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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(8): 1495-1499

www.thepharmajournal.com
Received: 22-05-2023
Accepted: 26-06-2023

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Combining ability analysis for yield and yield attributing traits in bitter gourd (*Momordica charantia* L.)

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Abstract
Bitter gourd is unique and versatile vegetable among the cucurbits due to its nutritional value. For the development of effective heterosis breeding programme in bitter gourd one need to elucidate the genetic nature of quantitatively inherited traits and estimated prepotency of parents in hybrid combinations. In the present investigation, GCA/SCA ratio was less than unity for all the studied traits. The results indicated the predominance of non-additive gene action. Gy 3-1-1-1-2, IC-505621 and Preethi were identified as good general combiners for yield and its related traits and can be used in future for developing superior new heterotic combinations. The cross combinations IC-470550 × Preethi, IC-66023 × Pusa Aushadhi and Gy 3-1-1-1-2 × Phule Green Gold exhibited superior *sca* effects and identified as top specific combiners for yield and its related traits. So these combinations can be used for development of hybrids for commercialization.

Keywords: Bitter gourd, hybrids, yield, combining ability

Introduction
Bitter gourd (*Momordica charantia* L.; 2n = 2x = 22) is a cucurbitaceae crop that is also known as bitter squash, cassilla, maiden apple and bitter cucumber (Morton, 1967) [1]. India and China are considered as the probable primary center of origin and secondary centre of diversity, respectively (Rao *et al.*, 2018) [2]. Bitter gourd supplies vitamins (Vitamin A and C) and minerals (P, Mg, Fe, Zn and Mn) along with various medicinal properties (Alam *et al.*, 2009; Bharathi *et al.*, 2012) [3, 4]. This crop is cultivated in tropical and subtropical regions of the world and widely grown in India, China, Sri Lanka, Thailand, Philippines, Japan, Australia, Malaysia, Africa and South America (Singh, 1990) [5]. The major bioactive compounds having pharmaceutical properties are saponins (momordicine I, II; momordicosides K, L; cucurbitacin) and these are associated with the bitterness of fruits (Khatib *et al.*, 2017) [6]. Charantin compound is used for diabetes treatment to reduce the blood sugar levels. Fiber (Uebanso *et al.*, 2007) [7], polypeptide-p insulin-like protein (Khanna *et al.*, 1981) [8], saponins (Klomann *et al.*, 2010) [9], triterpenes (Tan *et al.*, 2008) [10] and lipids (Klomann *et al.*, 2010) [9] in fruits exhibit antidiabetic property by improving the insulin sensitivity, lowering the blood glucose level and regulating the uptake of postprandial (intestinal) glucose (Krawinkel and Keding, 2006) [11]. In seeds and fruits, a protein (MAP-30) that inhibits HIV virus and lowers the cancer cells proliferation was identified by Lee-Huang *et al.* (1995) [12]. Due to its hypoglycemic action, it has acquired the nickname as 'vegetable insulin' and 'cornucopia of health' (Tan *et al.*, 2016) [13].

Every hybridization program is not accompanied by manifestation of hybrid vigour. Only certain parental combination gives heterotic progeny. Thus, for development of effective heterosis breeding programme in bitter gourd one need to elucidate the genetic nature of quantitatively inherited traits and estimated prepotency of parents in hybrid combinations. The line × tester (*l* × *t*) biometrical tool is one of the simplest and efficient method and first developed by Kempthorne (1957) [14] provides information of combining ability and gene action. Combining ability helps in the evaluation of inbreds in terms of their genetic value, in the selection of suitable parents with desirable attributes for hybridization (*gca*) by exploiting the existing variability in the breeding materials and distinguishing the relatedness among them and helps in the determining heterotic patterns among populations identification of

superior cross combination (*sca*) by or inbred lines and assigning them to heterotic groups. This serves as basis and utilized for commercial exploitation of heterosis. Therefore, the objectives of the present study were to evaluate GCA and SCA effects of seven lines and four testers and their 28 F_1 hybrids developed using line × tester mating system for yield and yield attributing traits and also to identify the best combiners among parents for economic traits which would help in adopting future breeding strategy.

Materials and Methods

In the present study, seven lines (IC-66023, IC-505623, IC-505621, IC-470550, IC-470556, Gy 3-1-1-1-2 and IC-398610) with each of the four testers (Pusa Aushadhi, Preethi, IC-50527 and Phule Green Gold) were crossed to develop 28 hybrids in line × tester fashion. The hybrids were evaluated along with parents and checks (Pusa Hybrid-2 and Vennela-43) in randomized complete block design (RCBD) with two replications at the University of Horticultural Sciences, Bagalkot, Karnataka. All the standard prescribed agronomic practices and plant protection measures advised by the University of Horticultural Sciences, Bagalkot were followed during the crop growing phase to promote good crop growth. Observations were recorded on vine length (m), internodal length (cm), number of primary branches per plant, fruit length (cm), fruit diameter (mm), average fruit weight (g), number of fruits per plant and total yield per plant (kg). The variation among the crosses was further partitioned into genetic components attributable to general combining ability (GCA) and specific combining ability (SCA) as outlined by Kempthorne (1957) [14]. The variance components and combining ability effects were estimated according to the Nadarajan *et al.* (2016) [15] and statistical analysis was performed using the INDOSTAT software.

Results and Discussion

The variance due to general combining ability was significant for internodal length and number of primary branches per plant. However, variance due to specific combining ability was highly significant for all the studied traits. In the present investigation, GCA/SCA ratio was less than unity for all the studied traits. The results indicated the predominance of non-additive gene action (Table 1). Therefore, heterosis breeding may be helpful for these traits. The negative estimate of combining ability effects were considered as desirable for internodal length and the positive estimates of combining ability effects were considered as desirable for the rest of the characters. The estimated *gca* effects of the eleven parental lines and *sca* effects of the twenty eight F_1 hybrids for yield and yield attributing traits are presented in Table 2 and Table 3, respectively.

Among the parental lines, *gca* effect for vine length was non-significant in desirable direction. With regard to internodal length, IC-505623 (-1.652) and IC-50527 (-0.323) were good combiners with highest negative *gca* effects. In case of number of primary branches per plant, the line IC-505623 (0.744) and a tester IC-50527 (1.024) expressed the maximum positive significant effects of *gca*. The line IC-505621 was a good general combiner for fruit length (1.536) and average fruit weight (15.682), whereas IC-398610 line was good combiner for fruit diameter (3.748) with highest significant *gca* effects in desirable direction. Gynoecious line, Gy 3-1-1-1-2 was found as best combiner for number of fruits per plant (3.845) and total yield per plant (0.350) with maximum significant *gca* effects in desirable direction. Among the testers, Preethi exhibited the maximum significant *gca* effects in positive direction for fruit length (1.136), fruit diameter (3.601), average fruit weight (8.358) and total yield per plant (0.292) and it was identified as the best general combiner. Even though *per se* performance of the line Gy 3-1-1-1-2 for total yield was poor but its *gca* effect for total yield per plant was more. This may be because of its inherent potential of giving more female flower and more number of fruits per plant. Dey *et al.* (2010) [16] used the gynoecious lines to assess combining ability for yield in bitter gourd and recorded the significant *gca* effect of DBGy-201 (gynoecious line) in desirable direction for number of fruits and yield per plant. They suggested that gynoecious parents can be used for the accumulation of favorable genes related to yield characters. These results were in conformity with those of Dey *et al.* (2010) [16], Angadi (2015) [17], Zehra (2018) [18], Kumari (2019) [19], Shetty (2019) [20], Naik (2020) [21], Alhariri *et al.* (2020) [22], Malve *et al.* (2021) [23], Shanmukhi (2021) [24] and Kundu *et al.* (2022) [25] in bitter gourd.

Among 28 crosses, significant positive *sca* effect was observed maximum in the cross combinations IC-505621 × IC-50527 (0.790) and IC-470556 × Pusa Aushadhi (0.664) for vine length. The specific combining ability effect was non-significant in desirable direction (negative) for internodal length. Hybrids IC-505621 × Pusa Aushadhi (2.095) and IC-66023 × IC-50527 (2.060) exhibited the significant positive *sca* effects for number of primary branches per plant. Out of 28 crosses, IC-470550 × Preethi (4.647) and IC-505621 × Pusa Aushadhi (3.369) crosses showed significant and positive *sca* effects for fruit length. The significant specific combining ability effect in desirable direction was observed maximum for fruit diameter in the hybrids of cross between IC-505623 and Preethi (10.972) followed by IC-470550 and Preethi (10.527). With respect to average fruit weight, the *sca* effect was observed positively and significantly in IC-470550 × Preethi cross with maximum of 54.075 followed by IC-505621 × Pusa Aushadhi (44.532) cross. The hybrids of cross combination IC-470550 × Preethi (11.024) and IC-66023 × Pusa Aushadhi (7.512) documented significant maximum specific combining ability effects in desirable direction with regard to number of fruits per plant. Significant positive *sca* effect was found highest in the IC-470550 × Preethi (1.833) and Gy 3-1-1-1-2 × Phule Green Gold (0.936) crosses for total yield per plant. In the cross combination IC-470550 × Preethi, the tester Preethi was good general combiner for multiple traits like fruit length, fruit diameter, fruit weight and total yield per plant which was specifically combined with line IC-470550 and explored the heterotic potential in combination. In the cross IC-505621 × Pusa Aushadhi, IC-505621 parent had good contribution to fruit length and fruit weight which was indicated by its general combining ability effect. The gynoecious derived cross combination, Gy 3-1-1-1-2 × Phule Green Gold was superior combiner for fruit diameter, fruit weight and total yield per plant. Similar observations for gynoecious derived hybrids were made by Dey *et al.* (2010) [16] and Alhariri (2018) [26]. Many researchers recorded the similar significant specific combining ability effect for various traits and identified the good heterotic combinations in bitter gourd (Dey *et al.*, 2010; Jadhav *et al.*, 2010; Shukla *et al.*, 2014; Angadi, 2015; Bhatt *et al.*, 2017; Zehra, 2018; Kumari, 2019; Shetty, 2019; Naik, 2020;

Alhariri *et al.*, 2020; Malve *et al.*, 2021; Shanmukhi, 2021; Kundu *et al.*, 2022) [16, 27, 28, 17, 29, 18, 19, 20, 21, 22, 23, 24, 25].

Gy 3-1-1-1-2 and IC-505621 were the top combiners among the lines and the tester Preethi was the best general combiner for yield and yield attributing traits. This represents a strong evidence of favourable gene flow from parents to offspring at high frequency and gives information about the predominance of additive genes. These parents can be used for development of new cultivars and inbreds to exploit their potential ability of additive gene action for various traits. The selected parental lines having better performance and high *gca* effect can then be crossed in suitable combination to exploit heterosis. Among the 28 cross combinations, IC-470550 × Preethi, IC-66023 × Pusa Aushadhi and Gy 3-1-1-1-2 × Phule Green Gold were found as top specific combiners. So these cross combinations can be used for exploitation of non-additive gene action in development of hybrids for commercialization.

Table 1: Estimates of variance of GCA, SCA and their ratio for different attributes in bitter gourd.

Sl. No.	Traits	Additive variance (Var. GCA)	Dominance variance (Var. SCA)	GCA/SCA
1.	Vine length (m)	0.0336	0.9258**	0.0363
2.	Internodal length (cm)	0.8746**	1.3566*	0.6447
3.	Number of primary branches per plant	1.2486*	3.7083**	0.3367
4.	Fruit length (cm)	1.6234	20.8200**	0.0780
5.	Fruit diameter (mm)	18.6096	146.5812**	0.1270
6.	Average fruit weight (g)	429.3852	4762.6434**	0.0902
7.	Number of fruits per plant	4.9005	99.7632**	0.0491
8.	Total yield per plant (kg)	0.1670	1.9923**	0.0838

* and ** indicates significance of values at p = 0.05 and p = 0.01, respectively
Var. GCA - Variance due to general combining ability
Var. SCA - Variance due to specific combining ability

Table 2: Estimates of general combining ability (*gca*) effects of lines and testers for different attributes in bitter gourd

Sl. No.	Genotypes	Vine length	Internodal length	Number of primary branches per plant	Fruit length	Fruit diameter	Average fruit weight	Number of fruits per plant	Total yield per plant
Lines									
1.	IC-66023	-0.198	0.065	-0.132	0.069	-1.298	-2.310	-0.154	-0.101
2.	IC-505623	-0.035	-1.652**	0.744*	-0.414	-2.388	6.841**	0.846	0.175
3.	IC-505621	0.182	0.446	-0.214	1.536*	2.851	15.682**	-0.197	0.036
4.	IC-470550	-0.018	0.248	-0.548	0.619	-1.112	-7.018**	-2.072*	-0.032
5.	IC-470556	-0.035	0.231	0.244	-0.673	-3.723*	-27.543**	-0.780	-0.381**
6.	Gy 3-1-1-1-2	0.140	0.106	0.203	0.044	1.922	10.907**	3.845**	0.350**
7.	IC-398610	-0.035	0.556*	-0.297	-1.181	3.748*	3.440	-1.487	-0.047
	S. E. Differnce	0.120	0.250	0.347	0.662	1.700	2.392	0.984	0.100
	CD (0.05)	0.246	0.513	0.711	1.358	3.488	4.909	2.019	0.205
	CD (0.01)	0.332	0.692	0.960	1.834	4.710	6.628	2.727	0.277
Testers									
1.	Pusa Aushadhi	-0.205**	0.397**	-0.595**	-0.336	-1.837	-6.266**	0.446	-0.011
2.	Preethi	0.042	-0.132	-0.024	1.136**	3.601**	8.358**	1.018	0.292**
3.	IC-50527	0.035	-0.323*	1.024**	-0.807*	-1.136	-6.570**	-0.339	-0.232**
4.	Phule Green Gold	0.128	0.059	-0.405*	0.007	-0.628	4.477**	-1.125*	-0.050
	S. E. Differnce	0.091	0.189	0.262	0.501	1.285	1.808	0.744	0.076
	CD (0.05)	0.186	0.388	0.537	1.027	2.637	3.711	1.526	0.155
	CD (0.01)	0.251	0.523	0.726	1.387	3.560	5.010	2.061	0.209

* and ** indicates significance of values at p = 0.05 and p = 0.01, respectively

Table 3: Estimates of specific combining ability (*sca*) effects of crosses for different attributes in bitter gourd

Sl. No.	Hybrids	Vine length	Internodal length	Number of primary branches per plant	Fruit length	Fruit diameter	Average fruit weight	Number of fruits per plant	Total yield per plant
1.	IC-66023 × Pusa Aushadhi	0.076	1.012	-0.987	1.536	1.993	3.390	7.512**	0.695**
2.	IC-66023 × Preethi	0.145	0.073	-1.062	-1.203	-1.755	-0.200	-3.726	-0.316
3.	IC-66023 × IC-50527	0.085	-0.668	2.060**	-0.593	1.285	6.229	1.632	0.129
4.	IC-66023 × Phule Green Gold	-0.307	-0.417	-0.011	0.260	-1.523	-9.419	-5.418*	-0.508*
5.	IC-505623 × Pusa Aushadhi	0.180	0.328	0.137	-0.981	-6.086	-41.759**	-3.491	-0.670**
6.	IC-505623 × Preethi	-0.101	0.190	0.733	-1.452	10.972**	32.317**	-0.726	0.392
7.	IC-505623 × IC-50527	-0.077	-0.185	-0.149	0.091	-8.968*	-11.455*	7.467**	0.438*
8.	IC-505623 × Phule Green Gold	-0.003	-0.334	-0.720	2.343	4.081	20.898**	-3.250	-0.160
9.	IC-505621 × Pusa Aushadhi	-0.219	0.230	2.095**	3.369*	2.031	44.532**	1.222	0.715**
10.	IC-505621 × Preethi	-1.200**	-0.941	-0.476	-4.302**	-3.307	-70.625**	1.817	-0.803**
11.	IC-505621 × IC-50527	0.790**	1.509**	-1.524*	1.574	2.990	38.870**	-3.329	0.104
12.	IC-505621 × Phule Green Gold	0.630*	-0.798	-0.095	-0.640	-1.715	-12.777*	0.290	-0.015

13.	IC-470550 × Pusa Aushadhi	-0.370	-0.905	-0.571	-2.081	5.222	4.666	-7.069**	-0.667**
14.	IC-470550 × Preethi	0.350	0.724	0.857	4.647**	10.527**	54.075**	11.024**	1.833**
15.	IC-470550 × IC-50527	0.140	-0.185	-0.191	-1.476	-5.551	-30.363**	-6.123**	-0.802**
16.	IC-470550 × Phule Green Gold	-0.120	0.366	-0.096	-1.090	-10.198**	-28.377**	2.169	-0.365
17.	IC-470556 × Pusa Aushadhi	0.664*	0.378	-0.530	-2.856*	-2.048	-18.009**	-4.363*	-0.378
18.	IC-470556 × Preethi	0.116	-0.526	0.066	-0.527	-8.496*	-18.566**	-0.270	-0.386
19.	IC-470556 × IC-50527	-0.010	0.265	1.684*	2.582	9.359*	35.495**	3.757	0.680**
20.	IC-470556 × Phule Green Gold	-0.769**	-0.117	-1.221	0.801	1.185	1.081	0.876	0.084
21.	Gy 3-1-1-1-2 × Pusa Aushadhi	-0.061	-0.163	-0.155	2.728*	-5.129	2.607	2.844	0.037
22.	Gy 3-1-1-1-2 × Preethi	0.574*	-0.335	0.274	0.723	-1.834	-2.983	-4.225*	-0.449*
23.	Gy 3-1-1-1-2 × IC-50527	-0.518*	-0.376	-0.607	-3.668*	-0.218	-38.088**	-2.034	-0.524*
24.	Gy 3-1-1-1-2 × Phule Green Gold	0.005	0.874	0.488	0.218	7.181*	38.464**	3.415	0.936**
25.	IC-398610 × Pusa Aushadhi	-0.270	-0.880	0.012	-1.714	4.017	4.574	3.345	0.267
26.	IC-398610 × Preethi	0.116	0.815	-0.393	2.114	-6.107	5.983	-3.893	-0.271
27.	IC-398610 × IC-50527	-0.410	-0.360	-1.274	1.490	1.102	-0.688	-1.369	-0.025
28.	IC-398610 × Phule Green Gold	0.564*	0.425	1.655*	-1.890	0.988	-9.869*	1.917	0.029
	S. E. Differnce	0.239	0.499	0.693	1.324	3.400	4.785	1.968	0.200
	CD (0.05)	0.492	1.025	1.422	2.717	6.976	9.817	4.038	0.410
	CD (0.01)	0.664	1.384	1.92	3.669	9.420	13.256	5.453	0.554

* and ** indicates significance of values at p = 0.05 and p = 0.01, respectively

Conclusion

Gy 3-1-1-1-2, IC-505621 and Preethi were identified as good general combiners for yield and its related traits and can be used in future for developing superior new heterotic combinations. These parents can be used for development of new cultivars and inbreds through recurrent selection. The cross combinations IC-470550 × Preethi, IC-66023 × Pusa Aushadhi and Gy 3-1-1-1-2 × Phule Green Gold exhibited superior *sca* effects and identified as top specific combiners for yield and its related traits. So these combinations can be used for development of hybrids for commercialization.

Acknowledgement

Authors thanks to the University of Horticultural Sciences (UHS), Bagalkot, India for providing research facilities. First author thanks to Department of Science and Technology, Government of India for providing Innovation in Science Pursuit for Inspired Research (INSPIRE) fellowship during the course of PhD research work.

Conflict of interest

All authors confirm that they have no conflict of interest.

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