**Annals of Plant and Soil Research 24(4):660-669 (2022)**
https://doi.org/10.47815/apsr.2022.10225

# Heterotic affinity and genetic control of monoecious cucumber (*Cucumis sativus* L.) inbred line for economic traits and tolerance to downy mildew disease

**SHIBASHIS DAS, SHUBASIS KUNDU, SWADESH BANERJEE, SK MASUDUL ISLAM, DEBMALA MUKHERJEE, SUBHRADEEP PRAMANIK, TANMOY GHOSH, ASIT KUMAR MANDAL[1] AND ARUP CHATTOPADHYAY***

Department of Vegetable Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India
[1]Department of Plant Pathology, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Received: September, 2022; Revised accepted: November, 2022

## ABSTRACT

*A cucumber (Cucumis sativus L.) hybrid could be acceptable to growers of tropical and subtropical climates if it is a high yielder with good fruit quality, and has appreciable tolerance against downy mildew disease which causes significant crop loss. Seven diverse parents were crossed in half diallel fashion to determine the extent of heterobeltiosis, mode of gene action, and combining ability effects for 17 quantitative characters at Research Farm, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nasia, West Bengal. Preponderance of non-additive gene action as realized from the predictability ratio for all the characters under study suggested heterosis breeding could be the best strategy to improve the yield and other component traits. On the basis of GCA effects and per se performance, two parents, BCCU-3 and BCCU-12 appeared consistently superior in respect of fruit yield/plant and other important horticultural traits including tolerance against downy mildew, and could be used as potential donors in future breeding. Outstanding hybrids based on SCA effects, heterobeltiosis manifested in them and per se performances were BCCU-16 × BCCU-4 and BCCU-3 × BCCU-16, and they could be commercially exploited after critical evaluations in tropics and subtropics. Commercially exploitable cucumber hybrids tolerant to downy mildew disease could be developed with the involvement of a single parent tolerant to this disease.*

**Keywords:** Combining ability, Cucumber, *Cucumis sativus*, Heterosis, Gene action

## INTRODUCTION

The cucumber is an important cucurbitaceous vegetable grown in tropical and subtropical countries which comprises 90 genera and 750 species. It is especially grown for its edible tender fruits, favoured salad additive, pickles, and desert fruit and as a cooked vegetable. Extensive use of local landraces or non-selfed seeds of improved varieties, and tremendous biotic stresses have resulted in drastic reduction in optimum productivity of cucumber over the last couple of years. Moreover, most of the hybrids developed by both public and private sectors are insipid or watery in taste and prone to attack of downy mildew which hinders the greater acceptability among the growers and consumers particularly in eastern Gangetic plains of India. Among cucurbits, cucumber is more prone to attack of downy mildew causing substantial yield losses during rainy and autumn-winter seasons in the Gangetic plains of eastern India (Das *et al.*, 2019a) and in some areas early infection with fungal disease has rendered the growing of cucumber uneconomical, causing whole field to be abandoned prior to harvest (Gupta *et al.*, 2014). The pathogen generally thrives well in warm and humid regions of tropical and sub-tropical climates. Leaf wetness of 8-10 hours is critical for infection to occur, with sporangia requiring free moisture to germinate, but a temperature of 15°C determines the rate of disease (Das *et al.*, 2019a). Downy mildew decreases flower set and fruit development by killing the foliage. The satisfactory control of disease may be achieved with the application of certain fungicides but complete and environmental safer protection from the disease through host plant resistance is more preferred and effective option. Therefore, the use of resistant cultivars/hybrids could provide farmers with economic and environmentally sound management strategies for downy mildew

**Corresponding authors' E-mail: chattopadhyay.arup@gmail.com*

control. Studies of the genetic bases of resistance to *P. cubensis* resulted in the identification of both single-gene-mediated and polygenically inherited resistance (Epinat and Pitrat, 1994). Therefore, much concentrated efforts are necessary to improve its yield, quality and host plant resistance against this fungal disease. The proper choice of parents is a prerequisite in any sound breeding programme. Genetic diversity as well as the combining ability is considered as the most important criteria for the selection of parents in the production of a hybrid. The study on the gene action of reproductive and fruit quality traits will be of great benefit to breeders for establishing suitable breeding strategies for the development of desired variety in cucumber.

Cucumber is highly amenable for heterosis breeding programme because of the cross pollination and monoecious nature of the crop and produces large number of seeds per fruit and low seed rate required per unit area, which provides ample scope for the utilization of heterosis breeding and has a great scope of improvement over its base population (Singh *et al.*, 2010; Das *et al.*, 2019b). In fact, cucumber hybrids have gained high importance both in export and domestic markets. However, scanty work on the development of cucumber hybrid by utilizing parents having monoecious sex form with appreciable tolerance against downy mildew disease necessitates further study. The present investigation also aimed to develop more flesh thickness and less fruit cavity thickness without carpel separation which is suitable for export, processing purpose and get more price from the consumer. The identification of highly heterotic combination involving parents showing predominantly non-additive gene action is required for their commercial exploitation as hybrid. Heterosis is rather a function of specific cross combinations, so analysis of combining ability helps to determine the feasibility of its utilization and identification of best combiners. It also helps in the identification of superior hybrid combinations which may be utilized for commercial exploitation of heterosis. Among mating designs, diallel crossing is most frequently used to determine nature and magnitude of gene action through estimates of genetic components, general and specific combining ability variances, and their effects in self, often-cross and cross-pollinated crops. Therefore, the main objective of the present investigation was to assess the extent of heterosis in desired direction, and to determine the nature of gene action for yield and other important attributes with a view to identify good combiners, as well as to frame the breeding strategy for the genetic improvement of such characters in cucumber.

## MATERIALS AND METHODS

The investigation was carried out at “C” Block Farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal under the research field of AICRP on Vegetable Crops during early autumn, 2018 and *kharif* season, 2019. Seven monoecious parents, BCCU1, BCCU7, BCCU3, BCCU12, BCCU16, BCCU13 and BCCU4 identified through multivariate analysis, were crossed in half diallel fashion during early autumn, 2018 to develop 21 $F_1$s. Previously bagged male and female flower were crossed between 6 a.m. and 8 a.m. and then crossed flowers were bagged again with butter paper bags. The $F_1$ seeds were extracted, sun dried and kept in a desiccator for evaluation in the next year. Selfing of parental lines was done in the same way.

Seeds of 21 $F_1$s along with 7 parental lines were sown separately in plots at a spacing of 1 m × 60 cm accommodating ten plants per plot following Randomized Complete Block Design with 3 replications during *kharif* season, 2019. Developing plants were supported on trellises made of bamboos and tied with nylon strings. The soil was ploughed and brought to fine tilth. Cow manure @ 10 $Mt{\cdot}ha^{-1}$ and N:P:K was applied at 80:40:40 $kg{\cdot}ha^{-1}$. Normal package of practices was followed as per Chattopadhyay *et al.* (2007). Five randomly selected plants from 21 hybrids and 7 parental lines were considered to record observations on number of branches/plant, internodal length (cm), days to first male flower appearance, days to first female flower appearance, nodal position of first female flower, days to 50% female flower appearance, days to 1$^{st}$ harvest, days to marketable maturity of fruit, fruit length (cm), fruit diameter (cm), number of fruits/plant, fruit weight (g), fruit flesh thickness (cm), fruit cavity thickness (cm) and fruit yield/plant (kg). Vitamin C content (mg/100 g fresh fruit) was estimated as per Sadasivam and Manickam (1996).

Severity of downy mildew disease was recorded periodically starting from 15 days after sowing (DAS) up to 90 DAS from all plants from each plot in each replication during early morning. The spread of the disease was studied through visual observation from initiation of the disease till final harvest. The disease severity (Percent Disease Index, PDI) was recorded by using disease rating scale (0-9) as proposed by Yangn *et al.* (2007).

Combining ability effects were calculated as per Griffing's (1956) Method-II and Model-I. Heterosis expressed as per cent increase or decrease in the mean values of $F_1$'s (hybrid) over mid parent (relative heterosis), over better-parent (heterobeltiosis) and over standard hybrid (standard heterosis) was calculated according to method suggested by Hayes *et al.* (1955). The significance of heterosis was tested by using t-test as suggested by Wynne *et al.* (1970).

## RESULT AND DISCUSSION

### Analysis of variance and study on genetic control of characters

Analysis of variance for parents and hybrids varied (Table 1). The parents were highly significant for all the characters under study. Among the highly significant parental differences, differences among both parents and hybrids were very high excepting fruit flesh thickness, fruit cavity thickness and vitamin C content. These highly divergent parental lines indicated their suitability for developing divergent hybrids. Parents *vs*. hybrids variance were also significant for most of the characters except number of branches/plant, internodal length, days to marketable maturity of fruit and fruit cavity thickness which indicated that average heterosis was also highly significant for such traits. Thus considerable amount of average heterosis was reflected in the hybrids. Significant differences among the hybrids for the studied characters indicated varying performance of the cross combinations for the characters.

The analysis of variance for combining ability based on Griffing's (1956) Model 1 and Method 2 illustrated that components of GCA and SCA mean squares were highly significant for fruit yield/ plant along with other quantitative traits in $F_1$ generation (Table 2). This indicated that the inheritance of fruit yield/plant, most of the yield components and downy mildew disease severity traits were apparently controlled by both additive and non-additive gene action. Highly significant GCA and SCA variances for fruit yield/plant and most of the component traits in cucumber were also observed by previous worker (Kumar *et al.,* 2013; Das *et al.*, 2019). The present study reflected the overwhelming response of non-additive gene effects for all the traits under study as their predictability ratios were less than 0.50 (Table 2). The importance of non-additive gene action for the conditioning of most of the yield components in the present study indicates heterosis breeding to be the best possible option for improving these traits in cucumber. Downy mildew tolerance was also controlled by non-additive gene action which suggested development of $F_1$ hybrid by crossing two highly resistant inbreed line would provide better tolerance to downy mildew disease. The overwhelming response of non-additive gene action for number of branches/plant, intermodal length, nodal position of female flower and fruit length, fruit diameter and fruit weight, vitamin C and fruit yield/plant were documented (Kaur *et al.*, 2016; Dhall, 2017; Kaur and Dhall, 2017).

### Identification of good general combiner(s)

The diallel analysis helps to identify the most promising combining parents and crosses for the different quantitative traits under study in addition to provide estimates of combining ability variances for the characters to be improved. The GCA effects of the parents used in the present study for seventeen quantitative traits are given in Table 3. No single parent was found to be a good combiner for all the traits under study. Among the parental lines, the maximum significant GCA effects in desired directions were recorded by BCCU-3 for twelve characters namely, fruit yield/plant followed by PDI of downy mildew, number of fruits/plant, fruit weight, fruit diameter, fruit length, days to marketable maturity of fruit, days to first harvest, days to 50% female flower, days to first male and female flowers appearance and intermodal length. Next to BCCU-3, significant GCA effect in desired direction was exhibited by BCCU-12 for fruit yield/plant, PDI of downy mildew, vitamin C content, number of fruits per pant, fruit cavity thickness, fruit flesh thickness and days to marketable maturity of fruit. Significant and

Table 1: Analysis of variance response for parents, hybrids and their interaction for characters affecting Cucumber in a 7 × 7 half diallel cross

| Source of variation | d.f. | NBPP | IL | DFMF | DFFF | NFFFA | D50FF | DFH | DMMF | FFT | FCT | FL | FD | FW | NFPP | VITC | PDIDM | FYPP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replicates | 2 | 0.73** | 0.099 | 0.769 | 0.026 | 0.400* | 1.750 | 7.005** | 0.008 | 0.004 | 0.000 | 0.196 | 0.295** | 37.687 | 0.153 | 0.266** | 2.463* | 0.020 |
| Parents | 6 | 0.48** | 0.68** | 32.44** | 54.57** | 8.795** | 52.714** | 60.635** | 0.537** | 0.072*** | 0.157** | 3.165** | 0.498** | 946.631** | 80.778** | 0.229** | 15.084** | 1.755** |
| Hybrids | 20 | 2.63** | 0.52** | 45.94** | 53.752** | 5.835** | 46.643** | 53.806** | 0.979** | 0.070** | 0.135** | 6.262** | 0.349** | 480.011** | 90.343** | 0.262** | 199.683** | 2.087** |
| Parent *vs.* Hybrids | 1 | 0.337 | 0.046 | 109.22** | 222.780** | 4.274** | 211.750** | 203.742** | 0.029 | 0.247** | 0.014 | 1.950** | 0.260** | 1057.431** | 32.616** | 0.433** | 689.277** | 2.019** |
| Error | 54 | 0.099 | 0.097 | 0.310 | 0.013 | 0.087 | 1.306 | 1.188 | 0.044 | 0.005 | 0.006 | 0.066 | 0.026 | 25.865 | 1.188 | 0.043 | 0.558 | 0.035 |

**, ** Significant at P ≤ 0.05 and P ≤ 0.01, respectively*

*NBPP =Number of branches/plant; IL= Internodal length (cm); DFMF=Days to first male flower; DFFF= Days to first female flower; NFFFA=Node at which first female flower appears; D50FF=Days to 50% female flower; DFH= Days to first harvest; DMMF =Days to marketable maturity of fruit; FFT = Fruit flesh thickness (cm); FCT=Fruit cavity thickness (cm); FL=Fruit length (cm); FD=Fruit diameter (cm); FW= Fruit weight (g); NFPP= Number of fruits/plant; VITC =Vitamin C content (mg/100 g); PDIDM =Percent disease index of downy mildew (%); FYPP=Fruit yield/plant (kg)*

Table 2: Analysis of variance (mean square) for combining ability (Griffing's Model 1 and Method 2)

| Source of variation | d.f. | NBPP | IL | DFMF | DFFF | NFFFA | D50FF | DFH | DMMF | FFT | FCT | FL | FD | FW | NFPP | VITC | PDIDM | FYPP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GCA | 6 | 0.073 | 0.386** | 15.398** | 26.459** | 2.153** | 24.507** | 26.981** | 0.300** | 0.030** | 0.026** | 0.930** | 0.194** | 178.68** | 43.61** | 0.048** | 45.00** | 0.961** |
| SCA | 21 | 0.865** | 0.118** | 15.008** | 18.237** | 2.142** | 16.186** | 18.381** | 0.276** | 0.024** | 0.050** | 2.054** | 0.106** | 208.27** | 24.42** | 0.098** | 62.91** | 0.587** |
| Error | 54 | 0.033 | 0.032 | 0.103 | 0.004 | 0.029 | 0.435 | 0.395 | 0.014 | 0.001 | 0.002 | 0.022 | 0.008 | 8.621 | 0.396 | 0.014 | 0.186 | 0.011 |
| α2a | | 0.008 | 0.078 | 3.398 | 5.878 | 0.472 | 5.349 | 5.907 | 0.063 | 0.006 | 0.005 | 0.201 | 0.041 | 37.79 | 9.604 | 0.007 | 9.95 | 0.211 |
| α2na | | 0.831 | 0.086 | 14.904 | 18.233 | 2.113 | 15.751 | 17.985 | 0.262 | 0.022 | 0.048 | 2.032 | 0.098 | 199.64 | 24.033 | 0.083 | 62.72 | 0.575 |
| $\alpha^2a/\alpha^2a+\alpha^2na$ | | 0.01 | 0.48 | 0.19 | 0.24 | 0.18 | 0.25 | 0.25 | 0.20 | 0.22 | 0.10 | 0.09 | 0.30 | 0.16 | 0.29 | 0.08 | 0.14 | 0.27 |

*** Significant at P ≤ 0.01.*

[a] *df = Degrees of freedom.*

*NBPP =Number of branches/plant; IL= Internodal length (cm); DFMF=Days to first male flower; DFFF= Days to first female flower; NFFFA=Node at which first female flower appears; D50FF=Days to 50% female flower; DFH= Days to first harvest; DMMF =Days to marketable maturity of fruit; FFT = Fruit flesh thickness (cm); FCT=Fruit cavity thickness (cm); FL=Fruit length (cm); FD=Fruit diameter (cm); FW= Fruit weight (g); NFPP= Number of fruits/plant; VITC =Vitamin C content (mg/100 g); PDIDM =Percent disease index of downy mildew (%); FYPP=Fruit yield/plant (kg).*

[b] *$\alpha^2a$ = Additive genetic variance,* [c] *$\alpha^2na$ = Non-additive genetic variance.* [d] *$\alpha^2a/\alpha^2a+\alpha^2na$ = Ratio of additive*

genetic variance to total genetic variance.positive GCA effects for fruit yield/plant, number of fruits/plant, number of branches/plant, fruit length, fruit diameter, fruit weight and vitamin C content were also reported (Bairagi *et al.*, 2013; Kaur, 2016; Moradipour *et al.*, 2016; Kaur and Dhall, 2017). While negatively significant GCA effects for days to first male and female flower appearance, nodal position of female flower and days to first harvest were also recorded (Tak *et al.*, 2017).

Two parental lines, BCCU-3 and BCCU-12 were found most promising donors because they showed high *per se* performance for fruit yield/plant along with number of fruits/plant and minimum severity of downy mildew disease. They produced the maximum frequency of high yielding hybrids with appreciable downy mildew disease tolerance when crossed with other parents.

**Identification of good specific combiner(s)**

Specific combining ability effects represent dominance and epistatic components of genetic variations which are not fixable but the crosses with high SCA effects involving good general combiner parents can be exploited in future breeding programme. The SCA effects for hybrids pertaining to seventeen characters are given in Table 3 and 4. Significant SCA effects in desired direction were recorded in eight crosses for days to first male flower, days to first female flower; seven crosses for days to marketable maturity of fruit and fruit cavity thickness; six crosses for fruit weight; five crosses for days to first harvest, fruit length and fruit flesh thickness; four crosses for fruit yield/plant, PDI of downy mildew, number of fruits/plant and vitamin C content of fruit.

Table 3: Estimates of general- and specific-combining ability effects of parents and hybrids for growth and fruit characters of Cucumber

| Parent | Number of branches /plant | Internodal length (cm) | Days to first male flower | Days to first female flower | Node at which first female flower appears | Days to 50% female flower | Days to first harvest | Days to marketable maturity of fruit | Fruit flesh thickness (cm) |
|---|---|---|---|---|---|---|---|---|---|
| BCCU-1 (P1) | -0.005 | -0.317 ** | -0.249* | -0.655** | -0.417** | -0.302 | -0.388 | -0.225** | -0.063** |
| BCCU-7 (P2) | -0.012 | 0.212** | 0.629** | 1.855** | 0.316** | 1.365** | 1.514** | 0.297** | 0.051** |
| BCCU-3 (P3) | 0.008 | -0.155** | -2.371** | -2.504** | 0.436** | -2.524** | -2.460** | -0.114** | -0.053** |
| BCCU-12 (P4) | -0.097 | 0.070 | 1.584** | 0.927** | 0.681** | 0.921** | 1.750** | -0.081* | 0.040** |
| BCCU-16 (P5) | -0.117* | -0.057 | 1.106** | 2.12 ** | -0.613** | 2.254** | 1.886** | -0.048 | 0.043** |
| BCCU-13 (P6) | 0.097 | 0.281** | -0.671** | -1.429** | -0.360** | -1.413** | -1.486** | 0.197** | 0.051** |
| BCCU-4 (P7) | 0.126* | -0.033 | -0.027 | -0.314 | -0.043 | -0.302 | -0.815** | -0.025 | -0.070** |
| SE (gi) | 0.209 | 0.207 | 0.370 | 0.075 | 0.196 | 0.760 | 0.725 | 0.139 | 0.049 |
| Hybrid | | | | | | | | | |
| BCCU 1 × BCCU 7 | -0.276 | 0.194 | 6.903 ** | 5.527** | -0.331* | 4.472** | 3.953** | 0.125 | -0.094* |
| BCCU 1 × BCCU 3 | 1.704** | -0.280 | -1.797** | -1.114 ** | -1.391** | -0.639 | -0.073 | -0.264* | -0.030 |
| BCCU 1 × BCCU 12 | 0.609** | 0.486** | -4.053** | -2.295** | 1.204** | -3.083** | -2.733** | -0.497** | -0.243** |
| BCCU 1 × BCCU 16 | -1.171** | 0.262 | -0.375 | -0.739** | -0.472** | 0.583 | -0.420 | -0.531** | -0.076 |
| BCCU 1 × BCCU 13 | -0.785** | -0.615** | 3.203** | 2.851** | -0.185 | 3.250** | 1.283* | 0.625** | 0.096* |
| BCCU 1 × BCCU 4 | -1.014** | -0.092 | -3.442** | -4.304** | 0.528** | -4.861** | -3.719** | -0.353** | -0.233** |
| BCCU 7 × BCCU 3 | -1.490** | -0.319 | -0.875** | 1.876** | -0.664** | 2.694** | 2.695** | 0.014 | 0.116** |
| BCCU 7 × BCCU 12 | -0.984** | 0.207 | 0.069 | 1.945** | 1.461** | 2.250** | 2.815** | 0.281* | -0.028 |
| BCCU 7 × BCCU 16 | 1.036** | -0.216 | -2.453** | -1.159** | 0.865** | -1.083 | -0.322 | -0.053 | -0.321** |
| BCCU 7 × BCCU 13 | 0.321 | -0.154 | 2.625*** | 3.301** | 1.282** | 2.583** | 3.720** | 0.503** | 0.171** |
| BCCU 7 × BCCU 4 | 0.592** | 0.059 | 6.681** | 6.356** | 0.175 | 5.472** | 4.379** | -0.075 | -0.008 |
| BCCU 3 × BCCU 12 | -0.604** | 0.464** | 2.069 ** | 5.304** | 0.491** | 5.139** | 4.349** | 1.192** | 0.017 |
| BCCU 3 × BCCU 16 | -0.434* | -0.130 | -0.953** | -3.741** | -1.135** | -4.194** | -4.347** | 0.358** | -0.106* |
| BCCU 3 × BCCU 13 | 0.471** | 0.313 | 0.325 | -0.341** | 0.472** | 0.472 | 1.025 | -0.486** | -0.084* |
| BCCU 3 × BCCU 4 | 0.972** | -0.064 | -2.819** | -3.455** | -1.045** | -2.639** | -3.646** | 0.336** | -0.053 |
| BCCU 12 × BCCU 16 | -0.339 | 0.026 | 0.592 | 0.678** | -2.721** | 0.361 | 0.003 | 0.125 | -0.020 |
| BCCU 12 × BCCU 13 | -0.243 | -0.702*** | 6.369** | 5.368** | -0.714** | 4.028** | 7.815** | -0.919** | 0.002 |
| BCCU 12 × BCCU 4 | 0.558** | -0.179 | 0.325 | 3.114** | 0.709** | 3.917** | 2.594** | 0.303* | 0.024 |
| BCCU 16 × BCCU 13 | 0.727** | 0.355* | -3.153** | -0.926** | 3.321** | -1.306* | -2.322** | 0.247 * | -0.031 |
| BCCU 16 × BCCU 4 | -1.302** | 0.078 | 4.203** | 2.919** | 2.014** | 3.583** | 3.457** | -0.731** | 0.140** |
| BCCU 13 × BCCU 4 | 0.884** | 0.590** | 0.381 | -1.421** | -1.129** | -1.750** | -1.621** | 0.025 | 0.102* |
| SE (sij) | 0.399 | 0.394 | 0.707 | 0.143 | 0.374 | 1.450 | 1.383 | 0.265 | 0.093 |

**,** Significant at P ≤ 0.05 and P ≤ 0.01, respectively*

Maximum significant SCA effects in desired direction for fruit yield/plant along with PDI of downy mildew, fruit weight, number of fruits/plant, fruit length, fruit cavity thickness, days to first harvest, days to 50% female flower, node at which first female flower appears, days to first female flower, days to first male flower were shown by the cross, BCCU-3 × BCCU-16 which also involved one of the parents as good general combiner for fruit yield/plant and other desirable horticultural traits, suggesting further exploitation of these crosses in segregation generation to identify superior lines. The cross, BCCU-1 × BCCU-12 exhibited significant SCA effects in desired direction for fruit yield/ plant with other desirable horticultural traits, indicating that this hybrid is expected to produce segregates with high yield, and better tolerance to downy mildew disease of fixable nature in segregating generations through simple pedigree method. The cross, BCCU-3 × BCCU-4 also exhibited high significant SCA effect in desired direction for fruit yield /plant, PDI of downy mildew, number of fruits/plant and vitamin C along with other traits.

Table 4: Estimates of general- and specific-combining ability effects of parents and hybrids for fruit characters and disease severity

| Parent | Fruit cavity thickness (cm) | Fruit length (cm) | Fruit diameter (cm) | Fruit weight (g) | Number of fruits/plants | Vitamin C content (mg/100 g) | Percent disease index of downy mildew (%) | Fruit yield /plant (kg) |
|---|---|---|---|---|---|---|---|---|
| BCCU-1 (P1) | -0.009 | 0.068 | -0.070* | -4.053** | 0.232 | 0.046 | -2.985** | -0.061 |
| BCCU-7 (P2) | 0.105** | 0.391** | 0.024 | -2.957** | -2.039** | 0.010 | 0.208 | -0.344** |
| BCCU-3 (P3) | -0.026 | 0.279** | 0.112** | 6.011** | 3.220** | -0.005 | -1.786** | 0.598 ** |
| BCCU-12 (P4) | -0.056** | -0.604** | -0.067* | -5.629*** | 2.017** | 0.115 ** | -0.762** | 0.149 ** |
| BCCU-16 (P5) | 0.029* | -0.014 | -0.085** | -0.374 | -0.201 | -0.001 | 0.009 | -0.020 |
| BCCU-13 (P6) | -0.046** | 0.018 | 0.262** | 4.361** | -3.223** | -0.121** | 3.912** | -0.370** |
| BCCU-4 (P7) | 0.002 | -0.138** | -0.177** | 2.641** | -0.007 | -0.044 | 1.404** | 0.048 |
| SE (gi) | 0.052 | 0.171 | 0.107 | 3.386 | 0.725 | 0.138 | 0.497 | 0.124 |
| Hybrid | | | | | | | | |
| BCCU 1 × BCCU 7 | -0.320** | 0.605** | -0.101 | 19.022** | 0.083 | 0.051 | -2.077** | 0.389** |
| BCCU 1 × BCCU 3 | -0.179** | -1.683** | -0.358** | -21.445** | 0.494 | -0.034 | -0.810* | -0.468** |
| BCCU 1 × BCCU 12 | 0.071 | 2.700** | 0.821** | 17.135** | 3.357** | -0.264* | -2.285** | 0.865** |
| BCCU 1 × BCCU 16 | 0.466** | 2.210** | 0.348** | -12.780 ** | 2.745** | -0.008 | -0.314 | 0.072 |
| BCCU 1 × BCCU 13 | -0.049 | -2.022** | -0.538** | -11.135** | 1.437* | 0.152 | 0.675 | 0.019 |
| BCCU 1 × BCCU 4 | 0.023 | -1.166** | -0.139 | 12.425** | -3.679** | -0.086 | 0.887* | -0.282** |
| BCCU 7 × BCCU 3 | 0.096* | -1.606** | 0.427** | 12.088** | -1.735** | 0.222 | -4.390** | -0.034 |
| BCCU 7 × BCCU 12 | -0.174** | 0.277 | -0.004 | -12.212** | 3.628** | 0.042 | -4.117** | 0.194 |
| BCCU 7 × BCCU 16 | -0.248** | -0.803** | -0.066 | -7.206* | -0.414 | 0.129 | 3.362** | -0.183 |
| BCCU 7 × BCCU 13 | -0.154** | 0.055 | -0.093 | 2.658 | 2.538** | 0.459** | -3.938** | 0.409** |
| BCCU 7 × BCCU 4 | 0.269** | 2.410** | 0.026 | 9.798** | -5.348** | -0.659** | 13.540** | -0.599** |
| BCCU 3 × BCCU 12 | 0.258** | -0.361* | 0.018 | -4.890 | -6.491** | 0.027 | 3.954** | -1.003** |
| BCCU 3 × BCCU 16 | -0.317** | 1.349** | 0.116 | 17.586** | 8.127** | -0.047 | -5.634** | 1.670** |
| BCCU 3 × BCCU 13 | 0.067 | -0.483** | 0.099 | -6.310* | -7.051** | -0.597** | 18.406** | -1.141** |
| BCCU 3 × BCCU 4 | 0.200*** | 0.073 | 0.218* | -8.330** | 9.983** | 0.416** | -6.175** | 1.168** |
| BCCU 12 × BCCU 16 | -0.087* | -2.017** | -0.245** | -12.344** | 0.131 | 0.013 | -3.655** | -0.265 * |
| BCCU 12 × BCCU 13 | -0.002 | -0.350* | -0.242** | 0.350 | -4.517** | -0.147 | 9.308** | -0.577** |
| BCCU 12 × BCCU 4 | -0.040 | -1.094** | -0.383** | -1.960 | -6.734** | 0.356** | 8.710** | -0.919** |
| BCCU 16 × BCCU 13 | 0.393** | 0.760** | 0.126 | -22.474** | 0.031 | 0.460** | 7.488** | -0.383** |
| BCCU 16 × BCCU 4 | -0.045 | -0.084 | 0.355** | -6.104* | -4.516** | 0.232* | 6.956** | -0.739** |
| BCCU 13 × BCCU 4 | -0.070 | -0.616** | 0.288** | -6.890* | 0.376 | 0.152 | -5.161** | -0.072 |
| SE (sij) | 0.100 | 0.326 | 0.204 | 6.456 | 1.383 | 0.264 | 0.948 | 0.237 |

**, ** Significant at P ≤ 0.05 and P ≤ 0.01, respectively*

It appeared different cross combinations exhibited different SCA effects and only a few crosses indicated consistently positive or negative SCA effects for certain characters. The highest *per se* performance for fruit yield/plant along with number of fruits/plant, and minimum severity of downy disease was recorded in cross, BCCU-3 × BCCU-16 followed by the crosses, BCCU-3 × BCCU- 4 and BCCU-1 × BCCU- 12 (Table 3 and 4). Based on SCA effects and *per se* performance, three cross combinations namely, BCCU-3 × BCCU-16, BCCU-3 × BCCU- 4 and BCCU-1 × BCCU- 12 could be identified as good specific combiners for future use in breeding programme of cucumber. Significant SCA effects in desired direction for all the economic traits of cucumber involving various combinations of GCA effects of the parents have also been reported by Kaur and Dhall (2017) for fruit weight, fruit yield/plant; Kaur *et al.* (2016) for vitamin C content; number of fruits/plant; Bairagi *et al.* (2013) for fruit length and diameter, number of branches/plant; Tak *et al.* (2017) for days to first male and female flower appearance, Kumar *et al.* (2013) for days to first harvest.

On the basis of GCA effects, the promising heterotic crosses involved four types of cross combinations, H × H, H × L, L × H and L × L, where H denotes significant GCA effect of parent in desired direction and L stands for non-significant GCA effect of the parent (Table 5). In the H × H type cross combination (BCCU 3 × BCCU 4for number of fruits/plant), additive as well as additive × additive type of interactions was involved. This cross would be very useful as desirable segregates would be fixed in early advance generation. On the other hand, crosses of H × L type (BCCU 1 × BCCU 13 for intermodal length; BCCU 13 × BCCU 16 for days to first female flower; BCCU 3 × BCCU 16 for days to 50% female flower, days to 1$^{st}$ harvest, PDI of downy mildew and fruit yield/ plant; BCCU 12 × BCCU 13 for Days to marketable maturity of fruit; BCCU 16 × BCCU 4 for fruit flesh thickness (cm); or L × H type (BCCU 16 × BCCU 4 for number branches/plant ; BCCU 16 × BCCU 13 for days to first male flower; BCCU 12 × BCCU 16 for node at which first female flower appears; BCCU 7 × BCCU 3 for percent disease index of downy mildew) involved at least one parent with significant GCA effect which indicated that predominantly additive effect was present in good combiner and possibly complementary epistatic effect in poor combiner and these two gene actions acted in complementary fashion to maximize the expression as suggested by Salimath and Bahl (1985). In crosses involving L × L category (BCCU- 1 × BCCU- 7 for fruit cavity thickness and fruit weight; BCCU- 1× BCCU- 16 for fruit length; BCCU- 1× BCCU- 12 for fruit diameter; BCCU- 16 × BCCU- 4 for number of fruits/plant and fruit yield/plant; BCCU- 16 × BCCU- 13 for vitamin C content), SCA effects seemed to have played a very important role and high performance was due to non-additive gene action (Bhutia *et al.*, 2015).

**Study on extent of heterosis**

Heterosis is thought to be the result from combined action and interaction of allelic and non-allelic factors, and usually closely, and positively, correlated with heterozygosity. Twenty-one cross combinations along with their seven parents were studied for seventeen characters to determine the manifestation of heterosis in them. The range and the magnitude of heterosis estimated over mid-parent (relative heterosis) and better-parent (heterobeltiosis) are presented in Table 5. The maximum extent of significant heterobeltiosis in desired directions occurred from hybrids in a seven-parent diallel of cucumber for node at which first female flower appears followed by fruit cavity thickness, number of fruits/plant, fruit yield /plant and percent disease index of downy mildew (Table 5). The maximum heterobeltiosis for fruit yield/plant was shown by BCCU-16 × BCCU-4 (34.14 %**) followed by BCCU-3 × BCCU-16 (29.82 %**). PDI is an important criterion to judge the tolerance level of cucumber hybrids against downy mildew disease. There is lack information available on magnitude of heterosis for PDI of downy mildew disease in cucumber. Significant heterosis in negative direction is desirable for percent disease index (%) of downy mildew. The maximum significant heterobeltiosis for PDI of downy mildew disease was noted in BCCU-7 × BCCU-3 (-33.97 %**) followed by BCCU-3 × BCCU-16 (-27.77 %**). Earliness in cucumber is judged through appearance of female flower at lower node and days to 50% female flower. The maximum significant heterobeltiosis in desired direction for node at which first female flower appears was noted in BCCU-12 × BCCU-16 (-53.30 %**). In case of days to 50% female flower, significant negative heterobeltiosis was observed in BCCU-3 × BCCU-16 (-25.00 %**). The negative heterosis estimation of fruit cavity thickness would be considered desirable. The positive heterosis for fruit cavity thickness indicated that there is no scope of selection of the hybrid as processing type. The maximum significant negative heterobeltiosis for fruit cavity thickness was observed in BCCU-1 × BCCU-7 (-46.36 %**) which could be suitable for processing.

Table 5: Most promising cross combinations in $F_1$ generation, their *per se* performance and type of cross combinations

| Character | Crosses with high heterobeltiosis (%) in desired direction | *per se* performance of the cross | Type of combinations[a] |
|---|---|---|---|
| Number of branches/plant | BCCU 16 × BCCU 4 (23.81**) | 4.80 | L × H |
| Internodal length (cm) | BCCU 1 × BCCU 13 (-15.46**) | 7.22 | H × L |
| Days to first male flower | BCCU 16 × BCCU 13 (-20.00**) | 24.00 | L × H |
| Days to first female flower | BCCU 3 × BCCU 16 (-26.62**) | 27.15 | H × L |
| Node at which first female flower appears | BCCU 12 × BCCU 16 (-53.30**) | 3.33 | L × H |
| Days to 50% female flower | BCCU 3 × BCCU 16 (-25.00**) | 30.00 | H × L |
| Days to 1st harvest | BCCU 3 × BCCU 16 (-22.86**) | 36.00 | H × L |
| Days to marketable maturity of fruit | BCCU 12 × BCCU 13 (-16.67**) | 6.00 | H × L |
| Fruit flesh thickness (cm) | BCCU 16 × BCCU 4 (2.65) | 1.16 | H × L |
| Fruit cavity thickness (cm) | BCCU 1 × BCCU 7 (-46.36**) | 0.81 | L × L |
| Fruit length (cm) | BCCU 1× BCCU 16 (16.55 **) | 17.25 | L × L |
| Fruit diameter (cm) | BCCU 1× BCCU 12 (20.20**) | 4.76 | L × L |
| Fruit weight (g) | BCCU 1 × BCCU 7 (17.07**) | 149.00 | L × L |
| Number of fruits/plant | BCCU 16 × BCCU 4 (26.30**) | 15.33 | L × L |
| | BCCU 3 × BCCU 4 (33.00**) | 33.25 | H × H |
| Vitamin C content (mg/100 g) | BCCU 16 × BCCU 13 (22.46**) | 3.98 | L × L |
| Percent disease index of downy mildew (%) | BCCU 7 × BCCU 3 (-33.97**) | 10.09 | L × H |
| | BCCU 3 × BCCU 16 (-27.77**) | 8.65 | H × L |
| Fruit yield/plant | BCCU 16 × BCCU 4 (34.14**) | 2.04 | L × L |
| | BCCU 3 × BCCU 16 (29.82 **) | 5.00 | H × L |

[a]*H= Significant GCA effects and L= Non-significant GCA effect*

Two promising crosses, BCCU-16× BCCU-4 and BCCU-3 × BCCU-16 which showed the maximum significant heterobeltiosis for fruit yield/plant also exhibited significant heterosis in desired direction over better-parent for PDI of downy mildew, number of fruits/plant and other desired characters. Cucumber hybrid with higher fruit yield along with good horticultural traits was earlier reported by many workers (Kaur and Dhall, 2017; Singh and Tiwari, 2018; Das *et al.*, 2019b; Preethi *et al.*, 2019; Ene *et al.*, 2019; Thakur *et al.*, 2019). As the *per se* performance is the realized value and the heterotic response is an estimate, the former should also be given preference when making a selection in cross combinations (Katiyar, 1979). Crosses showing desirable SCA effects involving parents with good GCA can be exploited effectively by conventional pedigree selection. According to Jinks (1983), the prerequisite for a high, uniform, and stable heterotic effect is the correct gene content, which can be assembled in the homozygous state or if the appropriate alleles are completely dominant as a heterozygote without affecting performance. Progress in improving the desired trait will be slow if the parental selection is based on average performance alone.

The study on heterosis revealed that crosses with significant relative heterosis in desired direction were more as compared to crosses with significant heterobeltiosis for most of the characters under study. It was also observed that crosses between parents of intermediate divergence classes showed comparatively higher magnitude of heterosis for fruit yield and other important traits than crosses between closely or distantly related parents. For yield attributes, some crosses were non-heterotic, which may be ascribed to cancellation of positive and negative effects exhibited by the parents involved in a cross combination and can also happen when the dominance is not unidirectional as observed by Gardner and Eberhart (1966), and Mather and Jinks (1982).

The essence of the superiority of the $F_1$ hybrids over the better parent *vis-a-vis* the standard hybrid can profitably be exploited for commercial production. More than 30% heterobeltiosis over better parent could reduce the cost of hybrid seed in cucumber. Thus, the crosses showing more than 30% heterobeltiosis may be exploited for hybrid cucumber production. Based on SCA effects, heterobeltiosis manifested in them, and *per se* performance, two hybrids 'BCCU-16 × BCCU-4'and 'BCCU-3 × BCCU-16'were identified as most promising considering fruit yield/plant and tolerance against downy mildew disease. These two hybrids could be exploited at commercial level after their critical evaluations in tropics and sub-tropics.

The preponderance of non-additive gene effects governs most traits under study in cucumber. Improvement of cucumber yield with appreciable tolerance against downy mildew disease could be through exploitation of hybrid vigour. The traits under study could not be judged with equal efficiencies by a single parent or hybrid. The genitors, BCCU-3 and BCCU-12 were the most promising donors for fruit yield along with good horticultural traits, and could be utilized in future breeding. The crosses, BCCU-16× BCCU-4 and BCCU-3 × BCCU-16 appeared to be promising in respect to fruit yield, quality, and level of field tolerance against downy mildew disease, and could be exploited at commercial level after critical evaluation. Promising hybrids could also be exploited in segregating generations to identify pure lines with desirable horticultural traits.

## ACKNOWLEDGMENTS

The work supported with partial financial assistance provided by the ICAR-Indian Institute of Vegetable Research, Varanasi, India.

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