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PRINCIPAL COMPONENT ANALYSIS AND COMBINING ABILITY STUDIES IN BITTER GOURD (*MOMORDICA CHARANTIA* L.)

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ABSTRACT

Bitter gourd (*Momordica charantia* L.) which is popularly known as bitter cucumber, bitter melon or karela is one of the vegetables belonging to cucurbitaceae family. A potential source of iron and popular for its anti-diabetic property due to the presence of charantin. Despite the crop potential, economic and its medicinal use the present study was undertaken during Rabi season of 2022-23 at Kittur Rani Chennamma College of Horticulture, Arabhavi, Belagavi, Karnataka using nine lines and three testers to develop 27 F_1 hybrids in L × T (Line × Tester) pattern. Evaluation of hybrids along with their parents revealed that Jonpuri, Katahi Vaibhav and HUB-1 were found to be good general combiners for traits under study. The cross combinations HUB-1 × Co-1, HUB-1 × White Long and Katahi Vaibhav × White Long showed highest SCA effect which were supercilious for earliness, yield and quality parameters resulting as best hybrids. Based on its yield potential and favoured earliness characteristics, the gynoecious HUB-1 × Co-1 hybrid was chosen as the best hybrid out of 27 cross combinations, with a yield of 18.38 t/ha. The hybrids Jonpuri × White Long and HUB-1 × Co-1 expressed superior quality parameters like beta-carotene, ascorbic acid and iron content. The gynoecious based hybrid HUB-1 × Co-1 showed resistant reactions for virus and fruit fly infestation, which further can be used in resistant breeding programme. All the characters studied exhibited non-additive gene interaction. So, hybridization, recurrent selection and marker assisted selection can be used to improve these traits. Hence the best hybrids are recommended for commercial exploitation of heterosis.

***Keywords*:** Bitter gourd, general combining ability, specific combining ability and Principle component Analysis

Introduction

Cucurbitaceae family in the vegetable sovereignty, is the largest family with the most edible species. Bitter gourd (*Momordica charantia* L.), a popular cucurbit native to Tropical Asia, specifically Indo Burma. The genus *Momordica* includes species of annual and perennial climbers, of which *Momordica charantia* is widely cultivated. It is a diploid with 22 chromosomal groups. *Momordica* is a Latin term that meaning "to bite" and which has jagged edges and appears to have been bitten (Singh *et al*., 2018). Immature tuberculate fruits are the edible part in this crop which possess a unique bitter taste which is due to Momordicin and Charantin is a typical cucurbitacin triterpenoid which plays a major role in reducing the blood sugar. The fruits are high in iron (1.8 mg), calcium (20 mg), phosphorous (55 mg), vitamin A (210 IU) and vitamin C (88 mg/100 g) and are a low-cost protein, fibre and mineral source (Aykryod, 1963).

The absence of superior, high yielding varieties and hybrids and the prevalence of pests and diseases account for India's low bitter gourd production and productivity. Despite the crop's potential, economic significance and medicinal use, crop improvement programmes have not received the proper attention. However, due to its nutritional worth and therapeutic significance, bitter gourd farming has recently gained popularity. The improvement in the yield and quality can be possible with the heterosis breeding. The success of any hybridization programme chiefly depends on combining ability of parents used in crossing programme. Combining ability provides an important tool for selection of desirable parents and to get required information regarding the nature of gene action controlling the desirable trait and their genetic effects (Sprague and Tatum, 1942). Line × tester analysis (L × T), an improved version of top cross design, is usually used for determining combining ability (GCA and SCA), identifying parental lines based on hybrid performance and estimating various types of gene activities (El-Komsan *et al*., 2003). Considering this the present study was planned to estimate combining ability effects and gene action using L × T for yield and its attributes. With this analysis, breeders can choose which inbreds are to be combined to achieve better hybrid performance if they have a better grasp of the pattern of combining ability in this germplasm.

Material and Methods

(a) Experimental material, design and experimental site

The present experiment was conducted at Kittur Rani Channamma College of Horticulture, Arabhavi, Belagavi district, Karnataka during Rabi 2022-23. The genotypes used in the present study comprised of nine inbred lines namely Green Long, Jonpuri, White Sheetal, Dharog Local, Solan Hara, Jhalri Long, Katahi Vaibhav, Chaman and HUB-1(gynoecious line) and three testers namely White Long, Faizabadi and Co-1 which are of broad genetic base and all these genotypes were collected from various parts of Karnataka, Kerala, Tamil Nadu and Maharashtra which were choosen based on their *per se* performance for yield attributes. These genotypes were crossed in line × tester pattern to obtain 27 hybrids and the obtained F_1's, their parents were grown in randomized block design with three replications along with two commercial checks (SW-814 and NS-1024). During experimentation all the necessary cultural practices were followed and plant protection measures were taken.

(b) Data collection and statistical analysis

The data on various growth, earliness, flowering, yield and quality parameters were recorded from five randomly selected plants. The mean data was subjected to analysis in INDOSTAT 2.0 software to obtain the combining ability effects (GCA and SCA) were used to rate the relative weight of additive and non-additive gene actions (Verma and Srivastava, 2004). The heterosis was estimated from mean values and its significance was tested using t-test.

The graphical analysis was done using R-software (R 2.2) to obtain graphical view, having concentric rings with vectors of entries which provides information about interrelationships among parents in producing heterotic crosses.

Results and Discussion

Combining ability refers to a parent's capacity to pass on to their offspring the best features or qualities. Sprague and Tatum provided a general definition of the words general and specific combining ability (1942). They described a hybrid line's typical performance as having a general capacity for combining. The performance of two specific parents who participated in the cross combination is referred to as specific combining ability.

The main effect is GCA and the interaction effect causes SCA. According to Sprague and Tatum (1942), additive gene action or additive × additive gene interaction is the primary cause of gca effects. The non-additive gene effect is responsible for a specific combining capacity. That might be an interaction between dominance × dominance and additive × dominance. Specific combining ability cannot be fixed in nature, but general combining ability can. If the trait is controlled by nonadditive gene interaction, it can easily be passed on by hybridization to the following generation

Table.1 shows the general combining ability of the parental lines used in the study. It helps in the selection of suitable parents (good general combiners) for hybridization.

The main effect is GCA and the interaction effect causes SCA. According to Sprague and Tatum (1942), additive gene action or additive × additive gene interaction is the primary cause of gca effects. The non-additive gene effect is responsible for a specific combining ability. That might be an interaction between dominance × dominance and additive × dominance. Specific combining ability cannot be fixed in nature, but general combining ability can. If the trait is controlled by non-additive gene interaction, it can easily be passed on by hybridization to the following generation.

General combining ability (GCA) effects of parents

It is revealed that the lines HUB-1 (gynoecious line), Solan Hara, White Sheetal, Katahi Vaibhav and Jhalri Long and among testers Co-1 in general exhibited highly significant and negative general combining ability (GCA) effects for node at which first female flower appears, days to 50 per cent flowering, days to first fruit harvest and sex ratio which indicates early maturing which indicates that these earliness traits were characterized by both additive and non-additive gene actions (Ray *et al*., 2015; Bhatt *et al*., 2017; Jat *et al*., 2016). Based on their highly significant and positive GCA effect, the lines Katahi Vaibhav, HUB-1, Jonpuri, Green Long, White Sheetal and tester Faizabadi were found to be best combiners for fruit characteristics and yield parameters which proves that they contribute significantly to the hybrid development (Karaagac, 2021) (Table. 1). Among lines Katahi Vaibhav for Zn and Cu content, HUB-1 for Mn and total phenols content was found to be superior combiners and among testers White Long and Faizabadi were found to be highly significant and superior

Fig. 1 : Lines and Testers used in the experiment

Table 1 : General combining ability effects for growth, flowering and yield parameters in bitter gourd.

Sl. No.	Genotypes / Lines	Vine length	No. of primary branches	Node at first female flower	Days to 50% flowering	Days to first fruit harvest	Sex ratio	No. of fruits per vine	Fruit diameter	Fruit length	L: D ratio	Average fruit weight	Fruit yield per plant	Fruit yield /plot
1	Green long	11.96**	-0.03	1.10**	1.88**	2.39**	-0.15	-6.60**	-1.45**	27.01**	0.66**	14.06**	-0.65**	-2.68**
2	Jonpuri	-16.92**	-0.05	0.84**	-0.44	0.5	0.27	3.80**	2.82**	-3.57	-0.29	19.52**	0.61**	0.16
3	White Sheetal	1.51	-0.24**	0.69**	-0.77	0.06	0.73	2.92**	-0.27	16.39**	0.39**	-2.07	0.25**	-1.11**
4	Dharog Local	-14.92**	0.23**	1.72**	1	4.06**	1.65**	-1.23**	0.16	-1.01	0.13	-7.80**	-0.23**	-0.71*
5	Solan Hara	-15.81**	0.09	0.59*	-0.77	1.06	1.28**	-0.033	-6.32**	-7.83**	0.11	-17.05**	-0.28**	-3.57**
6	Jhalri Long	9.74**	0.19**	-3.21**	3.22**	2.72**	2.79**	-5.68**	-1.16**	7.08**	0.58**	-5.65**	-0.52**	-2.25**
7	Katahi Vaibhav	28.63**	0.27**	-0.005	-0.44	-5.27**	0.93	8.71**	1.58*	-9.05**	-0.05	3.52*	0.80**	4.41**
8	Chaman	2.96	-0.30**	0.28	1.33	2.50**	1.52**	-8.72**	0.84	-8.62**	-0.46*	1.84	-0.91**	-4.37**
9	HUB-1	-7.14*	-0.16*	-2.04**	-5.00**	-8.04**	-9.03**	7.13**	3.80**	-20.39**	-1.07**	-6.36**	0.92	10.15**
	C.D @ 1%	8.66	0.19	0.48	1.82	2.01	1.04	0.39	0.45	2.23	0.20	3.58	0.04	0.79
	C.D @ 5%	6.5	0.14	0.64	1.36	1.51	0.78	0.29	0.92	4.48	0.40	2.68	0.09	0.59
	SEm ±	3.24	0.07	0.24	0.68	0.75	0.38	0.14	1.22	5.98	0.54	1.33	0.12	0.29
	Testers													
1	White Long	8.74**	0	-0.85**	0.593	0.35	0.69**	-0.25**	-0.50**	4.21**	0.21	-1.24	-0.03	0.14
2	Faizabadi	-6.40**	-0.07	0.12	0.481	0.17	0.11	1.13**	-0.32	5.99**	0.11	5.57**	0.13**	0.44*
3	Co-1	-2.33*	0.07	0.72**	-1.074**	-0.53**	-0.81**	-0.88**	0.82**	-10.21**	-0.32**	-4.32**	-0.09**	-0.59**
	C.D @ 1%	5	0.11	0.28	1.05	1.16	0.6	0.08	0.26	1.29	0.11	2.06	0.02	0.45
	C.D @ 5%	3.75	0.08	0.37	0.78	0.87	0.45	0.17	0.53	2.59	0.23	1.55	0.05	0.34
	SEm ±	1.87	0.04	0.14	0.39	0.43	0.22	0.22	0.70	3.45	0.31	0.77	0.07	0.17

Sl. No.	Genotypes / Lines	Fruit yield /ha	No. of seeds per fruit	β-carotene	Ascorbic acid	Pulp: skin ratio	Iron (Fe)	Copper (Cu)	Zinc (Zn)	Mang-anese (Mn)	Total phenols	Chloro-phyll A	Chloro-phyll B	Total chloro-phyll
1	Green long	-2.19**	-2.70**	-0.005**	-12.67**	0.25**	77.98**	0.25	6.42**	-2.23**	-17.39*	0.70**	0.75**	1.46*
2	Jonpuri	1.61**	-1.18**	-0.001	-3.82	0.14**	37.50**	-0.31	1.25**	-0.28	-4.95	0.62**	0.84**	1.44**
3	White Sheetal	-0.09	-1.60**	-0.002*	-5.79	-0.75**	-20.51**	-1.32**	-6.07**	-5.14**	-3.8	-0.27**	-0.48**	-0.64**
4	Dharog Local	0.43	-1.51**	-0.001	-20.53**	0.06**	-11.95**	0.64*	-2.24**	1.89**	4.23	-0.47**	-0.38**	-0.86**
5	Solan Hara	-3.37**	1.55**	-0.007**	0.6	0.50*	-19.38**	1.13**	-2.70**	-0.62	-17.87*	-0.63**	-0.48**	-1.14**
6	Jhalri Long	-1.61**	1.22**	0.016	30.09**	-0.04*	-22.56**	-0.5	-7.23**	-1.43**	-6.97	-0.21*	-0.07	-0.30**
7	Katahi Vaibhav	7.28**	1.74**	0.002	4.04	-0.74**	-18.43**	0.60**	8.16**	2.95**	16.85*	-0.24**	-0.33**	-0.58**
8	Chaman	-4.44**	1.74**	-0.010**	-6.28*	-0.07**	-17.39**	0.15	1.64**	1.03**	-7.55	0.53**	0.18*	0.71**
9	HUB-1	2.37**	0.74*	0.016**	14.36**	0.65**	-5.25*	-0.65*	0.77	3.84**	37.46**	-0.03	-0.02	-0.07
	C.D @ 1%	1.07	0.89	0.0009	8.32	0.016	4.93	0.28	0.43	0.32	19.07	0.17	0.23	0.07
	C.D @ 5%	0.80	0.67	0.001	6.25	0.032	3.7	0.56	0.86	0.66	14.31	0.13	0.17	0.14
	SEm ±	0.40	0.33	0.002	3.11	0.043	1.84	0.75	1.15	0.88	7.13	0.06	0.08	0.19
	Testers													
1	White Long	0.17	0.23	-0.001	0.92	-0.04**	25.41**	0.35*	2.48**	-0.21	-5.25	-0.16**	-0.08	-0.24**
2	Faizabadi	0.91**	0.10	0.003**	-7.92**	0.35**	1.19	0.86**	1.84**	1.03**	5.42	0.12*	0.06	0.19**
3	Co-1	-1.08**	-0.33	-0.002**	6.99**	-0.30**	-26.60**	-1.21**	-4.32**	-0.82**	-0.16	0.03	0.02	0.05
	C.D @ 1%	0.62	0.51	0.005	4.8	0.009	2.84	0.16	0.24	0.19	11.01	0.1	0.13	0.04
	C.D @ 5%	0.46	0.38	0.001	3.6	0.018	2.13	0.32	0.49	0.38	8.26	0.07	0.1	0.08
	SEm ±	0.23	0.19	0.001	1.79	0.024	1.06	0.43	0.66	0.5	4.11	0.03	0.05	0.11

Note: * and ** indicate significance of values at p=0.05 and p=0.01, respectivel

Table 2 : Specific combining ability effects for growth, flowering and yield parameters in bitter gourd

Sl. No.	Genotypes	VL	NPB	NFF	D50%	DFFH	SR	NFV	FD	FL	L: D ratio	AFW	FY/P	FY /Plot
1	Green Long × White Long	-25.18**	0.03	0.44	-2.81*	-2.91*	-1.89*	-1.24**	-1.36	7.23	0.3	2.69	-0.26**	-1.63**
2	Green Long × Faizabadi	-0.7	0.17	-1.76**	0.96	2.72	1.05	-0.85**	3.44**	-1.55	-0.53	19.96**	0.08	2.15**
3	Green Long × Co-1	25.88**	-0.2	1.32**	1.85	0.64	0.83	2.10**	-2.07*	-5.67	0.22	-22.66**	0.18*	-0.52
4	Jonpuri × White Long	-7.29	0.19	0.5	5.85**	6.30**	-0.46	-6.15**	-12.17**	-14.18**	0.67	-42.08**	-0.56**	-0.37
5	Jonpuri × Faizabadi	-23.48**	-0.37**	2.36**	-2.03	-3.17*	2.38**	0.66*	6.34**	1.03	-0.44	14.87**	-0.05	-4.41**
6	Jonpuri × Co-1	30.77**	0.18	-2.87**	-3.81**	-3.13*	-1.92**	5.49**	5.82**	13.14**	-0.22	27.21**	0.61**	4.78**
7	White Sheetal × White Long	1.92	0.01	-0.14	-4.14**	-6.58**	-0.25	-2.76**	-2.36**	-7.84*	0.03	-8.85**	-0.28**	-1.75**
8	White Sheetal × Faizabadi	-18.92**	-0.15	2.03**	-0.37	0.6	-0.07	6.82**	2.43**	-1.43	-0.23	16.28**	0.51**	3.76**
9	White Sheetal × Co-1	17.00**	0.13	-1.88**	4.51**	5.97**	0.33	-4.06**	-0.06	9.27*	0.19	-7.43**	-0.22**	-2.01**
10	Dharog Local× White Long	25.03**	0.001	-1.16**	2.07	3.08*	-2.05**	10.16**	9.68**	0.26	-1.06**	30.04**	1.02**	3.62**

11	Dharog Local × Faizabadi	-13.14*	-0.26*	-0.17	-2.81*	-1.06	1.28	-2.59**	-4.46**	2.48	0.72*	-9.30**	-0.20*	1.06*
12	Dharog Local × Co-1	-11.88*	0.26*	1.34**	0.74	-2.02	0.77	-7.56**	-5.22**	-2.74	0.34	-20.73**	-0.81**	-4.68**
13	Solan Hara× White Long	-11.07	-0.46**	2.46**	1.18	1.75	-1.95**	-7.22**	2.59**	4.74	0.56	2.71	-0.77**	-1.33*
14	Solan Hara × Faizabadi	28.07**	0.33*	-0.44	-2.03	-3.39*	-2.15**	5.20**	-4.41**	9.74*	-0.23	-4.59	0.50**	1.26*
15	Solan Hara × Co-1	-17.00**	0.12	-2.02**	0.85	1.64	4.09**	2.51**	1.81*	-14.49**	-0.33	1.87	0.27**	0.07
16	Jhalri Long × White Long	-23.63**	-0.33*	0.73	-1.81	-1.24	-0.28	1.27**	-1.70*	8.16*	0.48	-8.74**	0	2.59**
17	Jhalri Long × Faizabadi	0.51	0.3	-0.66	1.29	1.27	1.1	4.15**	-3.77**	-19.35**	0.32	-15.79**	0.33**	0.13
18	Jhalri Long × Co-1	23.11**	0.02	-0.06	0.51	-0.02	-0.82	-5.42**	5.48**	11.18**	-0.80*	24.54**	-0.33**	-2.72**
19	Katahi Vaibhav × White Long	5.14	-0.04	0.76	-0.14	1.08	-1.25	5.46**	4.27**	14.67**	-0.46	22.21**	0.38**	-0.38
20	Katahi Vaibhav × Faizabadi	-18.37**	0.02	-2.45**	1.29	1.27	-0.73	-8.26**	-1.46	4.79	0.71*	0.62	-0.89**	-2.75**
21	Katahi Vaibhav × Co-1	13.22*	0.01	1.69**	-1.14	-2.35	1.97**	2.80**	-2.81**	-19.46**	-0.24	-22.83**	0.51**	3.14**
22	Chaman× White Long	34.81**	0.06	-2.80**	0.4	-0.35	-0.4	1.04**	-1.4	-10.12*	-0.27	-10.23**	0.16*	0.32
23	Chaman × Faizabadi	29.63**	0.13	0.11	-0.48	-0.17	0.89	-2.16**	2.47**	-4.57	-0.32	-3.18	-0.16*	0.05
24	Chaman× Co-1	-64.44**	-0.2	2.68**	0.07	0.53	-0.49	1.12**	-1.07	14.70**	0.6	13.42**	0	-0.37
25	HUB-1 × White Long	0.25	0.53**	-0.78	-0.59	-1.13	8.54**	-0.04	2.46**	-2.93	-0.26	12.26**	0.31**	-1.05*
26	HUB-1 × Faizabadi	16.40**	-0.19	0.98*	4.18**	2.38	-3.76**	-2.96**	-0.58	8.86*	0.008	-18.87**	-0.11	-1.26*
27	HUB-1 × Co-1	-16.66**	-0.34**	-0.19	-3.59**	-1.24	-4.78**	3.01**	-1.87*	-5.92	0.25	6.60**	-0.20*	2.31**
	C. D @ 1%	15	0.34	1.12	3.15	3.48	1.8	0.68	2.12	10.35	0.93	6.2	0.22	1.37
	C. D @ 5%	11.26	0.25	0.84	2.36	2.61	1.35	0.51	1.59	7.77	0.7	4.65	0.16	1.03
	SEm ±	5.61	0.12	0.42	1.17	1.3	0.67	0.25	0.79	3.87	0.35	2.31	0.08	0.51

Note: * and ** indicate significance of values at p=0.05 and p=0.01, respectively

Table 3 : Specific combining ability effects for growth and flowering parameters in bitter gourd

Sl. No.	Genotypes	FY /ha	NSPF	β-carotene	Ascorbic acid	Pulp: skin ratio	Fe	Cu	Zn	Mn	Total phenols	Chlorophyll A	Chlorophyll B	Total chlorophyll
1	Green Long × White Long	-2.15**	0.53	0.005**	10.87*	-0.74**	105.00**	0.56	4.40**	0.43	6.44	-0.23*	-0.36*	-0.60**
2	Green Long × Faizabadi	2.55**	-0.77	-0.007*	9.39	1.22**	12.64**	5.08**	11.70**	5.84**	-8.29	0.06	0.34*	0.37**
3	Green Long × Co-1	-0.4	0.23	0.001	-20.26**	-0.48**	-117.64**	-5.65**	-16.11**	-6.27**	1.85	0.16	0.02	0.23
4	Jonpuri × White Long	-0.48	-0.3	-0.015**	-11.25*	-0.34**	41.31**	-0.19	1.32	2.56**	2.81	0.62**	1.002**	1.81**
5	Jonpuri × Faizabadi	-6.19**	1.29*	0.002	-15.67**	1.18**	-34.10**	0.38	-1.90*	-0.04	-10.54	0.30*	0.29	0.43**
6	Jonpuri × Co-1	6.68**	-0.98	0.012**	26.93**	-0.84**	-7.21*	-0.18	0.57	-2.51**	7.73	-0.92**	-1.29**	-2.25**
7	White Sheetal × White Long	-2.31**	-1.23*	0.006**	2.51	-0.08**	28.69**	2.24**	1.93*	3.08**	16.04	0.31	0.19	0.48**
8	White Sheetal × Faizabadi	4.69**	-1.64**	0.008**	8.41	-0.56**	-13.90**	-0.6	1.82*	-1.03	-21.31	-0.22*	-0.15	-0.32*
9	White Sheetal × Co-1	-2.38**	2.87**	-0.014**	-10.92*	0.64**	-14.79**	-1.63**	-3.75**	-2.05**	5.27	-0.08	-0.04	-0.15
10	Dharog Local× White Long	4.85**	-2.57**	0.001	2.51	-0.67**	-34.98**	-0.12	1.96*	0.39	42.50**	0.13	0.07	0.19
11	Dharog Local × Faizabadi	1.09	0.71	0.004*	-3.38	-0.16**	22.83**	0.76	-2.63**	1.20*	-23.98	-0.31**	-0.19	-0.51**
12	Dharog Local × Co-1	-5.94**	1.86**	-0.005**	0.87	0.83**	12.14**	-0.63	0.66	-1.59**	-18.51	0.18	0.11	0.32*
13	Solan Hara× White Long	-1.76*	0.08	-0.006**	12.34*	1.04**	-24.39**	-0.07	-5.87**	-5.29**	7.1	-0.14	0.11	-0.14
14	Solan Hara × Faizabadi	1.36	0.49	-0.005**	7.92	-0.70**	-8.76**	-2.04**	-6.32**	-4.31**	-8.06	0.15	-0.05	0.25
15	Solan Hara × Co-1	0.39	-0.57	0.011*	-20.26**	-0.33**	33.15**	2.11**	12.19**	9.61**	0.96	-0.01	-0.05	-0.1
16	Jhalri Long × White Long	3.47**	-0.19	-0.008**	-14.20*	-0.11**	-20.46**	1.15*	-0.84	-0.42	-9.72	-0.37**	-0.53**	-0.91**
17	Jhalri Long × Faizabadi	-0.13	-0.67	0.002	-0.92	-0.58**	6.28	-0.94	-4.19**	-0.62	22.41	-0.15	-0.47**	-0.62**
18	Jhalri Long × Co-1	-3.33**	0.86	0.006**	15.13**	0.69**	14.17**	-0.21	5.03**	1.05	-12.68	0.52**	1.00**	1.53**
19	Katahi Vaibhav × White Long	-0.49	1.47*	0.008**	-16.16**	0.72**	-19.46**	-2.97**	-10.16**	-2.86**	-28.12*	-0.29*	-0.1	-0.40**
20	Katahi Vaibhav × Faizabadi	-3.99**	-0.02	-0.012**	7.42	-0.57**	-8.41*	-0.54	10.00**	2.49**	59.20**	0.23*	0.29	0.53**
21	Katahi Vaibhav × Co-1	4.49**	-1.45*	0.003*	8.74	-0.14**	27.88**	3.52**	0.15	0.36	-31.10*	0.06	-0.19	-0.12
22	Chaman× White Long	0.44	1.53*	0.005**	3	0.08**	-32.65**	-0.58	5.31**	1.67**	3.16	0.004	-0.18	-0.18

23	Chaman × Faizabadi	-0.25	-0.88	0.006**	0.05	-0.23**	20.45**	-1.00*	-8.60**	-1.28*	-10.13	-0.29*	-0.21	-0.50**
24	Chaman× Co-1	-0.19	-0.64	-0.011**	-3.05	0.14**	12.20**	1.59**	3.28**	-0.38	6.96	0.28*	0.39*	0.68**
25	HUB-1 × White Long	-1.56*	0.67	0.003	10.37	0.11**	-43.05**	-0.004	1.92*	0.43	-40.22**	-0.03	-0.2	-0.24
26	HUB-1 × Faizabadi	0.86	1.49*	0.001	-13.21*	0.40**	2.98	-1.09*	0.12	-2.22**	0.72	0.22	0.15	0.38**
27	HUB-1 × Co-1	0.7	-2.17**	-0.004*	2.84	-0.51**	40.07**	0.97	-2.04**	1.78**	39.50**	-0.19	0.04	-0.14
	C. D @ 1%	1.86	1.55	0.004	14.42	0.07	8.54	1.3	1.99	1.52	33.03	0.3	0.4	0.33
	C. D @ 5%	1.39	1.16	0.003	10.82	0.05	6.41	0.97	1.49	1.14	24.78	0.22	0.3	0.25
	SEm ±	0.69	0.58	0.001	5.39	0.02	3.19	0.48	0.74	0.57	12.35	0.11	0.15	0.12

Note: * and** indicate significance of values at p=0.05 and p=0.01, respectively

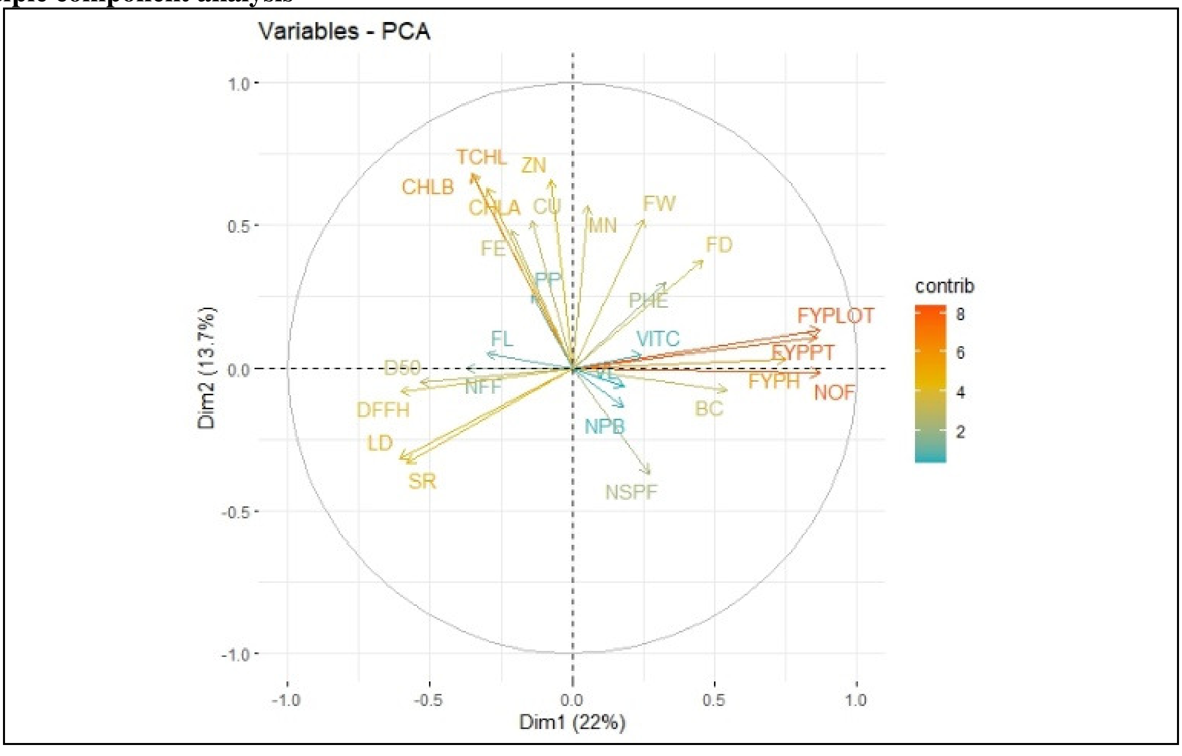
combiners for Fe, Zn, Cu and Mn (Kaur *et al.,* 2022). In general, parents with high mean performance had high gca values, indicating the presence of additive gene action (Janaranjani *et al*., 2016; Shafin *et al*., 2022).

Specific combining ability (SCA) effects of crosses

Table 2 accounts for the specific combining ability (SCA) effects of 27 cross combinations. Based on it, the cross combinations, Jonpuri × White Long and Chaman × White Long had best SCA effects for node at which first female flower appears, White Sheetal × White Long, Jonpuri × Co-1 for days to 50 per cent flowering, White Sheetal × White Long for days for first fruit harvest, HUB-1 × Co-1 and HUB-1 × Faizabadi for Sex ratio exhibited highly significant and negative SCA effects which may be caused by dominance × dominance kind of allelic interaction that produces excess dominance that is not fixable in nature (Fasahat *et al*., 2016; Kumar *et* al., 2021; Kumari *et al*., 2024).

Likewise, cross Dharog Local × White Long for both number of fruits per vine and fruit diameter , Katahi Vaibhav × White Long for fruit length, Dharog Local × White Long, Jonpuri × Co-1 for average fruit weight, Dharog Local × White Long for fruit yield per plant and Jonpuri × Co-1 for fruit yield per plot were found to be good specific combiners for most of the yield traits by exhibiting highly significant and positive SCA effects Higher SCA values for these traits specifies the predominance of non-additive gene action as resulted by Thangamani *et al.* (2011) and Prashant *et al*. (2018) (Table. 3).

Graphical analysis and interpretation
Principle component analysis



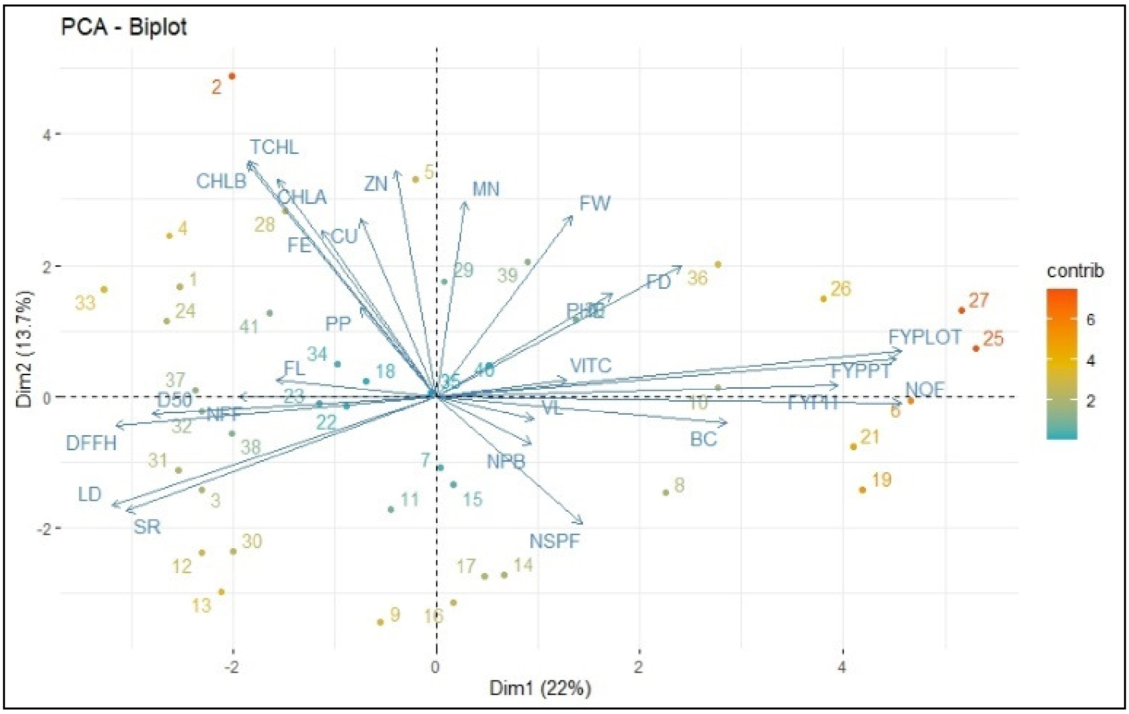


Fig. 2 : PCA biplot for traits under study (Left: PCA variable; Right: PCA biplot)

VL- Vine Length, NPB- Number of Primary Branches, NFF- Node at which First Female flower appears, D50%- Days to 50% flowering, DFFH- Days to First fruit Harvest, SR-Sex Ratio, NFV- Number of Fruits per Vine, FD- Fruit Diameter, FL- Fruit Length, L: D ratio- Length: Diameter ratio, AFW-Average Fruit Weight, FY/P- Fruit yield per Plant, FY/Plot- Fruit Yield per Plot, FY/ha – Fruit Yield per ha, NSPF- Number of Seeds per Fruit, BC-Beta Carotene, VITC- Vitamin-C, Fe- Iron, Cu-Copper, Zn- Zinc, Mn- Manganese, PHE-Phenols, CHLA- Chlorophyll A, CHLB- Chlorophyll B, TCHL- Total Chlorophyll.

The Fig. 2. shows PCA variables plot shows how strongly each characteristic influences a principal component. The angles between the vectors explains how characteristics correlate with one another. Out of 27 observations taken during the analysis, they have showed the different interrelationships among the parameters (Yan and Tinker, 2006; Hosen *et al.,* 2022).

Where two vectors forming a lesser angle (<90^0) represent they are positively correlated like fruit length, node at which first female flower appears, days to 50 per cent flowering, days to first fruit harvest and sex ratio(male: female), whereas the vectors meet each other at 90^0 they are not likely to be correlated like as shown in the figure (Fig.1) between days to 50 per cent flowering and fruit length with Mn content, fruit yield per plant and fruit yield per ha with micronutrients like Cu, Mn and Zinc. The other type where two vectors are diverged and form a large angle (>90^0) explains that there is negative correlation between the two parameters in the genotypes used in the experiment. For eg. Fruit yield per plant, fruit yield per plot, number of fruits with the chlorophyll content and earliness parameters with the beta-carotene content which shows that yield is negatively correlated with the quality parameters (Sharma *et al*., 2023).

Although not much progress is being made with respect to quality aspects in bitter gourd improvement, it should get highlighted during breeding. Heterosis and Combining ability studies may contribute to achieving this objective. Findings proves that high × low or low × high general combining ability. Studies on combining ability variance revealed that non additive gene action was predominant for all the characters studied and hence these characters can be improved through recurrent selection schemes or heterosis breeding. Later generations can benefit from isolating desirable transgressive segregants by utilizing the superior lines and crosses.

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