-0.02*
RCML-5 × RCNL-2	-0.13	-	-0.14	-1.49*	-5.97*	-3.68*	0.00	0.04	0.02*
RCML-5 × RCNL-4	0.15	-	-0.02	3.63*	1.54	2.54*	-0.06*	-0.02	-0.03*
RCML-6 × RCML-9	0.21	-	0.16	2.14*	-2.19*	-0.01	0.02	0.03	0.01*
RCML-6 × RCML-11	-0.15	-	-0.11	1.35	-0.20	0.53	0.06*	0.02	0.04*
RCML-6 × RCNL-1	-0.12	-	-0.17	0.05	3.98*	2.01*	0.04	-0.04	0.00
RCML-6 × RCNL-2	0.29*	-	0.36*	3.02*	1.49	2.17*	0.08*	0.05*	0.06*
RCML-6 × RCNL-4	0.14	-	0.12	0.83	-3.59*	-1.23*	0.05*	0.07*	0.06*
RCML-9 × RCML-11	0.00	-	-0.11	0.45	-6.07*	-2.67*	0.00	0.05*	0.02*
RCML-9 × RCNL-1	-0.31*	-	-0.06	2.11*	-0.37	0.79	-0.07*	-0.01	-0.04*
RCML-9 × RCNL-2	0.11	-	0.04	0.23	0.32	0.23	-0.08*	0.01	-0.03*
RCML-9 × RCNL-4	-0.15	-	-0.15	3.72*	3.68*	3.65*	0.07*	-0.02	0.02*
RCML-11 × RCNL-1	-0.14	-	-0.07	1.15	-2.93*	-0.68	0.00	0.01	0.01
RCML-11 × RCNL-2	0.11	-	0.02	1.43	5.81*	3.69*	-0.03	0.06*	0.02*
RCML-11 × RCNL-4	0.34*	-	0.28*	0.57	-1.37	-0.18	-0.06*	0.04	-0.01
RCNL-1 × RCNL-2	0.19	-	0.21*	3.89*	2.73*	3.18*	0.15*	0.05*	0.11*
RCNL-1 × RCNL-4	0.06	-	0.09	-0.11	-2.65*	-1.25*	0.12*	0.09*	0.11*
RCNL-2 × RCNL-4	0.49*	-	0.37*	2.49*	0.75	1.49*	0.11*	0.01	0.06*
SE(Sij) ±	0.15	-	0.12	0.69	0.81	0.48	0.02	0.02	0.01
SE(Sij-Sik) ±	0.17	-	0.13	1.15	1.20	0.75	0.03	0.03	0.02
SE(Sij-Skl) ±	0.16	-	0.11	1.10	1.13	0.69	0.03	0.03	0.02
CD(Sij)	0.26	-	0.19	1.48	1.61	1.11	0.05	0.05	0.02
CD(Sij-Sik)	0.43	-	0.34	2.44	2.39	1.58	0.08	0.08	0.03
CD(Sij-Skl)	0.39	-	0.30	2.15	2.25	1.48	0.07	0.07	0.03

*Significant at 5% level of significance; Y1, Year 2022–23; Y2, Year 2023–24; SE, Standard error; CD, Critical difference.

SCA effect of the cross combinations in Y2 for antioxidant activity was not calculated as the mean squares due to SCA was non-significant.

Table 7 Overall best cross combination (across traits) and trait specific combinations

Best cross combinations	Traits
Overall	
RCML-11 × RCNL-1	Marketable yield/plant, no. of fruits/plant, average fruit weight and shelf life
RCML-6 × RCML-11	Marketable yield/plant, no. of fruits/plant, shelf life
RCML-9 × RCNL-1	Marketable yield/plant, no. of fruits/plant, average fruit weight
Trait specific	
RCML-9 × RCNL-2	Earliness
RCNL-2 × RCNL-4	Antioxidant activity
RCML-3 × RCML-5	Ascorbic acid
RCML-3 × RCML-9	Capsaicin

non-significant mean sum of square due to SCA. With regards to shelf life, the cross combinations RCML-5 × RCML-9, RCML-6 × RCML-9, RCML-6 × RCNL-1 and RCML-9 × RCNL-2 showed significant positive SCA effects across environments.

For antioxidant activity (Table 6), specific combining ability effect of the cross combinations in Y2 was not calculated as the mean squares due to SCA was non-significant. In Y1, positive and significant SCA effects were observed for the cross combinations RCNL-2 × RCNL-4, RCML-11 × RCNL-4, RCML-3 × RCML-6, RCML-3 × RCML-11 and RCML-6 × RCNL-2. All of these cross combinations are average general combiners as their parents except RCML-3 which was a good general combiner. The cross combinations, viz. RCNL-2 × RCNL-4, RCML-6 × RCNL-2, RCML-3 × RCML-6, RCML-11 × RCNL-4, RCML-5 × RCNL-1 and RCNL-1 × RCNL-2 exhibited positive significant SCA effects in pooled environment, indicating their good specific combining ability. The higher values of these quality traits are associated with improved nutritional and functional quality. For ascorbic acid, in Y1 and pooled environment, 10 crosses and in Y2, 7 crosses showed positive and significant common across environments. Similarly in Y1 and Y2, 10 crosses and in pooled environment, 17 crosses showed significant positive SCA effects for capsaicin. The cross combinations, viz. RCML-3 × RCML-9, RCML-5 × RCML-9, RCML-6 × RCNL-1, RCML-6 × RCNL-4, RCNL-1 × RCNL-2 and RCNL-1 × RCNL-4 were common across environments. Top across traits and trait specific cross combinations is listed in Table 7. Earlier study also identified promising cross combination with significant SCA effects in capsicum species i.e. Grajales *et al.* (2009) for number of fruits/plant, Singh and Pan (2009) for fruit yield/plant and days to 50% flowering, Aiswarya *et al.* (2020) for ascorbic acid and capsaicin content, Varsha *et al.* (2021) for average fruit weight and days to first harvest and Syukur *et al.* (2024) for antioxidant activity. On the basis of SCA effects, it can be concluded that among 28 cross-combinations studied, no single cross-combination possessed consistently significant SCA effects for all the traits studied.

The results concluded that the lines RCML-6, RCML-11 and RCNL-1 performed best for yield and most of its related traits and could be exploited for developing high yielding variety or hybrids. Similarly for developing early variety or hybrids accessions, RCML-6 is most promising and could be exploited. For capsaicin content, the accession RCNL-1, RCNL-2 and RCNL-4 are promising. The cross combinations, viz. RCML-9 × RCNL-1, RCML-11 × RCNL-1, RCML-3 × RCML-9 and RCML-6 × RCML-11 were identified as best combinations for economic traits like yield and capsaicin content. All this identified potential accessions and cross combinations could be utilised for development of improved variety and hybrids through recurrent selection in future crop improvement programme of King chilli.

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