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Heterosis and combining ability for nutritional quality in bottle gourd (*Lagenaria siceraria)*

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ABSTRACT

The study was carried during *kharif* 2021 and *zaid* 2022 at Vegetable Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand to investigate the nutritional properties of bottle gourd [*Lagenaria siceraria* (Molina) Standl] across various genotypes and hybrid combinations. Bottle gourd, a versatile crop with nutritional benefits, was analysed for traits like dry matter content, ascorbic acid, reducing sugar, non-reducing sugar, total sugar and total soluble solids. Promising parent genotypes, P_6, P_1 and P_4 were identified based on their *per se* performance. The hybrid combination $P_2 \times P_7$ exhibited exceptional results considering relative heterosis, heterobeltiosis and standard heterosis. Parent P_3 demonstrated strong general combining ability for several traits. Notably, specific combining ability analysis identified hybrids like $P_2 \times P_6$, $P_5 \times P_6$, and $P_1 \times P_4$ as promising for multiple traits. The prevalence of significant σ^2SCA values over σ^2GCA values highlighted the dominance gene action's role in governing these traits, suggesting the potential of hybrid breeding for genetic enhancement. In conclusion, the study emphasizes the importance of nutrient quality and presents strategies for harnessing hybrid breeding to improve these traits in bottle gourd.

Keywords: Bottle gourd, Combining ability, Gene action, Heterosis, Nutritional

Bottle gourd [*Lagenaria siceraria* (Molina) Standl] is an incredibly versatile crop belonging to the family Cucurbitaceae with somatic chromosome of 2n = 2x = 22 (Beevy and Kuriachan 1996). Under cucurbits, bottle gourd is gaining importance due to its good taste, nutritional status, cooking quality, cheap market price, round the year availability, higher yield and export potential. As per the database of U.S. Department of Agriculture's, the nutrients in 100 g raw bottle gourd have moisture (96.10%), protein (0.62 g), fat (0.02 g), fibre (0.50 g), carbohydrate (3.39 gm), energy (14.00 kcal), Ca (26.00 mg), phosphorous (13.00 mg), potassium (150.00 mg), Fe (0.20 mg), magnesium (11.00 mg), sodium (0.20mg), niacin (0.20 mg) and vitamin C (10.00 mg) (Martin *et al.* 2012). Bottle gourd also holds promise for its yet unexploited possible uses of some nutrients like oil and protein and also serves as raw material for agro-based industries (Hassan *et al*. 2008). Because it contains more choline than any other vegetable now known to man, as well as other essential vitamins, minerals, and amino acids needed for the formation of neurotransmitters, it is listed in the scriptures as a remedy for mental health disorders. A slice of melon, a handful of pumpkin seeds, and a slice of gourd are all that we need to be healthy in place of vitamin tablets (Rahman 2003). Bottle gourd pulp is used as an antidote to several toxins as well as a remedy for constipation, cough, and night blindness. Additionally, the plant may have anti-inflammatory, adaptogenic, laxative, cardioprotective, diuretic, hepatoprotective, hypolipidemic, anti-helmintic, anti-hypertensive, immunosuppressive, analgesic, and free radical scavenging properties (Ahmad *et al.* 2011). India possesses a rich collection of bottle gourd germplasm, which includes both wild and cultivated species with tremendous morphological and genetical variability. Presently, there is a requirement to develop nutrient-rich varieties or hybrids. Additionally, evaluating the pre-potency of parent plants in hybrid combinations is crucial. By harnessing hybrid vigour, it becomes possible to enhance the quality traits of bottle gourd significantly. The key lies in comprehensively unravelling the crop's genetic makeup, which would enable the development of high-quality hybrids. Therefore, an experiment was performed to determine the nutritional properties in bottle gourd genotypes and its hybrids.

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MATERIALS AND METHODS

The experiment was conducted during *kharif* (2021) and *zaid* (2022) at Vegetable Research Centre of the G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Based on the diversity and eliteness for different economically important traits, eight promising genotypes namely Pusa Sandesh (P_1), Pant Lauki-4 (P_2), Angad (P_3), Ghiya Hisar-22 (P_4), Gutka (P_5), Pusa Samridhi (P_6), Pant Lauki-3 (P_7) and Pusa Santushti (P_8) were selected to use in crossing programme. Crosses were made in half diallel fashion in all possible combinations excluding reciprocal during *zaid* season of 2021 and 28 hybrids and that of parents (obtained by selfing) were harvested separately, raised in randomized complete block design with 3 replications during *kharif* (2021) and *zaid* (2022). All recommended packages of practices were followed.

The dry matter estimation was done as per Hossain *et al.* (2021), ascorbic acid as Ranganna (1979), reducing sugar, non-reducing sugar and total sugar was estimated as per Ranganna (1986). Total soluble solid fresh fruit juice of was determined with the help of hand refractometer (Erma, Japan) of 0–32% range (Tigist *et al.* 2013). The pooled analysis of variance was performed manually in an MS Excel-2013 spreadsheet using the data recorded on the 28 crosses and their 8 parents in accordance with Panse and Sukhatme (1967). Further, half-diallel analysis was done through OPSTAT software (Sheoran *et al.* 1998). The degree of heterosis was evaluated based on three reference points: the mid-parent (MP), better parent (BP), and standard parent (SP). The formulas used for estimating heterosis were derived from the works of Turner (1953), Hayes *et al.* (1956) and Fonseca and Patterson (1968). The additive and dominance genetic variance were calculated as per Singh and Chaudhary (1997).

RESULT S AND DISCUSSION

Per se *performance and heterosis*: Results revealed significant and desirable variations in all the nutritional characteristics examined and pooled mean value range between for all the traits, viz. dry matter (mg/100 g) (parents = 3.05–6.13 and hybrids = 2.62–6.82), ascorbic acid (mg/100 g) (parents = 6.60–8.90 and hybrids = 5.55–12.20), reducing sugar (%) (parents = 2.13–5.25 and hybrids = 2.00–4.70), non-reducing sugar (%) (parents = 0.46–1.93 and hybrids = 0.24–3.61), total sugar (%) (parents = 3.47–7.18 and hybrids = 2.43–7.22), total soluble solids (°B) (parents = 3.57–5.12 and hybrids = 3.49–6.17). On the basis of pooled *per se* performance top 3 parents (Table 1) i.e. P_8, P_6, P_1 for dry matter, P_8, P_7, P_6 for ascorbic acid, P_5, P_4,P_6 for reducing sugar, P_1, P_2, P_4 for non-reducing, P_1, P_6, P_4 for total sugar, P_1, P_3, P_5 for total soluble solids were observed whereas, top 3 hybrids (Table 1) i.e. $P_1 \times P_4$, $P_2 \times P_5$, $P_4 \times P_8$ for dry matter, $P_2 \times P_7$, $P_2 \times P_4$, $P_2 \times P_6$ for ascorbic acid, $P_1 \times P_6$, $P_2 \times P_7$, $P_3 \times P_4$ for reducing sugar, $P_4 \times P_5$, $P_1 \times P_8$, $P_4 \times P_6$ for non-reducing, $P_2 \times P_7$, $P_1 \times P_8$, $P_3 \times P_4$ for total sugar, $P_3 \times P_7$, $P_3 \times P_8$, $P_5 \times P_7$ for total soluble solids were observed. Similar range of results for nutrients composition in cucumber was observed by Bisht *et al.* (2023) and in pumpkin by Nagar *et al.* (2018). According to Allard (1960) choosing parents based on average performance does not provide desirable outcomes. Therefore, we have identified heterosis, combining, and gene action for all the traits under study in order to choose the best performing parents.

In the present study, the pooled mean data indicated varying degrees of heterosis (Table 2) for dry matter content across different hybrid combinations when compared to mid-parent, better parent, and check Pusa Naveen. The range of heterosis ranged from -33.61% ($P_5 \times P_8$) to 88.05% ($P_2 \times P_5$) for mid-parent, from -45.94% ($P_5 \times P_8$) to 62.12% ($P_2 \times P_5$) for better parent, and from -50.51% ($P_5 \times P_8$) to 28.04% ($P_4 \times P_8$) for check Pusa Naveen. Out of the total 28 crosses, 14 hybrids displayed significant positive relative heterosis, 9 hybrids exhibited significant heterobeltiosis, and 6 hybrids showed significant standard heterosis in terms of dry matter content. Regarding ascorbic acid content, 19 hybrids displayed noteworthy relative heterosis ranging -30.84%

Table 1 Pooled *per se* performance of parents, hybrids and standard check for quality traits

	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)	Reducing sugar (%)	Non-reducing sugar (%)	Total sugar (%)	Total soluble solids (°B)
Range (Parents)	3.05–6.13	6.60–8.90	2.13–5.25	0.46–1.93	3.47–7.18	3.57–5.12
Mean	4.57	7.94	3.88	1.03	4.92	4.17
Parents (Best)	P_8, P_6, P_1	P_8, P_7,P_6	P_5, P_4,P_6	P_1, P_2,P_4	P_1, P_6,P_4	P_1, P_3,P_5
Range (Hybrids)	2.62–6.82	5.55–12.20	2.00–4.70	0.24–3.61	2.43–7.22	3.49–6.17
Mean	4.91	8.54	3.39	1.45	4.83	4.56
Hybrids (Best)	$P_1 \times P_4$, $P_2 \times P_5$, $P_4 \times P_8$	$P_2 \times P_7$, $P_2 \times P_4$, $P_2 \times P_6$	$P_1 \times P_6$, $P_2 \times P_7$, $P_3 \times P_4$	$P_4 \times P_5$, $P_1 \times P_8$, $P_4 \times P_6$	$P_2 \times P_7$, $P_1 \times P_8$, $P_3 \times P_4$	$P_3 \times P_7$, $P_3 \times P_8$, $P_5 \times P_7$
Mean (checks)	4.84	1.69	3.49	1.36	4.84	4.48
SEM±	0.06	0.23	0.12	0.02	0.12	0.05
CD (5%)	0.17	0.31	0.33	0.05	0.33	0.15

*Significant at P=0.05; P, Parent; P_1, Pusa Sandesh; P_2, Pant Lauki-4; P_3, Angad; P_4, Ghiya Hisar-22; P_5, Gutka; P_6, Pusa Samridhi; P_7, Pant Lauki-3; P_8, Pusa Santushti.

($P_1 \times P_3$) to 57.46% ($P_2 \times P_7$), 14 hybrids exhibited notable heterobeltiosis ranging from -33.93% ($P_1 \times P_3$) to 37.12% ($P_2 \times P_7$), and 9 hybrids demonstrated significant standard heterosis when compared to the check variety Arke Bahar, with values ranging from -37.66% ($P_1 \times P_3$) to 37.06% ($P_2 \times P_7$). Heterosis for reducing sugar showed, 6 hybrids exhibit significant relative heterosis with values ranging from -55.82% ($P_4 \times P_5$) to 65.62% ($P_2 \times P_3$), 3 hybrids showed significant heterobeltiosis varied from -60.03% ($P_4 \times P_5$) to 44.63% ($P_2 \times P_3$) and 6 hybrids showed significant standard heterosis over the check Arka Bahar varied from -46.58% ($P_6 \times P_7$) to 25.42% ($P_1 \times P_6$). Heterosis for non-reducing sugar content showed 17 hybrids exhibits significant relative heterosis varied from -73.65% ($P_2 \times P_6$) to 201.53% ($P_4 \times P_5$), 16 hybrids showed significant heterobeltiosis varied from -82.25% ($P_2 \times P_6$) to 157.39% ($P_1 \times P_8$) and 5 hybrids showed significant standard heterosis over the check Pusa Naveen varied from -88.77% ($P_2 \times P_6$) to 71.52% ($P_4 \times P_5$). For total sugar 13 hybrids exhibits significant relative heterosis ranged from -54.21% ($P_4 \times P_8$) to 71.96% ($P_2 \times P_3$), 8 hybrids showed significant heterobeltiosis ranged from -61.31% ($P_4 \times P_8$) to 69.47% ($P_2 \times P_3$) and 10 hybrids showed significant standard heterosis over the check Pusa Naveen ranged from -52.35% ($P_6 \times P_7$) to 41.57 % ($P_1 \times P_8$). For total soluble solids, 15 hybrids exhibits significant relative heterosis ranged from -20.29% ($P_1 \times P_5$) to 48.44% ($P_4 \times P_6$), 8 hybrids showed significant heterobeltiosis ranged from -25.07% ($P_1 \times P_5$) to 45.90% ($P_4 \times P_6$) and 9 hybrids showed significant standard heterosis over the check Pusa Naveen ranged from -26.35% ($P_6 \times P_7$) to 30.01% ($P_3 \times P_8$). These outcomes align with the observations made by Dhakne *et al.* (2021) and Masud *et al.* (2021).

The ranking of the hybrids based on their relative heterosis, heterobeltiosis, and standard heterosis for the studied traits is listed in Table 2. In terms of dry matter, notable relative and heterobeltiosis effects were observed in top hybrids $P_2 \times P_7$, $P_2 \times P_5$, $P_4 \times P_8$, while significant standard heterosis was seen in $P_4 \times P_8$, $P_2 \times P_5$, and $P_1 \times P_4$. As for ascorbic acid, significant relative, heterobeltiosis, and standard heterosis were found in top hybrids $P_2 \times P_7$, $P_2 \times P_4$, and $P_2 \times P_6$. Regarding reducing sugar, notable relative and heterobeltiosis effects were seen in $P_2 \times P_3$, $P_2 \times P_7$ and $P_3 \times P_8$, whereas significant standard heterosis occurred in $P_1 \times P_6$, $P_3 \times P_4$, and $P_2 \times P_7$. For non-reducing sugar, significant relative and heterobeltiosis effects were observed in $P_4 \times P_5$, $P_1 \times P_8$ and $P_5 \times P_8$, with significant standard heterosis seen in $P_4 \times P_5$, $P_4 \times P_6$ and $P_1 \times P_8$. Concerning total sugar, top hybrids $P_2 \times P_3$, $P_2 \times P_7$ and $P_1 \times P_8$ displayed significant relative and heterobeltiosis effects, and $P_1 \times P_8$, $P_2 \times P_7$ and $P_3 \times P_4$ exhibited significant standard heterosis. Lastly, for total soluble solids, significant relative and heterobeltiosis effects were noted in $P_4 \times P_6$, $P_3 \times P_8$ and $P_3 \times P_7$, while significant standard heterosis was seen in $P_3 \times P_8$, $P_3 \times P_7$, and $P_5 \times P_7$.

Combining ability: Utilizing combining ability analysis stands as a highly efficient approach to identify the best parents for crossing, whether the goal is to harness heterosis or to accumulate favourable genes (Sprague and Tatum 1942). In this study, all the parents exhibited strong general combining ability for various quality traits across both seasons as well as in the pooled analysis. Results showed that among the parents, four were identified as good general combiners for dry matter, ascorbic acid, non-reducing sugar, and total sugar (Table 2). Additionally, three parents showed significant GCA for reducing sugar, and two parents demonstrated the same for total soluble solids. The presence of low GCA (whether positive or negative) suggests minimal divergence between parental and cross means. Conversely, high GCA (positive or negative) indicates that parental means are either superior or inferior to the general cross mean. This observation signifies the transfer of genetic influence from parents to their offspring (Fasahat *et al.* 2016).

The optimal cross combinations for various traits (Table 2), exhibit strong SCA effects alongside high individual performance across pooled analyses. For instance, in terms of dry matter content, top hybrids $P_1 \times P_4$, $P_2 \times P_5$, and $P_4 \times P_8$ displayed favourable SCA effects and noteworthy intrinsic performance. Similarly, the best hybrids for ascorbic acid, reducing sugar, non-reducing sugar, total sugar and total soluble solids, such as $P_2 \times P_7$, $P_1 \times P_6$, $P_4 \times P_5$, $P_2 \times P_7$, $P_3 \times P_4$, $P_3 \times P_7$, demonstrated high performance and favourable SCA effects in the pooled analysis.

The presence of strong SCA effects, especially when combined with good GCA parents, suggests the potential for obtaining valuable transgressive segregants in future generations (Jinks and Jones 1958). Notably, the results (Table 2) indicate that hybrids with superior performance might arise even from parents with poor GCA effects. This underscores that the best crosses don't solely arise from high GCA parent crosses. Promising crosses, driven by additive gene action and fixable, hold promise for heterosis breeding and segregant selection in advanced generations. Comparable studies have been conducted by other researchers, such as Masud *et al.* (2021) and Patel and Mehta (2021).

Gene action: For crop enhancement, evaluating both additive and non-additive components of genetic variance is crucial. The estimates of σ^2SCA were notably larger than σ^2GCA in the study (Table 3). This indicates the influence of non-additive or dominance effects on these traits. This underscores the potential of heterosis breeding to enhance nutritional traits. In this research, average dominance ratios were consistently below one for all examined traits, further confirming the prominence of non-additive gene actions governing nutritional characteristics (Table 3). Hence, the investigation of gene actions highlights the substantial role of non-additive mechanisms in trait expression. Heterosis breeding stands as a valuable approach for elevating the nutritional quality of bottle gourd.

In the context of eradicating malnutrition, assessing nutrient quality is pivotal. This study focused on bottle gourd's nutritional parameters to gauge its nutrient content, both in parent lines and their cross combinations. Among

Table 2 Heterosis (relative heterosis, heterobeltiosis and standard heterosis), top performing general and specific combiner for quality traits in bottle gourd

		Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)	Reducing sugar (%)	Non-reducing sugar (%)	Total sugar (%)	Total soluble solids (°B)
Relative heterosis	Range (%)	-33.61 to 88.05	-30.84 to 57.46	-55.82 to 65.62	-73.65 to 201.53	-54.21 to 71.96	-20.29 to 48.44
	Relative heterosis (No.)	14	19	6	17	13	15
	Hybrid (Best)	$P_2 \times P_7$ $P_2 \times P_5$ $P_4 \times P_8$	$P_2 \times P_7$ $P_2 \times P_4$ $P_2 \times P_6$	$P_2 \times P_3$ $P_2 \times P_7$ $P_3 \times P_8$	$P_4 \times P_5$ $P_1 \times P_8$ $P_5 \times P_8$	$P_2 \times P_3$ $P_2 \times P_7$ $P_1 \times P_8$	$P_4 \times P_6$ $P_3 \times P_8$ $P_3 \times P_7$
Heterobeltiosis	Range (%)	-45.94 to 62.12	-33.93 to 37.12	-60.03 to 44.63	-82.25 to 157.39	-61.31 to 69.47	-25.07 to 45.90
	Heterobeltiosis (No.)	9	14	3	16	8	8
	Hybrid (Best)	$P_2 \times P_7$ $P_2 \times P_5$ $P_4 \times P_8$	$P_2 \times P_7$ $P_2 \times P_4$ $P_2 \times P_6$	$P_2 \times P_3$ $P_2 \times P_7$ $P_3 \times P_8$	$P_1 \times P_8$ $P_2 \times P_7$ $P_5 \times P_8$	$P_2 \times P_3$ $P_2 \times P_7$ $P_1 \times P_8$	$P_4 \times P_6$ $P_2 \times P_8$ $P_3 \times P_8$
Standard heterosis	Range (%)	-50.51 to 28.04	-37.66 to 37.06	-46.58 to 25.42	-88.77 to 71.52	-52.35 to 41.57	-26.35 to 30.01
	Standard heterosis (No.)	6	9	6	5	10	9
	Hybrid (Best)	$P_4 \times P_8$ $P_2 \times P_5$ $P_1 \times P_4$	$P_2 \times P_7$ $P_2 \times P_6$ $P_2 \times P_4$	$P_1 \times P_6$ $P_3 \times P_4$ $P_2 \times P_7$	$P_4 \times P_5$ $P_4 \times P_6$ $P_1 \times P_8$	$P_1 \times P_8$ $P_2 \times P_7$ $P_3 \times P_4$	$P_3 \times P_8$ $P_3 \times P_7$ $P_5 \times P_7$
GCA effects	Parents (No.)	4	4	3	4	4	2
	Parents (Best)	P_2, P_3, P_4, P_8	P_2, P_8	P_2, P_8	P_3	P_2, P_5, P_8	P_1, P_2, P_4, P_6
SCA effects	Hybrids (No.)	12	16	11	14	12	10
	Hybrids (Best)	$P_1 \times P_3$, $P_5 \times P_6$, $P_3 \times P_4$, $P_4 \times P_5$, $P_2 \times P_3$, $P_3 \times P_5$, $P_1 \times P_5$, $P_6 \times P_8$, $P_1 \times P_4$, $P_4 \times P_8$, $P_2 \times P_5$, $P_2 \times P_7$	$P_7 \times P_8$, $P_5 \times P_6$, $P_4 \times P_7$, $P_5 \times P_7$, $P_1 \times P_8$, $P_2 \times P_3$, $P_4 \times P_8$, $P_4 \times P_5$, $P_1 \times P_5$, $P_4 \times P_6$, $P_3 \times P_8$, $P_1 \times P_6$, $P_3 \times P_5$, $P_2 \times P_4$, $P_2 \times P_6$, $P_2 \times P_7$	$P_5 \times P_8$, $P_3 \times P_5$, $P_7 \times P_8$, $P_1 \times P_8$, $P_4 \times P_7$, $P_2 \times P_6$, $P_3 \times P_8$, $P_1 \times P_6$, $P_3 \times P_4$, $P_2 \times P_3$, $P_2 \times P_7$	$P_3 \times P_8$, $P_3 \times P_4$, $P_1 \times P_3$, $P_6 \times P_8$, $P_3 \times P_7$, $P_1 \times P_6$, $P_5 \times P_8$, $P_2 \times P_3$, $P_7 \times P_8$, $P_2 \times P_5$, $P_2 \times P_7$, $P_1 \times P_8$, $P_4 \times P_6$, $P_4 \times P_5$	$P_3 \times P_5$, $P_4 \times P_6$, $P_4 \times P_5$, $P_3 \times P_8$, $P_2 \times P_5$, $P_5 \times P_8$, $P_3 \times P_4$, $P_7 \times P_8$, $P_1 \times P_6$, $P_2 \times P_3$, $P_1 \times P_8$, $P_2 \times P_7$	$P_2 \times P_4$, $P_1 \times P_4$, $P_5 \times P_6$, $P_3 \times P_6$, $P_2 \times P_7$, $P_5 \times P_7$, $P_2 \times P_8$, $P_3 \times P_7$, $P_3 \times P_8$, $P_4 \times P_6$

P, Parent; P_1, Pusa Sandesh; P_2, Pant Lauki-4; P_3, Angad; P_4, Ghiya Hisar-22; P_5, Gutka; P_6, Pusa Samridhi; P_7, Pant Lauki-3; P_8, Pusa Santushti.

Table 3 Estimation of genetic component of variance for nutritional traits

Trait	σ^2 GCA	σ^2 SCA	σ^2 A	σ^2 D	σ^2 GCA / σ^2 SCA
Dry matter (g/100 g)	0.16	1.03	0.33	1.03	0.16
Ascorbic acid (mg/100 g)	0.25	2.45	0.49	2.45	0.10
Reducing sugar (%)	0.06	0.94	0.12	0.94	0.06
Non-reducing sugar (%)	339.11	8864.32	678.21	8864.32	0.04
Total sugar (%)	0.07	1.93	0.15	1.93	0.04
Total soluble solids (ºB)	0.09	0.43	0.17	0.43	0.20

parent lines, P_6, P_1, and P_4 showed superior performance, while hybrid $P_2 \times P_7$ excelled based on *per se* performance for most traits. The cross combination $P_2 \times P_7$ emerged as the best choice considering relative heterosis, heterobeltiosis, and standard heterosis. Parent P_3 demonstrated good general combining ability, excelling in all quality traits except dry matter. Notably, for specific combining ability, $P_2 \times P_6$, $P_5 \times P_6$, and $P_1 \times P_4$ exhibited promise for multiple traits among the 28 cross combinations. The prevalence of higher σ^2SCA over σ^2GCA values highlights the dominance gene action's paramount role in governing these traits, underscoring the potential of hybrid breeding for their genetic enhancement. In conclusion, this study underscores the significance of nutrient quality and provides insights into the promising avenues for harnessing hybrid breeding to enhance these traits.

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