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RESEARCH ARTICLE

Heterosis studies for yield-related traits in cucumber (*Cucumis sativus* L.)

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Abstract

Using a randomized complete block design (RCBD) with 3 replications, 30 F1's and their 13 parents were evaluated at the Main Experimental Station, Department of Vegetable Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, during the zaid seasons of 2023 and 2024. The optimum genotypes were recommended based on the findings of studies on heterosis and combining ability. To determine the best parental combination and the best-performing hybrid, the hybrids were assessed for seven distinct qualities. The best hybrid combination, both in terms of overall heterosis effects and per se performance, was NDCU-23-11 x Punjab Naveen. The cross combinations NDCU-23-11 x Punjab Naveen, VRCU-2203 x Pusa Uday and NDCU-23-11 x Pusa Uday outperformed the midparent in terms of fruit yield, while the combinations NDCU-23-11 x Pusa Uday, VRCU-2203 x Pusa Uday and VRCU-2203 x Arka Veera outperformed the standard variety in terms of heterosis. Heterosis over normal variety ranged from 15.05 to 112.31 %, whereas over better parent it ranged from 0.00 to 106.49 %. The predominance of dominant gene activation suggests the possibility of hybrid breeding for genetic enhancement in cucumbers.

Keywords: cucumber; heterosis; heterobeltiosis; hybrids; significant; standard heterosis

Introduction

Cucumber (*Cucumis sativus* L.) belongs to the family Cucurbitaceae, which comprises 117 genera and 825 species (1). The cucumber originated in India. The genus *Cucumis* contains approximately 30 species that are in two areas: the Southeast Himalayan, which is an important origin of the Asiatic group with chromosome number 2x = 14 and is distributed in India, China, Myanmar and Korea, where cucumber belongs and the African group, which includes the species *Cucumis sativus* var. *sativus* and *Cucumis sativus var. hardwickii* (Royle). These species can also be found in Africa, the Middle East, Sudan, Egypt, Ethiopia and Pakistan. Cucumber has surpassed tomato, cabbage and onion to become the world's fourth most significant vegetable (2).

Although it is vulnerable to cold damage, this crop is commonly grown in India throughout the summer and rainy seasons. For optimal pollination, fertilisation and fruit set, the soil temperature should be between 18 and 32 °C. The ideal soil temperature for seed germination is 27 °C. Since the 1900s, various cucumber breeding programs have had as one of their main goals improving cucumber yields (3). In addition to using better cultural practices, breeding cucumbers for disease resistance has increased yield. The introduction of high producing varieties or hybrids has also contributed to direct yield improvement, as has the improvement of qualitative features, including enhanced fruit colour and gynoecious sex expression (3).

Cucumber has an outstanding health benefit. Cucumber contains different types of flavonoids such as apigenin, diosmetin, fisetin, luleolin, quercetin, kaempferol, luteolin, naringenin, the aflavanoside I and vicenin. Previous reports stated that cucumber eating in daily basis can improve hair growth and soothes skin, reduce swelling of eye (4). Cucumber juice can improve the skin texture and cures skin infections, eczema. Cucumber seeds contain a wide variety of phytonutrients, including both carotenoids and flavonoids. Since cucumbers are monoecious, there is plenty of room to use hybrid vigour on a commercial scale. Heterosis is also much easier to utilise in cross-pollinated crops. One of the most effective methods for estimating the effects of combining abilities and helping choose acceptable parents and crosses for future use is combining ability analysis.

Since cucumbers are native to India, the country has a high level of genetic variety in both vegetative and fruit characteristics. Cucumber improvement is severely limited by low fruiting ability and yield suppression brought on by its innate fruiting tendencies (5). Unfortunately, its genetic enhancement using genetically superior parents has received very little attention. By evaluating genetic variability and taking advantage of heterosis, a rapid improvement can be achieved. When hybrids outperform their parents in traits like yield, repeatability, resistance, etc., this is known as heterosis. Heterosis in cucumber was first reported by previous researchers (6).

Crop improvement includes methods for improving yield and yield component quality as well as yield's inherent capability. Heterosis breeding (7) and merging ability estimations (8) are two ways to enhance cucurbits. The superior traits identified in the parents cannot be guaranteed in their progenies if such traits cannot be transferred (9). For this reason, it has become imperative to screen crop germplasm to isolate potential combining lines and desirable cross combinations either to exploit heterosis or to obtain new recombinants. Hence, any method helpful in choosing desirable parents and crosses will be of interest to breeders. Genetic analysis provides a guideline for the assessment of relative breeding potential of the parents or identifies best combiners in crops (10), which could be utilised either to exploit heterosis in F1 or to accumulate fixable genes to evolve new variety.

Due to its cross-pollinated nature and production of large number of seeds per fruit, it is very receptive to going for heterosis breeding in cucumber (11). In cucumber, significant heterosis has been reported by previous researchers (12–15). It is essential to assess the parent plants' potential in hybrid pairings. The qualitative characteristics of cucumber can be greatly improved by utilising hybrid vigour. The secret is to fully understand the genetic composition of the crop so that superior hybrids can be created. Parental line selection based solely on past performance does not always produce the desired results (16). Parental selection for planned hybridisation must be based on the putative parents' absolute genetic information and prevalence (17). The goal of the current study was to identify high-yield and high-quality cucumber hybrids that could be planted in the tropics under open farmed conditions.

Materials and Methods

During the zaid seasons of 2023 and 2024, the F1's and their parents were assessed at the Main Experimental Station, Department of Vegetable Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, using a randomized block design (RBD) with 3 replications. Situated between latitudes 24.47° and 26.56° N and longitudes 82.12° and 83.58° E, the experimental site is 113 m above mean sea level and has a humid subtropical climate. At the experimental site, the soil type was sandy loam, with a pH range of 7.5 to 8.5 and an average fertility level. Thirteen promising genotypes in which 10 were lines and 3 testers, were identified based on their diversity and superiority status for various economically significant features. The list of genotypes is mentioned below:

List of genotypes used in the current study

Sl. No.	List of genotypes
1	NDCU-23-1 x Pusa Uday
2	NDCU-23-1 x Punjab Naveen
3	NDCU-23-1 x Arka Veera
4	NDCU-23-3 x Pusa Uday
5	NDCU-23-3 x Punjab Naveen
6	NDCU-23-3 x Arka Veera
7	NDCU-23-4 x Pusa Uday
8	NDCU-23-4 x Punjab Naveen
9	NDCU-23-4 x Arka Veera
10	NDCU-23-5 x Pusa Uday
11	NDCU-23-5x Punjab Naveen
12	NDCU-23-5 x Arka Veera
13	NDCU-23-7 x Pusa Uday
14	NDCU-23- 7x Punjab Naveen
15	NDCU-23-7 x Arka Veera
16	NDCU-23-8 x Pusa Uday
17	NDCU-23- 8 x Punjab Naveen
18	NDCU-23-8 x Arka Veera
19	NDCU-23-9 x Pusa Uday
20	NDCU-23- 9 x Punjab Naveen
21	NDCU-23-9 x Arka Veera
22	NDCU-23-10 x Pusa Uday
23	NDCU-23- 10 x Punjab Naveen
24	NDCU-23-10 x Arka Veera
25	NDCU-23-11 x Pusa Uday
26	NDCU-23- 11 x Punjab Naveen
27	NDCU-23-11 x Arka Veera
28	VRCU-2203 x Pusa Uday
29	VRCU-2203 x Punjab Naveen
30	VRCU-2203 x Arka Veera

The node at which the first female blossom appears was observed on 5 plants per plot. After that, an average value was calculated. Fruit parameters were recorded for five randomly selected fruits from each plot and the average value was then calculated.

Estimation of heterosis

Data on several quantitative and fruit quality characteristics were used to examine the extent of heterosis. The method proposed by previous researchers was used to compute the percentage increase or decrease in the mean values of F_1 (hybrid) over better-parent (heterobeltiosis) and standard variety (standard heterosis) (18). The following formulas are used to estimate heterosis:

Heterosis over better parent (Heterobeltiosis) (19)

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100; \text{ where BP : Better Parent}$$

Heterosis over standard check Zoya (Standard heterosis) (20)

$$\text{Standard heterosis (\%)} = \frac{\overline{F_1} - \overline{SH}}{\overline{SH}} \times 100; \text{ where SH : Standard Heterosis}$$

A line X tester mating design was used to create crosses, encompassing every feasible combination except for reciprocals. A randomized complete block design (RCBD) with 3 replications was used to produce 30 hybrids and their corresponding parents (obtained by selfing) after they were harvested separately. Every suggested package procedure was adhered to. Genotype Zoya was taken as standard check. A total of 30 genotypes were studied for 7 characters. Number of fruits were measured by counting individual fruit and based on their weight per plant, yield was calculated. The characters studied are mentioned in Table 1.

Ascorbic acid: The ascorbic acid content of fresh fruit was determined using titration with 2, 6-dichlorophenol-indophenol dye and the results were expressed in mg/100 g of fresh fruit (21).

$$\text{Ascorbic acid (mg/100 g)} = \frac{\text{Titrated valu (mL)} \times \text{Dye factor} \times \text{Vol. made up (mL)}}{\text{Aliquot of extract ta ken (mL)} \times \text{Weight of sample taken for estimation (g)}} \times 100$$

Table 1. The list of characters studied in cucumber

Sl. No.	Character
1	Nodes per vine
2	Fruit length (cm)
3	Fruit breadth (cm)
4	Number of fruits per plant
5	Fruit yield per plant(kg)
6	Total soluble solids (%)
7	Ascorbic acid (mg/100 g fresh fruit)

Total soluble solids: Using a hand refractometer (Erma, Japan) with a range of 0–32%, the total soluble solids (TSS) of the fresh fruit juice from each line and F1 hybrid were measured. The percentage of TSS in fresh fruit juice was calculated and recorded at 20 °C (22).

In accordance with earlier technique, the pooled analysis of variance was carried out manually in an MS Excel 2013 spreadsheet utilising the data collected from 30 crosses and their 13 parents (23). Method of calculating additive and dominant genetic variance was used (24). Line x Tester analysis proposed by earlier researchers received considerable attention to assess the genetic differences in the parents on quantitative characters (25).

It is supposed to be the most convenient method since the large number of genotypes used as lines could be tested for their combining ability even against a minimum of 2 or 3 testers. This line x tester analysis indicates this relative capacity of female and male parents to produce a desirable recombinant. Data collected on the above character will be subjected to the (26) statistical analysis to determine the variances and their effects.

Results and Discussion

The ANOVA showed that the mean sum of squares derived from genotypes for each of the attributes were significant. This suggests that the genotypes differ sufficiently from one another in both years (Y_1, Y_2 and pooled). Strong homogeneity between the characters is suggested by the fact that not all the replications were statistically significant (27) in both years (Y_1, Y_2 and pooled). These characteristics illustrated the greater possibility of selection-based improvement. Table 2 provides a summary of the information gathered on several aspects. Also, due of their economic viability, these combinations having higher heterosis over standard variety can be used commercially (28).

Heterosis over better parent and standard heterosis

Heterosis calculated as per cent increase or decrease over better parent and standard variety for eight characters in Y_1, Y_2 and pooled is described as follow (Table 3 & 4):

Nodes per vine

In case of year 2023, the magnitude of heterobeltiosis for nodes per vine ranged from -3.19 (NDCU-23-1 x Pusa Uday) to 61.15 % (NDCU-23–11 x Punjab Naveen) over better parent while, for standard heterosis it varied from -12.81 (NDCU-23-1 x Pusa Uday) to 28.26 % (VRCU-2203 x Punjab Naveen). Out of 36 crosses, 27 crosses showed significant positive and 0 crosses showed negative heterosis over better parent whereas, 24 crosses showed significant positive and 01 crosses showed significant negative heterosis over standard variety. In case of year 2024, the magnitude of heterobeltiosis for nodes per vine ranged from -2.50 (NDCU-23-1 x Pusa Uday) to 58.76 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from -9.55 (NDCU-23-1 x Pusa Uday) to 29.08 % (VRCU-2203 x Punjab Naveen). Out of 36 crosses, 27 crosses showed significant positive and 0 crosses showed negative heterosis over better parent whereas, 24 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of pooled data, the magnitude of heterobeltiosis for nodes per vine ranged from -2.83 (NDCU-23-1 x Pusa Uday) to 59.91 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from -11.13 (NDCU-23-1 x Pusa Uday) to 28.69 % (VRCU-2203 x Punjab Naveen). Out of 36 crosses, 27 crosses showed significant positive and 0 crosses showed negative heterosis over better parent whereas, 24 crosses showed significant positive and 01 crosses showed significant negative heterosis over standard variety. Similar findings were shown by previous researchers (29).

Fruit length

In case of year 2023, the magnitude of heterobeltiosis for fruit length ranged from -1.73 (NDCU-23-1 x Punjab Naveen) to 40.02 % (NDCU-23-7 x Punjab Naveen) over better parent while, for standard heterosis it varied from -6.52 (NDCU-23-1 x Punjab Naveen) to 20.69 % (NDCU-23-3 x Arka Veera). Out of 36 crosses, 17 crosses showed significant positive and 0 crosses showed negative heterosis over better parent whereas, 9 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of year 2024, the magnitude of heterobeltiosis for fruit length ranged from -2.12 (NDCU-23-1 x Punjab Naveen) to 37.11 % (NDCU-23-7 x Punjab Naveen) over better parent while, for standard heterosis it varied from -4.38 (NDCU-23-1 x Punjab Naveen) to 20.37 % (NDCU-23-3 x Arka Veera). Out of 36 crosses, 17 crosses showed significant positive and 0 crosses showed negative heterosis over better parent whereas, 7 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of pooled data, the magnitude of heterobeltiosis for fruit length ranged from -1.93 (NDCU-23-1 x Punjab Naveen) to 38.48 % (NDCU-23-7 x Punjab Naveen) over better parent while, for standard heterosis it varied from -5.40 (NDCU-23-1 x Punjab Naveen) to 20.53 % (NDCU-23-3 x Arka Veera). Out of 36 crosses, 17 crosses showed significant positive and 0 crosses showed negative heterosis over better parent whereas, 8 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. Similar results were shown in earlier reports (29).

Fruit breadth

In case of year 2023, the magnitude of heterobeltiosis for fruit breadth ranged from -12.59 (NDCU-23-1 x Punjab Naveen) to 61.65 % (NDCU-23-9 x Punjab Naveen) over better parent while, for standard heterosis it varied from -9.40 (NDCU-23-1 x Punjab Naveen) to 38.40 % (VRCU-2203 x Pusa Uday). Out of 36 crosses, 22 crosses showed significant positive and 01 crosses showed negative heterosis over better parent whereas, 21 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. Similar results also reported previously (30). In case of year 2024, the magnitude of heterobeltiosis for fruit breadth ranged from -11.90 (NDCU-23-1 x Punjab Naveen) to 54.59 % (NDCU-23-9 x Punjab Naveen) over better parent while, for standard heterosis it varied from -7.88 (NDCU-23-1 x Punjab Naveen) to 35.14 % (VRCU-2203 x Pusa Uday). Out of 36 crosses, 21 crosses showed significant positive and 0 crosses showed negative heterosis over better parent whereas, 20 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. Similar results were reported in previous studies (29, 30). In case

Table 2. Analysis of variance for quality and yield traits in cucumber

Source	df	Nodes per vine			Fruit length (cm)			Fruit breadth (cm)			Number of fruits per plant			Fruit yield per plant (kg)			TSS (Brix)			Ascorbic acid (mg/100 g)		
		Y_1	Y_2	P	Y_1	Y_2	P	Y_1	Y1	Y1	Y1	Y_2	P	Y_1	Y_2	P	Y_1	Y_2	P	Y_1	Y_2	P
REPLN	2	4.55	2.33	3.36	1.36	1.67	1.46	0.04	4.55	4.55	4.55	0.76	0.31	0.011	0.016	0.013	0.038	0.017	0.027	0.020	0.099	0.051
GENO	42	29.41**	33.17**	31.24**	13.17**	13.76**	13.45**	1.56**	29.41**	29.41**	29.41**	10.11**	9.72**	0.312**	0.338**	0.324**	0.536**	0.519**	0.509**	1.434**	1.488**	1.458**
CROSS	29	9.62**	9.85**	9.73**	5.84**	5.72**	5.77**	1.07**	9.62**	9.62**	9.62**	7.83**	7.76**	0.176**	0.178**	0.176**	0.572**	0.543**	0.543**	0.808**	0.898**	0.853**
PARENT	12	10.93**	11.15**	11.02**	6.11**	6.15**	6.13**	0.40**	10.93**	10.93**	10.93**	6.48**	6.21**	0.084**	0.097**	0.091**	0.294**	0.379**	0.310**	0.581**	0.528**	0.553**
LINE(p)	9	12.65**	12.65**	12.64**	6.54**	6.66**	6.59**	0.41**	12.65**	12.65**	12.65**	7.64**	7.23**	0.096**	0.112**	0.105**	0.351**	0.468**	0.385**	0.624**	0.580**	0.600**
TEST(p)	2	7.06*	9.00*	7.98*	7.09**	6.91**	7.00**	0.35**	7.06*	7.06*	7.06*	2.42	2.75	0.048**	0.044*	0.046**	0.121	0.133	0.128	0.264**	0.195**	0.228**
L(P)vT(P)	1	3.18	1.90	2.50	0.37	0.06	0.18	0.41*	3.18	3.18	3.18	4.13	3.96	0.042	0.066	0.052	0.127	0.075	0.001	0.833**	0.726**	0.779**
CrovsPAR	1	824.98**	973.67**	897.8**	310.39**	338.12**	324.15**	29.86**	824.98**	824.98**	824.98**	119.95**	108.65**	7.014**	7.877**	7.406**	2.373**	1.508**	1.920**	29.824**	30.091**	29.873**
ERROR	84	1.69	2.51	2.01	1.91	2.21	1.99	0.08	1.69	1.69	1.69	0.46	0.36	0.006	0.014	0.009	0.020	0.022	0.020	0.043	0.048	0.044
TOTAL	128	10.83	12.57	11.62	5.59	5.99	5.74	0.56	10.83	10.83	10.83	3.63	3.43	0.106	0.120	0.112	0.189	0.185	0.181	0.499	0.521	0.508

*, ** significant at 5% and 1% level, respectively

Table 3. Components analysis for quality and yield traits in cucumber

Parents	Nodes per vine			Fruit length (cm)			Fruit breadth (cm)			Number of fruits per plant			Fruit yield per plant (kg)			TSS (Brix)			Ascorbic acid (mg/100 g)		
	Y_1	Y_2	P	Y_1	Y_2	P	Y_1	Y_2	P	Y_1	Y_2	P	Y_1	Y_2	P	Y_1	Y_2	P	Y_1	Y_2	P
COV(HS)	0.131	0.135	0.133	-0.016	-0.017	-0.016	-0.001	0.001	0.000	0.089	0.092	0.090	0.002	0.001	0.002	-0.003	-0.004	-0.004	0.006	0.008	0.007
COV(FS)	2.680	2.442	2.573	0.795	0.656	0.725	0.238	0.237	0.228	2.518	2.530	2.531	0.059	0.060	0.059	0.168	0.147	0.154	0.221	0.244	0.233
s^2A	0.263	0.271	0.133	0.031	0.034	0.016	0.002	0.003	0.000	0.177	0.184	0.090	0.004	0.005	0.002	0.006	0.008	0.004	0.013	0.016	0.007
s^2D	0.223	0.068	0.089	1.566	1.418	1.491	0.349	0.282	0.307	0.884	0.800	0.851	0.022	0.013	0.017	0.234	0.245	0.237	0.140	0.141	0.141
s^2g (gca)	0.131	0.135	0.267	-0.016	-0.017	-0.032	-0.001	0.001	0.000	0.089	0.092	0.181	0.002	0.003	0.005	-0.003	-0.004	-0.007	0.006	0.008	0.014
s^2s (sca)	0.223	-0.068	0.089	1.566	1.418	1.491	0.349	0.282	0.307	0.884	0.800	0.851	0.022	0.013	0.017	0.234	0.245	0.237	0.140	0.141	0.141
A. Degree. Domi.	0.923	0.503	0.815	7.097	6.487	9.595	12.599	10.414	55.444	2.233	2.084	3.072	2.353	1.694	2.870	6.523	5.539	8.227	3.333	2.995	4.455
Pridicti ratio	0.540	0.798	0.601	0.019	0.023	0.011	0.006	0.009	0.000	0.167	0.187	0.096	0.153	0.258	0.108	0.023	0.032	0.015	0.083	0.100	0.048
% cont. (line)	79.28	79.77	79.56	28.17	26.85	27.51	34.26	40.70	37.66	71.98	72.60	72.27	70.15	74.46	72.50	16.05	8.46	10.94	62.32	65.85	64.12
% cont. (tester)	3.93	3.74	3.84	0.91	1.31	1.10	0.32	1.34	0.56	4.14	4.39	4.27	4.68	6.01	5.36	5.92	5.02	5.67	1.51	1.10	1.31
% cont. (L x T)	16.79	16.49	16.60	70.92	71.84	71.39	65.42	57.96	61.78	23.89	23.00	23.46	25.17	19.53	22.14	78.03	86.52	83.39	36.16	33.05	34.57
Narrow heri (%)	10.848	8.557	5.211	0.871	0.881	0.441	0.507	0.632	0.024	12.89	12.41	6.83	12.22	13.43	6.98	2.14	2.92	1.35	6.20	7.39	3.55

Table 4. Ranking of three desirable parents based on *per se* performance and heterosis effect for quality and yield traits in cucumber

Character	Desirable parents according to per se performance	Best parents based on per se performance & heterosis effects
Nodes per vine	VRCU-2203 x Punjab Naveen VRCU-2203 x Arka Veera VRCU-2203 x Pusa Uday	VRCU-2203 x Punjab Naveen
Fruit length (cm)	NDCU-23-7 x Arka Veera NDCU-23-9 x Punjab Naveen NDCU-23-3 x Pusa Uday	NDCU-23-3 x Arka Veera
Fruit breadth (cm)	VRCU-2203 x Pusa Uday NDCU-23-4 x Arka Veera NDCU-23-3 x Pusa Uday	VRCU-2203 x Pusa Uday
Number of fruits per plant	NDCU-23-10 x Arka Veera NDCU-23-5 x Arka Veera NDCU-23-1 x Punjab Naveen	NDCU-23-10 x Arka Veera
Fruit yield per plant (kg)	NDCU-23-1 x Punjab Naveen NDCU-23-10 x Arka Veera NDCU-23-5 x Arka Veera	NDCU-23-1 x Punjab Naveen
TSS (Brix)	NDCU-23-11 x Pusa Uday NDCU-23-1 x Pusa Uday NDCU-23-5 x Arka Veera	NDCU-23-11 x Pusa Uday
Ascorbic acid (mg/100 g)	NDCU-23-7 x Arka Veera NDCU-23-8 x Pusa Uday NDCU-23-3 x Punjab Naveen	NDCU-23-7 x Arka Veera

of pooled data, the magnitude of heterobeltiosis for fruit breadth ranged from -11.81 (NDCU-23-1 x Punjab Naveen) to 57.99 % (NDCU-23-9 x Punjab Naveen) over better parent while, for standard heterosis it varied from -8.68 (NDCU-23-1 x Punjab Naveen) to 396.57 % (VRCU-2203 x Pusa Uday). Out of 36 crosses, 22 crosses showed significant positive and 01 crosses showed negative heterosis over better parent whereas, 21 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety.

Number of fruits per plant

In case of year 2023, the magnitude of heterobeltiosis for number of fruits per plant ranged from -23.18 (NDCU-23-8 x Pusa Uday) to 60.92 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from -8.27 (NDCU-23-8 x Pusa Uday) to 74.75 % (VRCU-2203 x Pusa Uday). Out of 36 crosses, 14 crosses showed significant positive and 06 crosses showed negative heterosis over better parent whereas, 24 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of year 2024, the magnitude of heterobeltiosis for number of fruits per plant ranged from -19.32 (NDCU-23-8 x Pusa Uday) to 57.31 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from -8.03 (NDCU-23-8 x Pusa Uday) to 72.48 % (VRCU-2203 x Pusa Uday). Out of 36 crosses, 14 crosses showed significant positive and 02 crosses showed negative heterosis over better parent whereas, 24 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of pooled data, the magnitude of heterobeltiosis for number of fruits per plant ranged from -21.23 (NDCU-23-8 x Pusa Uday) to 60.08 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from -8.18 (NDCU-23-8 x Pusa Uday) to 73.54 % (VRCU-2203 x Pusa Uday). Out of 36 crosses, 14 crosses showed significant positive and 04 crosses showed negative heterosis over better parent whereas, 24 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. These findings confirm with the findings reported by previous researchers (30).

Fruit yield per plant

In case of year 2023, the magnitude of heterobeltiosis for fruit yield per plant ranged from -1.53 (NDCU-23-4 x Punjab Naveen) to 108.93 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from 15.99 (NDCU-23-8 x Pusa Uday) to 114.39 % (VRCU-2203 x Pusa Uday). Out of 36 crosses, 24 crosses showed significant positive and 00 crosses showed negative heterosis over better parent whereas, 30 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of year 2024, the magnitude of heterobeltiosis for fruit yield per plant ranged from 0.68 (NDCU-23-8 x Pusa Uday) to 104.62 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from 16.06 (NDCU-23-8 x Pusa Uday) to 113.72 % (NDCU-23-11 x Pusa Uday). Out of 36 crosses, 23 crosses showed significant positive and 00 crosses showed negative heterosis over better parent whereas, 30 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of pooled data, the magnitude of heterobeltiosis for fruit yield per plant ranged from 0.00 (NDCU-23-8 x Pusa Uday) to 106.49 % (NDCU-23-11 x Punjab Naveen) over better parent while, for standard heterosis it varied from 15.05 (NDCU-23-8 x Pusa Uday) to 112.31 % (NDCU-23-11 x Pusa Uday). Out of 36 crosses, 23 crosses showed significant positive and 00 crosses showed negative heterosis over better parent whereas, 30 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. Similar findings were observed by (31, 32).

Total soluble solids

In case of year 2023, the magnitude of heterobeltiosis for total soluble solids ranged from -48.28 (NDCU-23-3 x Pusa Uday) to 16.48 % (NDCU-23-4 x Arka Veera) over better parent while, for standard heterosis it varied from 15.22 (NDCU-23-3 x Pusa Uday) to 57.70 % (NDCU-23-10 x Punjab Naveen). Out of 30 crosses, 3 crosses showed significant positive and 19 crosses showed negative heterosis over better parent whereas, 21 crosses showed significant positive and 01 crosses showed significant negative heterosis over standard variety. In case of year 2024, the magnitude of heterobeltiosis for total soluble solids ranged from -39.03 (NDCU-23-3 x Pusa Uday) to 12.81 % (NDCU-23-5 x Arka Veera) over better parent while, for standard heterosis it varied from -8.63 (NDCU-23-9 x Arka Veera) to 52.27 % (NDCU-23-11 x Pusa Uday). Out of 30 crosses, 1 cross showed significant positive and 19 crosses showed negative heterosis over better parent whereas, 19 crosses showed significant positive and 0 crosses showed significant negative heterosis over standard variety. In case of pooled data, the magnitude of heterobeltiosis for fruit yield per plant ranged from -43.59 (NDCU-23-3 x Pusa Uday) to 13.45 % (NDCU-23-5 x Arka Veera) over better parent while, for standard heterosis it varied from -10.44 (NDCU-23-3 x Pusa Uday) to 54.77 % (NDCU-23-11 x Pusa Uday). Out of 30 crosses, 2 crosses showed significant positive and 19 crosses showed negative heterosis over better parent whereas, 20 crosses showed significant positive and 1 cross showed significant negative heterosis over standard variety. The findings were supported by previous studies (30).

Ascorbic acid content

In case of year 2023, the magnitude of heterobeltiosis for ascorbic acid ranged from -11.93 (NDCU-23-3 x Arka Veera) to 45.00 % (NDCU-23-8 x Pusa Uday) over better parent while, for standard heterosis it varied from -15.28 (NDCU-23-3 x Arka Veera) to 30.49 % (NDCU-23-7 x Arka Veera). Out of 36 crosses, 21 crosses showed significant positive and 02 crosses showed negative heterosis over better parent whereas, 18 crosses showed significant positive and 3 crosses showed significant negative heterosis over standard variety. In case of year 2024, the magnitude of heterobeltiosis for ascorbic acid ranged from -13.01 (NDCU-23-3 x Arka Veera) to 44.18 % (NDCU-23-8 x Pusa Uday) over better parent while, for standard heterosis it varied from -14.63 (NDCU-23-3 x Arka Veera) to 32.53 % (NDCU-23-7 x Arka Veera). Out of 36 crosses, 22 crosses showed significant positive and 02 crosses showed negative heterosis over better parent whereas, 20 crosses showed significant positive and 3 crosses showed significant negative heterosis over standard variety. In case of pooled data, the magnitude of heterobeltiosis for ascorbic acid ranged from -12.68 (NDCU-23-3 x Arka Veera) to 44.52 % (NDCU-23-8 x Pusa Uday) over better parent while, for standard heterosis it varied from -15.00 (NDCU-23-3 x Arka Veera) to 31.62 % (NDCU-23-7 x Arka Veera). Out of 30 crosses, 21 crosses showed significant positive and 02 crosses showed negative heterosis over better parent whereas, 20 crosses showed significant positive and 3 crosses showed significant negative heterosis over standard variety. In Table 5, the best promising genotypes were listed. Similar results were reported earlier (30).

Conclusion

Because their performance was due to additive gene effects, the results also suggest that some crosses may be a source for choosing high-yielding lines in their segregating generations. In cucumbers, heterosis breeding was justified due to the prevalence of non-additive gene action for all parameters except fruit length. The degree and extent of different heterotic effects varied from character to character and from cross to cross. For fruit yield, the cross NDCU-23-11 x Punjab Naveen showed the highest heterosis of 106.49 over better parent and cross NDCU-23 -11 x Pusa Uday showed the highest heterosis of 112.31 over standard variety. Some other combinations like VRCU-2203 x Pusa Uday, VRCU-2203 x Arka Veera and NDCU-23-11 x Pusa Uday can also be suggested for fruit yield character. Hence, this combination can be suggested for future breeding strategies.

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Authors' contributions

All authors contributed equally to this manuscript. All authors read and approved the final manuscript.

Table 5. Best 3 crosses selected based on heterosis for quality and yield traits in cucumber

Character	Heterosis over BP		Heterosis over SV		Range Over	
	Crosses	% Heterosis	Crosses	% Heterosis	BP	SV
Nodes per vine	NDCU-23-11 x Punjab Naveen	59.91	VRCU-2203 x Punjab Naveen	28.69	-2.83 to 59.91 %	-11.13 to 28.69 %
	NDCU-23- 10 x Punjab Vaveen	56.13	VRCU-2203 x Arka Veera	28.15		
	NDCU-23-11 x Arka Veera	42.23	VRCU-2203 x Pusa Uday	26.81		
Fruit length (cm)	NDCU-23-7 x Punjab Naveen	38.48	NDCU-23-3 x Arka Veera	20.53	-1.93 to 38.48 %	-5.40 to 20.53 %
	NDCU-23-9 x Punjab Naveen	30.09	NDCU-23-10 x Punjab Naveen	20.48		
	NDCU-23-5 x Punjab Naveen	26.69	NDCU-23-7 x Punjab Naveen	19.71		
Fruit breadth (cm)	NDCU-23-9 x Punjab Naveen	57.99	VRCU-2203 x Pusa Uday	36.57	-11.81 to 57.99 %	-8.68 to 36.57 %
	VRCU-2203 x Punjab Naveen	56.16	NDCU-23-9 x Punjab Naveen	34.07		
	NDCU-23-9 x Arka Veera	47.61	NDCU-23-8 x Punjab Naveen	33.83		
Number of fruits per plant	NDCU-23-11 x Punjab Naveen	60.08	VRCU-2203 x Pusa Uday	73.54	-21.23 to 60.08 %	-8.18 to 73.54 %
	VRCU-2203 x Pusa Uday	48.87	NDCU-23-11 x Pusa Uday	69.34		
	VRCU-2203 x Pusa Uday	45.26	NDCU-23-11 x Arka Veera	64.42		
Fruit yield per plant (kg)	NDCU-23-11 x Punjab Naveen	106.49	NDCU-23-11 x Pusa Uday	112.31	0.00 to 106.49 %	15.05 to 112.31 %
	VRCU-2203 x Pusa Uday	84.43	VRCU-2203 x Pusa Uday	112.31		
	NDCU-23-11 x Pusa Uday	84.43	VRCU-2203 x Arka Veera	108.24		
TSS (Brix)	NDCU-23-5 x Arka Veera	13.45	NDCU-23-11 x Pusa Uday	54.77	-43.59 to 13.45 %	-10.44 to 54.77 %
	NDCU-23-4 x Arka Veera	9.54	NDCU-23-10 x Punjab Naveen	48.29		
Ascorbic Acid (mg/100 g)	NDCU-23-8 x Pusa Uday	44.52	NDCU-23-7 x Arka Veera	31.62	-12.68 to 44.52 %	-15.00 to 31.62 %
	VRCU-2203 x Pusa Uday	37.77	NDCU-23-8 x Pusa Uday	30.90		
	NDCU-23-9 x Pusa Uday	35.23	NDCU-23-9 x Pusa Uday	30.66		

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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