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# Exploitation of heterosis and combining ability in cucumber (*Cucumis sativus*) for earliness and yield contributing traits

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ABSTRACT

The present experiment was conducted during the rainy (*kharif*) seasons 2021 and the summer season of 2022 at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhnad to investigate the earliness, yield, variation and its effect on cucumber (*Cucumis sativus* L.). The present study comprised of 30 $F_1$ hybrids, developed by line × tester, crossing 10 lines (gynoecious) i.e. PPCUC-2 and PPCUC-3 (parthenocarpic gynoecious line developed by GBPUA&T, Pantnagar), PPCUC-4, PPCUC-5, PPCUC-6, PPCUC-7, PPCUC-9, PPCUC-10, PPCUC-11 and PPCUC-12 and 3 testers (monoecious) parents viz. PCUC-8, PCUC-28 and PCUC-51. A significant difference for mean sum of square was found in all the horticultural traits under study. PPCUC-2 and PPCUC-9 were superior for earliness and PPCUC-3 was best general combiner for yield, which can be used as a parent in breeding programme for development of genoecious × monoecious hybrids. In the cross combination, PPCUC-2 × PCUC-28 for earliness and PPCUC-7 × PCUC-8 is found best hybrids for yield. PPCUC-3 × PCUC-28 was best specific combiner for fruit number. Information of gene actions obtained from the study indicated the predominance of non-additive gene action which is highly desirable to develop hybrids in cucumber with yield traits. Based on heterosis, PPCUC-2 × PCUC-28 and PPCUC-9 × PCUC-28 were most promising crosses for earliness and yield contributing traits. Based on finding, it is also possible to segregate generations using promising hybrids in order to find pure lines with high yields and superior quality fruit.

**Keywords**: Combining ability, Cucumber, Gynoecious, Heterosis, Monoecious

The Cucumber (*Cucumis sativus* L., 2n=2x=14) is a warm season vegetable belongs to the family Cucurbitaceae. It is one of the earliest vegetables to be grown in the history for over thousands of years and probably originated in India (Tatlioglu 1993). In north India, the wild relative, *Cucumis sativus* var. *hardwicki*, grows in the foothills of the Himalayas as a laxative (Deakin *et al.* 1971). Since ancient times, cucumbers have been utilised in therapeutic treatment and cosmetic applications due to their abundance of nutrients and bioactive components (Dixit and Kar 2010). Cucumbers are also extremely low in calories and high in water. It is high in phytochemicals and polyphenols, which likewise has a variety of biological properties including anti-inflammatory, analgesic, anti-carcinogenic, anti-hyaluronidase, and anti-elastase properties (Nema *et al.* 2011, Mukherjee *et al.* 2013). Consuming cucumbers is also advised for the treatment of hypertension, Alzheimer's disease, and prevention of sunburn and other skin conditions, such as swelling beneath the eyes (Mukherjee *et al.* 2013). In addition, cucumbers are said to provide cooling, restorative, calming, emollient, and anti-itching properties for inflammatory skin (Uthpala *et al.* 2020).

Except in times of frost, cucumbers may be cultivated round the year in open field and under covered structures. Off-season cultivation of cucumber fetch high price in the market but its cultivation under open field in north India during winter months becomes difficult due to severe cold and fog (Kumar *et al.* 2017) and because gynoecious varieties and hybrids are not readily available, its cultivation under protected structures is restricted (Kumar *et al.* 2016). The development of high performance stable parthenocarpic gynoecious variety/hybrids for round the year production is need of today and the varieties/hybrids which are available become unstable after few years due to high temperature (Cantliffe 1981).

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Various breeding techniques have been used in the improvement of cucumber. Heterosis breeding is one the most useful breeding tools for improvement, while other breeding techniques require more time (Sherpa *et al.* 2014). Gynoecious lines provide a better chance of developing high yielding hybrid as well as considerably lower the cost of producing seeds (Kumar *et al.* 2017). Significance of hybrid developed through use of gynoecious line as one of the parent was shown by various scientist (Jat *et al.* 2015, Pati *et al.* 2015, Gou *et al.* 2022). To start any breeding programme, genetic variability is pre-requisite and most important for hybridization (Bisht *et al.* 2022). Breeding design like diallel, partial diallel, line × tester, test cross, bi-parental cross are availble and in order to assess breeding lines, numerous crossings are used (Nduwumuremyi *et al.* 2013). Hayes and Jones (1916) in cucumber showed heterosis in terms of fruit quantity and size. Germplasm is further divided into heterotic groups to get most out of heterosis for hybrids. Heterotic grouping is grouping of those germplasm which are superior in performance when crossed and are genetically unique (Melchinger and Gumber 2015). There are three subtypes of heterosis: standard/economic heterosis, heterobeltiosis/better parent heterosis, and average heterosis/mid parent heterosis. Different scientists around the world had used different mating designs as an aid in the choice of parents, and to understand the nature of the genetics involved. Line × tester (L × T) mating design is a popular design used in plant breeding for development of hybrids and exploit the full-sib and half-sib progenies. The studies of GCA and SCA effect on parents and hybrids and estimation of various gene effect is done by L × T design (Kempthorne 1957). Keeping in mind the above facts, the present experiment was planned to estimate heterosis, combining ability, gene action using L × T for horticultural traits. The result of the experiment will be beneficial to develop early and high yielding varieties.

## MATERIALS AND METHODS

*Experimental site, materials and layout plan*: The experiment was carried out during the rainy (*kharif*) season of 2021 and the summer season of 2022 at the Vegetable Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (29.50°N, 79.30°E; at an elevation 344 m amsl), Uttarakhand under natural ventilated protected conditions. Ten female gynoecious line i.e. PPCUC-2 and PPCUC-3 (parthenocarpic gynoecious line developed by GBPUA&T, Pantnagar), PPCUC-4, PPCUC-5, PPCUC-6, PPCUC-7, PPCUC-9, PPCUC-10, PPCUC-11 and PPCUC-12 (advance breeding line and are parthenocarpic gynoecious) and three male monoecious line viz. PCUC-8, PCUC-28 and PCUC-51 (monoecious advance breeding line) were crossed under naturally ventilated polyhouse in line × tester design to generate 30 $F_1$ hybrids of cucumber. $GA_3$ @2000 ppm is applied at 2–3 true leaf stage to maintain all of the parental gynoecious lines. By manually pollinating the female flowers of gynoecious parents with the male flower of monoecious parents, hybrids were produced. After that, three replications of selfed seeds along with $F_1$ of each cross were planted in randomized block designs (RBD). Every plant was positioned with a 60 × 90 cm gap between them in an umbrella training pattern (Klieber *et al.* 1993). To produce a quality crop, all advised agronomic practices were followed (Thind and Mahal 2021).

*Data recording and statistical analysis*: Data on the following characteristics, including days to initial and final harvests, node and days to initial female flower, number of fruits/plant, vine length, fruit diameter, weight and length and yield/plant were collected from five randomly selected plants. Windowstat 8.0 (INDOSTAT Service Limited, Hyderabad, India) was used for data computation. By using Kempthorne (1957) line × tester analysis to the data, information regarding general combining ability (GCA) and specialized combining ability (SCA) was acquired. Griffing (1956) technique 2 model I was utilised to estimate the genetic component ($\sigma^2$gca and $\sigma^2$sca). As a result, they were calculated as a percentage change in $F_1$'s over the mid-parent (MP) and better parent (BP) provided by Turner (1953) and Hayes *et al.* (1956). The heterosis estimation formula given by Fonseca and Patterson (1968) and the methods given by Singh and Chaudhary (1997) were used to determine the additive and dominant portions of variance.

## RESULTS AND DISCUSSION

*Analysis of variance for line × tester analysis*: After statistical analysis of the ANOVA for L × T, it was discovered that the mean sum of square due to crosses was significant ($p$< 0.05 and 0.01) for every parameter (Table 1), with the exception of days to final harvest. Simultaneously, the tester indicated a significant value only for fruit diameter, while the variance analysis due to line was significant for all characters except days to initial harvest, vine length, and fruit weight. For the majority of qualities, the analysis of variance resulting from lines and crosses was very significant, suggesting that there is enough genetic variation in the germplasm. The findings are consistent with those of Pati *et al.* (2015) and Das *et al.* (2020), who also discovered a substantial variation in the mean sum of square for the characters under study.

*General combining ability (GCA) effect of parents*: From the Table 2, it was revealed that the line PPCUC-2, PPCUC-5 and PPCUC-9 were found to have significant and negative GCA for early female flowering. In node to initial flower and days to initial harvest, similar effect of GCA was found in PPCUC-2 and PPCUC-9. Similarly, PPCUC-11 for days to final harvest and vine length, and PPCUC-2 for vine length (highest) and number of fruit/plants showed significant and favourable GCA effect. PPCUC-3, PPCUC-7, and PPCUC-9 showed a significant and positive GCA effect for fruit weight and length. PPCUC-2, PPCUC-3, and PPCUC-4 showed positive and significant GCA for numbers of fruit/plant, whereas PPCUC-3 and PPCUC-4 showed significant and positive GCA for fruit yield/plant. Among the tester, only PCUC-28 had significant and positive GCA for fruit diameter. In the present study, all the line

Table 1 Analysis of variance and genetic component in L×T analysis

| Source of variations | df | Days to initial female flower | Node to initial female flower | Days to initial harvest | Days to final harvest | Vine length | Fruit length | Fruit diameter | Number of fruit/ plant | Fruit weight | Fruit yield/ plant |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Replicates | 2 | 79.53** | 6.97** | 35.58** | 16.47 | 0.07 | 0.24 | 0.07 | 0.06 | 3102.78 | 0.11 |
| Environments | 1 | 0.31 | 70.21** | 18.07* | 1211.66** | 2.05** | 441.46** | 14.34** | 19.08** | 384094.80** | 0.07 |
| Rep. × Env. | 2 | 28.02** | 2.80 | 14.72* | 13.32 | 0.06 | 1.16 | 0.26 | 1.24 | 43.40 | 0.03 |
| Crosses | 29 | 11.73** | 3.02** | 7.70** | 12.48 | 0.22** | 16.34** | 0.27** | 3.12** | 1962.86* | 0.13** |
| Line effect | 9 | 24.39** | 7.19** | 14.03* | 10.56 | 0.31 | 35.29** | 0.20 | 7.61** | 696.38 | 0.23* |
| Tester effect | 2 | 14.86 | 1.93 | 3.82 | 14.55 | 0.05 | 2.70 | 0.96* | 0.47 | 715.13 | 0.11 |
| Line × Tester effect | 18 | 5.06 | 1.06 | 4.97 | 13.21 | 0.19** | 8.39** | 0.23* | 1.17** | 2734.73** | 0.08* |
| Env. × Crosses | 29 | 6.43 | 2.14* | 3.36 | 10.87 | 0.28** | 6.52** | 0.29** | 0.74* | 3542.72** | 0.21** |
| Env. × Line effect | 9 | 7.23 | 2.85* | 5.65 | 10.70 | 0.52* | 8.74 | 0.24 | 1.16 | 3164.09 | 0.46** |
| Env. × Tester effect | 2 | 14.10 | 8.64** | 5.09* | 4.49 | 0.21 | 9.03 | 0.05 | 0.07 | 3160.41 | 0.01 |
| Env. × (L × T) effect | 18 | 5.18 | 1.06 | 2.02 | 11.67 | 0.17* | 5.14** | 0.34** | 0.61 | 3774.51** | 0.10** |
| Error | 116 | 4.79 | 1.25 | 3.51 | 10.58 | 0.09 | 2.10 | 0.12 | 0.45 | 1219.80 | 0.04 |
| $\sigma^2$ g | | 0.06 | 0.02 | 0.03 | -0.01 | 0.0002 | 0.07 | 0.0004 | 0.02 | -7.22 | 0.004 |
| $\sigma^2$ s | | -0.01 | -0.06 | 0.25 | 0.43 | 0.01 | 0.9 | 0.01 | 0.11 | 175.06 | 0.19 |
| $\sigma^2$ e | | 0.85 | 0.24 | 0.58 | 1.77 | 0.02 | 0.5 | 0.03 | 0.08 | 280.73 | 0.16 |
| $\sigma^2$ A | | 0.12 | 0.04 | 0.05 | -0.01 | 0.001 | 0.15 | 0.001 | 0.04 | -14.43 | 0.01 |
| $\sigma^2$ D | | -0.01 | -0.06 | 0.25 | 0.43 | 0.01 | 0.9 | 0.01 | 0.11 | 175.06 | 0.19 |
| ($\sigma^2$A/ $\sigma^2$ D) | | -13.87 | -0.61 | 0.21 | -0.03 | 0.04 | 0.17 | 0.07 | 0.33 | -0.08 | 0.04 |

*, ** significance at 5% and 1% respectively; $\sigma^2$g, GCA variance; $\sigma^2$s, SCA variance; $\sigma^2$e, Error variance; $\sigma^2$A, Additive variance; $\sigma^2$D, Dominance variance.

Table 2 Best general and specific combiner for horticultural traits in cucumber

| Traits | Best General Combiner | Best Specific Combiner |
|---|---|---|
| Days to initial female flower | PPCUC-2 (-1.34), PPCUC-5 (-1.71), PPCUC-9 (-1.59) | PPCUC-2 × PCUC-28 (-1.00), PPCUC-10 × PCUC-8 (-1.85), PPCUC-12 × PCUC-28 (-0.92) |
| Node to initial female flower | PPCUC-2 (-1.10), PPCUC-9 (-0.59) | PPCUC-3 × PCUC-8 (-0.89), PPCUC-5 × PCUC-51 (-0.58) |
| Days to initial harvest | PPCUC-2 (-1.04), PPCUC-5 (-1.14), PPCUC-9 (-1.38) | PPCUC-10 × PCUC-8 (-1.65) |
| Days to final harvest | PPCUC-11 (1.64) | PPCUC-12 × PCUC-51 (2.37), PPCUC-3 × PCUC-28 (1.57) |
| Vine length (m) | PPCUC-2 (0.21), PPCUC-11 (0.19) | PPCUC-9 × PCUC-51 (0.22), PPCUC-12 × PCUC-28 (0.19) |
| Fruit length (cm) | PPCUC-3 (1.89), PPCUC-7 (1.65), PPCUC-9 (1.46) | PPCUC-7 × PCUC-28 (1.71), PPCUC-10 × PCUC-51 (1.46) |
| Fruit diameter (cm) | PCUC-28 (0.12) | PPCUC-7 × PCUC-8 (0.29), PPCUC-9 × PCUC-51 (0.19) |
| Number of fruit/plant | PPCUC-2 (0.58), PPCUC-3 (0.90), PPCUC-4 (1.05) | PPCUC-3 × PCUC-28 (0.78) |
| Fruit weight (g) | PPCUC-3 (8.49), PPCUC-7 (6.38), PPCUC-9 (7.53) | PPCUC-11 × PCUC-8 (28.53), PPCUC-12 × PCUC-51 (23.50) |
| Fruit yield/plant (Kg) | PPCUC-3 (0.24), PPCUC-4 (0.11) | PPCUC-4 × PCUC-28 (0.15), PPCUC-7 × PCUC-8 (0.14) |

showed significant (positive/negative) GCA effect for at least one of the parameters under study. The only traits i.e. fruit diameter was significant and positive for tester. This demonstrated the need for improvement in terms of yield, earliness, and associated traits. These findings are consistent with those of other researchers who reported good general combiner parents in their investigations (Kumar *et al.* 2013, Melchinger and Gumber 2015, Das *et al.* 2020, Manggoel *et al.* 2021). Genotypes PPCUC-2 and PPCUC-9 for earliness traits like days to initial harvest, node to initial female, days to initial female flowers and PPCUC-3 for yield and related traits were best lines. Among testers, PCUC-28 was best tester.

*Specific combining ability effect of crosses*: Specific combining ability (SCA) of 30 $F_1$'s has been revealed in Table 2. The cross combination PPCUC-10 × PCUC-8 had desirable significant and negative SCA for days to initial harvest. Likewise, cross PPCUC-7 × PCUC-28 and PPCUC-10 × PCUC-51 for fruit length and PPCUC-3 × PCUC-28 for number of fruit/plant had significant positive SCA. Whereas none of crosses were found to be significant for days to initial female flower, node to initial female flower, vine length and fruit yield/plant. For specific combining ability, PPCUC-10 × PCUC-8 for earliness and PPCUC-3 × PCUC-28 and PPCUC-7 × PCUC-28 for yield related traits were best. The significant SCA was reported by Reddy *et al.* 2014 and Kumari *et al.* 2021. In most of the cross combination, the hybrid developed by crossing gynoecious and monoecious lines were intermediated between gynoecious and monoecious. Most of gynoecious were best for earliness and yield related characters and most of monoecious were good for fruit characters like length, width and weight. As a result, most of hybrids developed were less superior to parents.

*Heterosis (Mid-parent and better parent) analysis*: One of the key tools for using of genetic variation is heterosis, or hybrid vigour (Kumar *et al.* 2013). The ranges for the better parent and mid parent were -12.56–1.14 and -3.82–7.47 for days to the initial female flower, respectively (Table 3). The range of the better parent is -25.79–2.79 and that of the mid parent is 9.19–43.00 for node to female flower, respectively. The range of average heterosis and heterobeltiosis for days to initial harvest was -0.39–8.16 and -6.95–3.45, respectively. Nine hybrids showed negative heterobeltiosis for days to initial female flower and node to initial female flower, and five hybrids showed negative heterobeltiosis for days to initial harvest. None of the hybrids exhibited negative relative heterosis for days to initial female flower, days to initial node, or days to initial harvest. Seven hybrids had positive relative heterosis, while none had heterobeltiosis for the number of days till final harvest. The range of average heterosis and heterobeltiosis for days to final harvest was -0.73–4.10 and -4.13–1.25, respectively. The range of average heterosis and heterobeltiosis for vine length was -7.75–17.12 and -24.35–8.51, respectively. Eight hybrids had positive relative heterosis for vine length, but none of the hybrids showed heterobeltiosis. Average heterosis and heterobeltiosis varied from 9.33–45.66 and -7.79–31.70 for fruit length, respectively. Of the hybrids with fruit length, 28 had positive relative heterosis and 16 had heterobeltiosis. The range of average heterosis and heterobeltiosis for fruit diameter was 6.05–25.49 and -7.79–9.94, respectively. 28 hybrids had positive relative heterosis for fruit diameter, whereas 7 hybrids had heterobeltiosis. Fruit weight ranged from -22.84–5.44 for average heterosis and -5.03–54.30 for heterobeltiosis, respectively; 15 hybrids displayed heterobeltiosis for fruit weight. In terms of fruit number, the range of average heterosis and heterobeltiosis was -72.55 to -44.68 and -83.10–64.52, respectively; in terms of yield/plant, the range was –37.87 to -1.43 and -21.15 to -51.72, respectively; in terms of both fruit number and fruit yield/plant, none of the hybrids showed positive relative heterosis or heterobeltiosis. The crosses PPCUC-2 × PCUC-28 (Fig. 1) followed by PPCUC-9 × PCUC-28 were best hybrid for most of traits under study. Heterosis manifest the performance of hybrid progeny than the parental inbreds.

A positive or negative heterosis is possible. Because negative heterosis transfers energy from the vegetative phase into the reproductive phase and increases production. It is helpful for early measurements such as days to initial

Table 3 Range of heterosis for horticultural traits over better and mid parents

| Traits | Range of heterosis | | Number of significant cross over | |
|---|---|---|---|---|
| | Mid | Better | Mid | Better |
| Days to initial female flower | -3.82 to 7.47 | -12.56 to 1.14 | 6 | 9 |
| Node to initial female flower | 9.19 to 43.00 | -25.79 to 2.79 | 27 | 9 |
| Days to initial harvest | -0.39 to 8.16 | -6.95 to 3.45 | 21 | 5 |
| Days to final harvest | -0.73 to 4.10 | -4.13 to 1.25 | 7 | 3 |
| Vine length (m) | -7.75 to 17.12 | -24.35 to 8.51 | 10 | 9 |
| Fruit length (cm) | 9.33 to 45.66 | -7.79 to 31.70 | 28 | 16 |
| Fruit diameter (cm) | 6.05 to 25.49 | -7.79 to 9.94 | 28 | 7 |
| Number of fruit/plant | -72.55 to -44.68 | -83.10 to 64.52 | 30 | 30 |
| Fruit weight (g) | 22.84 to 85.48 | -5.03 to 54.30 | 30 | 15 |
| Fruit yield/plant (kg) | -37.87 to -1.43 | -21.15 to -51.72 | 24 | 30 |


Fig. 1 Best parents (PPCUC-3 and PCUC-28) and best hybrid (PPCUC-2 × PCUC-28).

female flower, node to initial female flower, days to initial harvest, etc. In the cutthroat market, early-fruiting cucumbers command a premium price, making them a coveted characteristic. This might be the cause, as an early female flowering at a lower node leads to an early fruit growth and harvest. Similar results on earliness's negative significant heterosis were noted by Bairagi *et al.* 2013, Kumar *et al.* 2017 and Kumari *et al.* 2021. When it comes to characteristics that are connected to yield, such as the quantity of fruits produced/plant, the size, length, weight, and diameter of the fruits, positive heterosis is preferred. Higher yield is primary objective of all cucumber growers. More number of fruits result in higher yield. The results were in close proximity to those of Jat *et al.* 2015 and Tiwari and Singh 2016 who revealed hybrid vigour for number of fruits/plant in various cross combinations.

*Gene action*: Relative estimates of the additive and non-additive genetic variation components are crucial for crop development. With the exception of days to initial female flower and node to initial female flower (Table 1), the estimate of $\sigma^2$SCA was larger than $\sigma^2$GCA for all traits. Moreover, the ratio of $\sigma^2$SCA/$\sigma^2$GCA was greater than unity, suggesting that non-additive gene action predominates in determining these traits. The role of non-additive gene action in cucumber was also reported by earlier scientists like Kumar *et al.* 2016.

Although considerable progress has been made in the field of monoecious cucumber, but there was little progress in the gynoecious cucumber. The parents gynoecious PPCUC-3 (female) and monoecious PCUC-28 (male) were best parents and can be used as for further breeding programmes as a parent. The best hybrid combinations, PPCUC-2 × PCUC-28 and PPCUC-9 × PCUC-28, which showed desirable heterotic effects, should be evaluated further for commercial release. Crucially, the genetic analysis confirmed that non-additive gene action controls most yield and fruit characteristics. Therefore, the most efficient breeding strategy for this cucumber germplasm is the exploitation of hybrid vigour (heterosis) through the development of $F_1$ hybrids, rather than pure-line selection. The results provide a robust foundation for developing early, high-yielding, and stable gynoecious × monoecious hybrids necessary for round-the-year cucumber production.

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