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Utilizing parthenocarpic gynoecious *beit alpha* cucumber inbreds for their heterotic potential under different poly-net house environments

Prakash Singathiya[1], Rajinder Kumar Dhall[1]✉, Pooja Manchanda[2], Priyanka Kumari[1], Ritika Lnu[1] & S. Praveen[1]

The present study was conducted to exploit heterotic potential and combining ability for developing early maturing, high-yielding, and good quality parthenocarpic gynoecious beit alpha cucumber hybrids tailored to specific environmental conditions. The experimental material comprised 11 parthenocarpic gynoecious beit alpha cucumber parents which were crossed to produce 28 F_1 hybrids through a line × tester mating design, plus two commercial check hybrids (PKH-11 and Emirstar) and further evaluated for yield and quality attributes under two different environments (winter and summer seasons) in a poly-net house. The mean sum of squares due to genotypes, environments, and G × E interaction was found significant ($p \leq 0.01$) for all the traits, except for the G × E interaction in fruit diameter. The wide range of variability for yield and quality traits provided an opportunity to select hybrids suitable for across the environments. The nature and magnitude of heterosis was estimated over two commercial checks and tester's contribution was found highest in line × tester analysis for almost the studied traits. Based on the results of pooled environments, it was concluded that parental lines PBRK-16, PK-1 and testers PBRK-8, PBRK-1 exhibited superior and stable performance on the basis of mean performance, GCA effects for yield and its contributing traits. On basis of heterosis, mean performance and SCA effects, the cross combinations PBRK-16 × PBRK-8, PBRK-16 × PBRK-1 and PBRK-16 × PBRK-18 were found to have stable performance for fruit yield and number of fruits per plant. However, fruits of hybrid PBRK − 16 × PBRK-8 were shorter in length and more in thickness which will get least market acceptance by stakeholders. As medium size beit alpha type fruits are mostly preferred in market having fruit length of 15–18 cm and fruit weight of 125–170 g. Therefore, F_1 hybrids PBRK − 16 × PBRK-18 and PBRK − 16 × PBRK-1 having desirable fruit length and diameter can be released for commercial cultivation in poly-net house for both the seasons. The non-additive gene effects and low narrow-sense heritability for most of the traits studied, indicating that heterosis can be effectively utilized for their improvement. Hence, these promising hybrids can also be utilized in segregating generations to identify pure lines with high yield and superior fruit quality. Furthermore, the year-round cultivation of these promising hybrids can significantly increase farmers' profitability, strengthen food security, and more effectively meet market demands.

Keywords Heterosis, Combining ability, Parthenocarpic gynoecious, Line × tester

Cucumber (*Cucumis sativus* L. 2n = 2× = 14) belonging to family Cucurbitaceae, is a widely cultivated warm season vegetable crop in the subtropical and tropical areas of the world. It is believed to be indigenous to India and had been cultivated over 3000 years. It is the second largest cultivated cucurbit after watermelon for internal trade and export[1]. Worldwide cucumbers production in 2022 reached about 94.17 million metric tonnes, up 2.3% from 92.62 million metric tonnes in 2021. China is the world largest producer and exporter of cucumbers,

[1]Department of Vegetable Science, College of Horticulture and Forestry, Punjab Agricultural University, Ludhiana 141004, India. [2]School of Agricultural Biotechnology, College of Agriculture, Punjab Agricultural University, Ludhiana 141004, India. ✉email: rajinderkumar@pau.edu

accounting for over 81% of global production at 77.26 million tonnes followed by Turkey, Russia, Ukraine, Mexico with India ranking 22th position[2]. In India, its production is 1.665 million tonnes from an area of 1.18 lakh hectares, however, in Punjab, production is 108.71 thousand metric tonnes from an area of 3.99-thousand-hectare[3]. Cucumber can be grown throughout year under poly-net house conditions and mainly beit alpha type parthenocarpic gynoecious cucumber varieties/hybrids are cultivated as these do not need pollination for fruit setting. Parthenocarpic gynoecious cucumber varieties/hybrids often yield more than conventional seeded cultivars, largely due to their gynoecious trait. Additionally, parthenocarpic hybrids do not require pollination for fruit setting and these hybrids are seedless, therefore, the energy needed to produce seeds in others (monoecious and gynoecious based hybrids) is used to produce more fruits in these hybrids. In India, different cucumber segments are grown which includes slicer (green, mottle green and bicolour), beit alpha (medium length and dark green colour) and picking (gherkins). The slicer type cucumbers of different colours are grown in open field condition during summers and in low plastic tunnels during winter. The beit alpha type of cucumber is grown throughout year in poly-net houses but only medium length is preferred and this type of cucumber get premium price in market as compared to slicer type. The third type of cucumber is picking type (gherkin) which is grown exclusively for export purpose and used for pickle making. In India, the cultivation of cucumber under protected conditions is limited because there are no suitable parthenocarpic gynoecious varieties or hybrids available from the public sector, and the hybrid seeds developed by the private sector are prohibitively expensive[4]. Only limited studies are reported in India on beit alpha type parthenocarpic cucumber development but there are few varieties or hybrids (Pant Parthenocarpic Cucumber-2, Pusa Parthenocapic Cucumber-6, Punjab Kheera-1, PKH-11 and KPCH-1) which has been developed by public sector for growing in poly-net house. The Punjab Agricultural University (PAU) in Ludhiana, Punjab, is a leading institution in India for developing and commercially utilizing parthenocarpy in cucumbers[5]. To date, PAU has developed two high-yielding parthenocarpic cucumber cultivars, Punjab Kheera-1 and PKH-11, specifically for cultivation in poly-net houses[6–8] and additionally, three memoranda of agreement (MOAs) have recently been signed with private seed companies for the commercialization of these cultivars. The efforts are currently underway to develop new parthenocarpic gynoecious cucumber hybrids with high yield potential, early maturity, desirable fruit size, and strong parthenocarpy across various environmental conditions. To achieve this, there is a need to develop high-yielding, early-maturing, and desirable fruit size parthenocarpic gynoecious hybrids suited for cultivation in different environments through heterosis breeding by utilizing new parthenocarpic gynoecious cucumber lines. Recently, two genes *CsWD-40* and *CsPIN-4* as candidate genes responsible for regulating parthenocarpy in cucumber identified[9]. Devi et al.[10] reported the major QTL *Parth6.1* for parthenocarpy expression and identified flanking markers SSR01148 and SSR01012, which can be utilized in marker-assisted backcrossing (MABC) programs. Wu et al.[11] identified a stable major-effect QTL, *Parth2.1*, and CsARF19, CsWD40, CsEIN1, CsPPR, CsHEXO3, CsMDL, CsDJC77, and CsSMAX1 genes controlling parthenocarpy. Zhu et al.[12] discovered the molecular marker InDel-16y-46 for *Parth2.1*, enabling marker-assisted selection (MAS) for breeding cucumber cultivars with enhanced parthenocarpy traits. Bommesh et al.[13] reported the markers SSR-02021 and SSR18718 and Narayanan et al.[14] identified marker SNP 2,13,85,488 which are effective for early selection of gynoecious lines. To advance molecular breeding in cucumber, it is essential to identify promising parental lines and hybrids.

However, before developing hybrids, a crucial task for vegetable breeders is selecting the right parental lines. The selection of parents on the basis of mean performance does not necessarily lead to desirable results[15]. It is, therefore, essential to find out the combining ability of parental lines in hybrid combination for effective transfer of desirable genes in the resulting hybrid combination. The combining ability studies assist in identifying suitable parental lines with good general combining ability (GCA) and their performance in specific cross combinations[16]. The line × tester analysis suggested by Kempthorne[17] was used to assess the combining ability among parents so that best crosses can be adopted. Understanding the type and magnitude of gene action, heritability and degree of dominance is critical for improving quantitative traits. Besides, there is lot of variation in yield and quality of same variety/hybrid grown in different environments of poly-net house[18]. Plant breeders focused on enhancing cucumber yield are keen to understand genotype × environment effect (G × E) for yield variation under different environment. Genotype × environment effect occurs when there is a scale shift or rank shift in genotypic performance across environments[19]. There are limited studies reported on genotype × environment (G × E) interaction on the performance of yield and quality traits in parthenocarpic gynoecious cucumber hybrids.

Although significant research has been conducted on heterosis and combining ability using parthenocarpic lines, but there is very less information available on these aspects in cucumber, specifically involving *beit alpha* parthenocarpic gynoecious varieties or hybrids under different environmental conditions in poly-net houses. Furthermore, there is a lack of suitable parthenocarpic gynoecious varieties or hybrids from the public sector for year-round cultivation under poly-net house in India. Hence, the findings of this study will identify superior *beit alpha* type parthenocarpic gynoecious cucumber lines and F_1 hybrids for cultivation in various environments in poly-net houses which can be further released for commercial cultivation and could use in advance breeding program. However, the present study aimed to assess the heterotic potential of various cross combinations of parthenocarpic gynoecious cucumber, evaluate their specific combining ability, and dominance effects for yield, earliness, and quality traits to identify suitable hybrids for cultivation in across the two different environments (winter and summer) with the following objectives (i) to estimate heterotic potential of parthenocarpic gynoecious cucumber hybrids (ii) to estimate general combining ability and specific combining ability of parents and hybrids, respectively and (iii) to estimate potence ratio of parthenocarpic gynoecious hybrids.

Materials and methods

Location and climatic conditions

The present investigation was carried out from February 2021 to June 2022 at the Vegetable Research Farm and Quality Analysis Laboratory, Department of Vegetable Science, Punjab Agricultural University, Ludhiana, India. Ludhiana is situated at an altitude of 247 m above mean sea level, positioned at 30.91°54′ N latitude and 75.85°51′ E longitude. The experimental site experiences a subtropical climate characterized by hot summers with desiccating winds from April to June and cold winters with occasional ground frost from December to January. The region receives an average annual rainfall of approximately 700 mm, primarily concentrated between July and September. Weekly data on temperature and relative humidity within the poly-net house were recorded for two key seasons: the winter season (September 2021 to December 2021) and the summer season (February 2022 to June 2022). This data is presented in Figs. 1 and 2, providing a detailed overview of the climatic conditions during the experimental period.

Experiment material, design and agronomic practices

The experimental material included 11 parthenocarpic gynoecious cucumber parental lines (Table 1), each with distinct fruit and quality characteristics, which were used to produce hybrids using a line × tester scheme from February 2021 to June 2021. The performance of the parents, F_1 hybrids along with two standard checks (PKH-11 and Emirstar) were evaluated for yield and quality attributes in two different environments (winter – E1 and summer – E2) under a poly-net house. The seedlings of hybrids, parents and checks were transplanted in poly-net house by September 2021 for winter season and February 2022 for summer season evaluation. Both the trials were transplanted in randomized complete block design with three replications having 10 plants per replication. The seedlings were transplanted on raised beds of 100 cm width and 15 cm height in a paired row pattern with a spacing of 60 cm between the rows and 40 cm spacing between the plants. After one week of transplanting, plants were trained using plastic clips and nylon rope and after each fruit picking, the old leaves were removed which allows maximum air circulation and reduces pest control problems. For good growth and development, 40 kg N, 20 kg P_2O_5 and 20 kg K_2O supplied through water soluble fertilizers viz. N.P.K. 19:19:19, Urea phosphate 18:18:18, Calcium Nitrate (18.8% Ca + 15.5% N), Potassium Nitrate (13:0:45), Mono-potassium Phosphate (0:52:34), Mono-ammonium Phosphate (12:61:0) and Potassium Sulphate (0:0:50) with fertigation of single strength solution in plastic tank of 1000 L capacity. In September transplanted crop during the initial stage, plant was infected by fusarium wilt which was controlled by drenching of seedlings with Captan 50 WP (captan) @ 2 g per liter of water. In winter crop, attack of botrytis rot was observed which was controlled by benomyl dupont 0.4 g/liter of water. There was a serious attack of downy mildew in the summer crop, which was controlled by spraying Ridomil gold (Metalaxy-M 4% + Mancozeb 64% WP) @ 2 g per liter of water. The white fly was also observed during both the seasons but more active in the September transplanted crop which was controlled by spraying Pegasus 50WP (Diafenthiuron 50%WP) @ 0.8 g/liter of water. The yellow sticky traps were also used to manage white fly in the poly-net house. Red spider mite attack was also observed in April-June

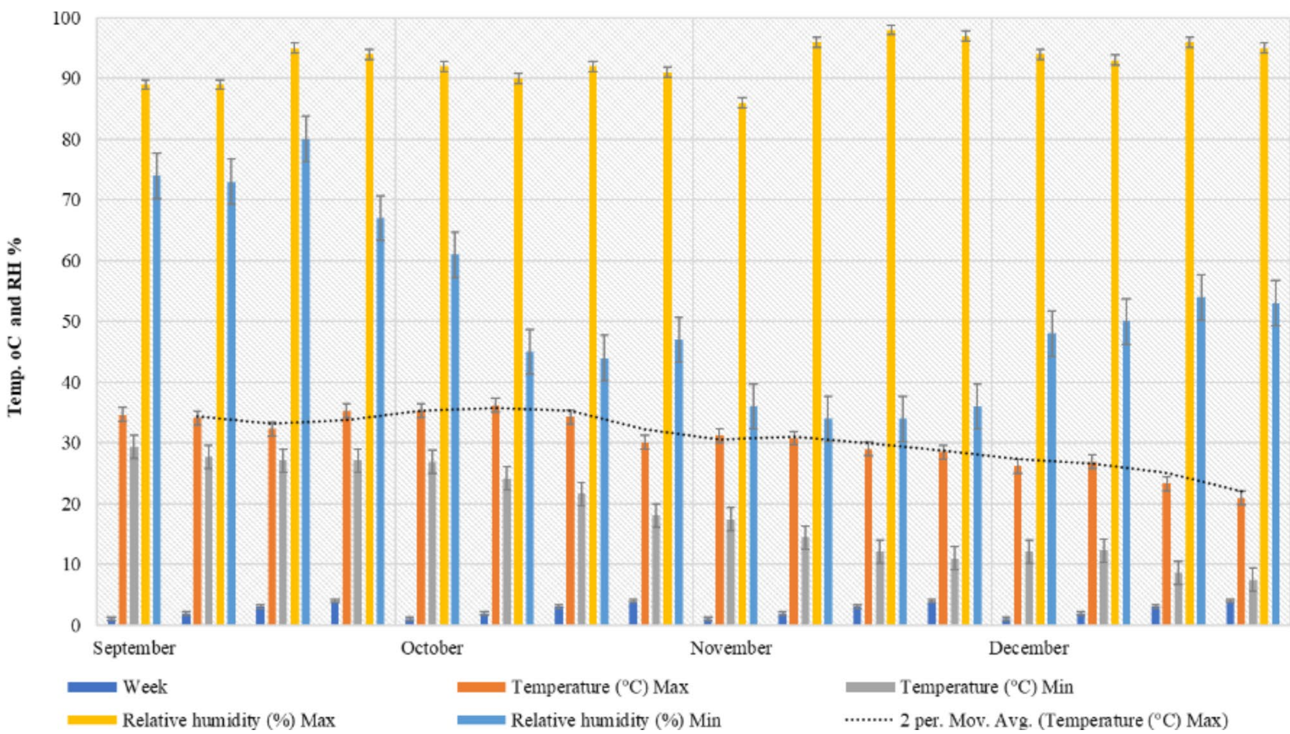

Fig. 1. Mean weekly temperature (max. and min.) and relative humidity (max. and min.) of winter season recorded during September 2021- December 2021.

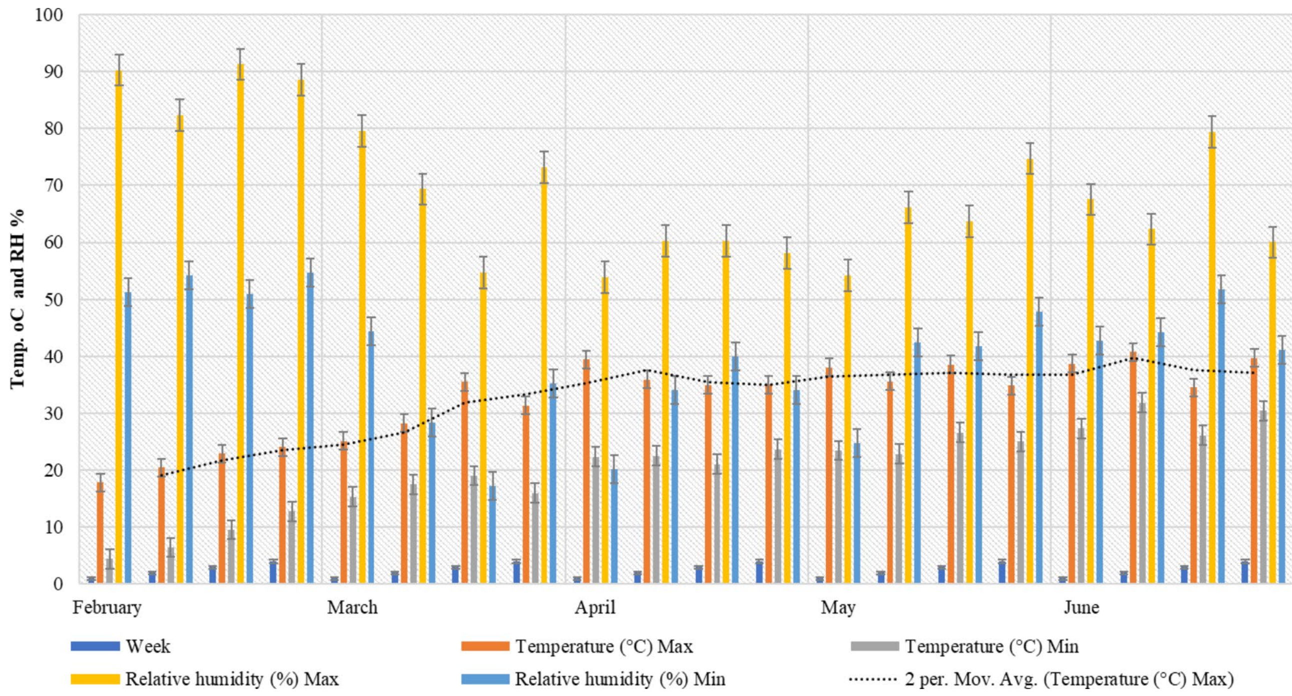

Fig. 2. Mean weekly temperature (max. and min.) and relative humidity (max. and min.) of summer season recorded during February 2022- June 2022.

Lines	Source	Salient features
Punjab Kheera-1 (PK-1)	PAU, Ludhiana	1–2 fruits per node, fruit medium size having length of 13–15 cm
PBRK-9	PAU, Ludhiana	1–2 fruits per node, good fruit size having length of 15–16 cm
PBRK-15	PAU, Ludhiana	2–3 fruits per node, fruit length is 17–18 cm
PBRK-16	PAU, Ludhiana	2–3 fruits per node, good fruit size having length of 15–16 cm
Testers		
PBRK-1	PAU, Ludhiana	1–2 fruits per node, slightly long fruit having length of 18–20 cm
PBRK-8	PAU, Ludhiana	2–3 fruits per node, small fruit size having length of 11–12 cm, light green colour
PBRK-10	PAU, Ludhiana	one fruit per node, large fruit size having more length of 20–25 cm, more flesh thickness, small seed cavity
PBRK-14	PAU, Ludhiana	1–2 fruits per node, fruit medium size having length of 14–15 cm, more fruit thickness
PBRK-17	PAU, Ludhiana	1–2 fruits per node, fruit length is 15–18 cm
PBRK-18	PAU, Ludhiana	1–2 fruits per node, slightly long fruit having length of 17–19 cm, fruit is thick
Pusa Parthenocarpic Cucumber-6 (PPC-6)	IARI, New Delhi	1–2 fruits per node, fruit medium size having length of 14–15 cm and more fruit thickness
Check (F_1 hybrid)		
PKH-11 (Check 1)	PAU, Ludhiana	Commercial, F_1 hybrid, bear 1–2 fruits per node, good fruit size having length of 16–18 cm
Emirstar (Check 2)	Rizk Zwaan India Seeds Pvt. Ltd. Bangalore.	Commercial, F_1 hybrid, fruit in cluster of 2–3, good fruit size having fruit length of 16–18 cm

Table 1. List of parthenocarpic gynoecious cucumber parents (lines and testers) and checks along with their sources and key features used in present investigation.

due to high temperature and dry weather which was controlled by spraying of miticide Omite (Propargite 57% EC) @ 1.0 ml per liter of water along with periodic use of water fogging. The other crop management practices during both the seasons were followed as per the recommended by the university[20].

Data collection

The September transplanted crop was ready for first harvest in 42–45 days but the February transplanted crops took 58–60 days to first harvest. The duration of September transplanted crop was less than the February transplanted crop because the September transplanted get completed in end December but February transplanted crop got finished in first week of June. The fruits were harvested twice in a week in both the seasons. Data was recorded for ten yield and quality traits in parents, F_1 hybrids and two standard checks. Data were recorded on morphological traits including fruit yield per plant (kg), number of fruits per plant, fruit weight (g), fruit length (cm), fruit diameter (cm), node at which the first female flower appears, and days to first fruit picking. Besides, data was also recorded on quality traits including total soluble solids (˚brix), flesh to seed cavity ratio and water content (%).

For TSS estimation, first of all the whole fruit is crushed and its juice is extracted. The digital refractometer (Model HI 9680, ERMA, Bunkyo City, Tokyo, Japan)[21] was used for estimation of TSS. First of all, this digital refractometer is calibrated with the distilled water afterwards few drops of the homogenized fruit juice is put on the digital refractometer to estimate TSS. For each replication per genotype, the value of TSS taken from five fruits were averaged and expressed in ˚brix. More flesh and less seeds are desirable from consumer point of view; therefore, flesh-to-seed cavity (F/C) ratio was determined using the following formula:

$$\mathrm{F/C\ ratio\ } = (\mathrm{P} \times \mathrm{E})/(\mathrm{P'} \times \mathrm{E'}) \times 100$$

P represents the polar diameter of the fruit, E denotes the equatorial diameter of the fruit, P' signifies the polar diameter of the fruit cavity, and E' indicates the equatorial diameter of the fruit cavity.

For water content (%) estimation, 50 g sample of fresh cucumber was placed in a petri dish and dried in an oven at 65 ± 2 °C until it reached a consistent weight. The percentage of water content was then determined using the following formula.:

$$\mathrm{Water\ content\ } (\%) = (\mathrm{Fresh\ weight} - \mathrm{Dried\ weight})/\ \mathrm{Fresh\ weight} \times 100$$

Statistical analysis

Analysis of variance (ANOVA) and F-test for significance was performed for experimental designs, as per the model suggested by Panse and Sukhatme[22] and all the statistical analysis was done by using the computer software program WINDOSTAT version 9.2 (INDOSTAT services Ltd, Hyderabad, India).

Estimation of heterosis

Heterosis estimates were calculated by measuring the deviation of the F_1 mean from the standard checks (PKH-11 and Emirstar) following the methods of Briggle[23] and Hayes et al.[24]. The following formula was used for calculation:

$$\mathrm{Standard\ heterosis\ } (\%) = [(\mathrm{F}_1 - \mathrm{SC})/\mathrm{SC}] \times 100$$

F_1 represent the mean value of the F_1 progeny and SC represent the mean value of the standard check variety/hybrid. To test the significance of heterosis, the least square differences (LSD) were calculated using the formula: LSD = SE(d) × 't'. Here, SE(d) (standard error of the difference) is given by SDd = ± 2MSE/r, where MSE represents the mean square error derived from the randomized complete block design (RCBD) involving F_1 hybrids, parent lines, and standard checks. The number of replications is denoted by 'r'. The LSD was evaluated at both the $p \leq 0.05$ and $p \leq 0.01$ levels of significance, considering the error degrees of freedom (df).

Estimation of combining ability

Line × Tester mating design was used for combining ability analysis carried out as per Kempthorne[17] and the methodology outlined by Singh and Chaudhary[25], based on Griffing[26] fixed effect model formula:

$$\mathrm{Xij} = \mu + \mathrm{gi} + \mathrm{gj} + \mathrm{Sij} + 1/\mathrm{bc} \sum \mathrm{k} \sum \mathrm{l\ eijkl}$$

Where i, j = 1, … p, (number of parents) k = 1, … b, (number of blocks or replications) l = 1, …c, (number of observations taken in each plot) Xij = Mean performance of i^{th} x j^{th} genotype over k and l μ = Population means g_i (or g_j) = General combining ability of i^{th} (or j^{th}) parent, Sij = Specific combining ability of the crosses between the i^{th} x j^{th} parents such that Sij = Sji and eijkl = the environmental effect corresponding to the $ijkl^{th}$ observation.

Estimation of potence ratio

The potence ratio was calculated manually in MS Excel–2021 using the method described by Smith[27] to assess the degree of dominance, with the following formula:

$$\mathrm{P} = \mathrm{F}_1 - \mathrm{MP}/0.5\ (\mathrm{P2} - \mathrm{P1})$$

Where P represents the relative potence of the gene set, F_1 is the mean of the first generation, P1 is the mean of the lower parent, P2 is the mean of the higher parent, MP is the mid-parent value, calculated as (P1 + P2)/2. Complete dominance is indicated by P = + 1; while partial dominance is indicated when "P" falls between − 1 and + 1, except for zero, which signifies the absence of dominance. Over-dominance is indicated when the potence ratio exceeds 1 ± 1. The positive or negative sign of P reflects the direction of dominance from either parent.

Estimation of genetic components of variance

Additive variance (σ^2_A), dominance variance (σ^2_D), degree of dominance at F = 0 (cucumber being a cross-pollinated crop) and environmental interaction variances were estimated as described by Mather and Jinks[28].

$$2\sigma^2\mathrm{A} \;=\; 2\sigma^2\mathrm{gca}/[(1\,+\,\mathrm{F})/4] \;=\; 4\sigma^2\mathrm{gca}$$
$$\sigma^2\mathrm{D} \;=\; \sigma^2\mathrm{sca}/[(1\,+\,\mathrm{F})/2] \;=\; 2\sigma^2\mathrm{sca}$$
$$\text{Degree of dominance} \;=(2\sigma^2{}_{\mathrm{D}}/\sigma^2{}_{\mathrm{A}})^{1/2}$$

where, F is inbreeding coefficient, $\sigma^2{}_{A}$ is additive variance and $\sigma^2{}_{D}$ is dominance variance.

$$\sigma^2{}_{\mathrm{SCA}\times\mathrm{Env.2}} = \; \mathrm{MS}_{\mathrm{SCA}}\times_{\mathrm{Env.}} - \mathrm{MS}_{\mathrm{Error}}/\mathrm{r}\times\mathrm{e}$$
$$\sigma^2{}_{\mathrm{GCA}\times\mathrm{Env.2}} = \; \mathrm{MS}_{\mathrm{GCA}}\times_{\mathrm{Env.}} - \mathrm{MS}_{\mathrm{Error}}/\mathrm{r}\times\mathrm{e}$$

Where, MS {SCA × Env.} = Mean square for the interaction of SCA with the environment, MS {GCA × Env.} = Mean square for the interaction of GCA with the environment, MS_{Error} = Mean square for the error term, r = Number of replications, e = Number of environments.

Heritability percentages, in narrow senses (h_2), were calculated according to Gibrel et al.[29], using the following formula:

$$\mathrm{h}_2 \;=\; 2\sigma^2\mathrm{gca}/[2\sigma^2\mathrm{gca}+2\sigma^2\mathrm{sca}\;+\;\sigma^2\mathrm{e}]$$

Results

Analysis of variance for the experimental design over the environments

The mean sums of squares due to the genotype were highly significant ($p \le 0.01$) for all studied traits in both the environments (Table 2); providing a perusal that there was sufficient variation present among the genotypes. Moreover, the analysis of variance for the experimental design on a pooled season basis also revealed highly significant differences among both the environments for all the evaluated traits under protected conditions. Similarly, highly significant differences were observed in genotypes by environments (G × E) for all the studied traits except for fruit diameter (indicated that two different growing conditions did not affect this traits).

Analysis of variance for combining ability in line × tester design over the environments

The analysis of variance (ANOVA) for combining ability (Table 2) showed that the mean square (MS) values due to parents, testers and SCA crosses were highly significant ($p \le 0.01$) for all studied traits across the environments except fruit diameter trait in E1. The MS values due to lines were non-significant for number of fruits per plant in E2; fruit yield per plant, fruit diameter, node at which first female flower appears and water content in E1, but significant for rest of the traits. Pooled across the environments, the MS values due to lines were non-significant for number of fruits per plant and node at which first female flower appears, and significant for rest of the traits. The MS values due to GCA lines were significant for fruit weight, fruit length and water content in E2; none of the traits were significant in E1. The pooled analysis indicated that the MS due to GCA lines were significant for fruit weight, whereas, MS due to GCA testers were significant for number of fruits per plant, fruit weight, fruit length and node at which first female flower appears in E1 and pooled analysis; number of fruits per plant, fruit weight and fruit length in E2. The interaction effects due to cross × environment and line × tester × environment was highly significant for all the studied traits whereas interaction effects due to parent × environment were significant all the traits except fruit diameter, indicating that the various environmental factors influenced the yield and quality attributes traits in parthenocarpic gynoecious cucumber.

Mean performance of parents, hybrids and checks pooled across the two environments

The mean performance of parents (lines and testers), F_1 hybrids and checks for the studied traits are presented in Table 3. High yield is the main objective of breeders in any crop improvement programme. The fruit yield per plant of the parents ranged from 2.18 to 2.83 kg and parent PBRK-14 showed highest fruit yield per plant which was significantly at par with both checks and followed parents PBRK-16 and PBRK-8. Among hybrids, fruit yield/plant varied from 2.07 – 3.33 and cross combination PBRK-16 × PBRK-8, PBRK-16 × PBRK-1 and PBRK-15 × PBRK-8 produced higher yield per plant which was at par with check (Emirstar) and significantly different from check (PKH-11) (Fig. 3; Table 3). Number of fruits per plant is a key component to increase yield of parthenocarpic gynoecious cucumber, it is varied in parents from 12.50 – 23.19 and parent PBRK-8 produced highest number of fruits per plant which was significantly at par with check (Emirstar) and significantly different from check (PKH-11) and followed parents PBRK-15 and PBRK-18. Among hybrids, single plant produced 15.00 – 23.79 fruits per plant and cross PBRK-15 × PBRK-8 was produced maximum which was significantly at par with check (Emirstar) and followed crosses PBRK-16 × PBRK-8 and PBRK-9 × PBRK-14 (21.95) but statistically higher than check (PKH-11). Fruit weight also one of the most important trait which directly contribute towards total yield. There is more preference of parthenocarpic cucumber fruits having average fruit weight of 140–180 g. in parents, it varied from 121.56 to 209.71 g and parent PBRK-10 fruit was highest in weight which was significantly different from both the checks and followed parents PBRK-1 and PBRK-14. In case of hybrids, it is ranged from 120.56 to 212.35 g and cross combination PBRK-16 × PBRK-1 exhibited highest fruit weight which was significantly different from both the checks but statistically similar with followed crosses PBRK-16 × PBRK-10 and PBRK-9 × PBRK-10. The parthenocarpic cucumber fruits having 15–18 cm length are more desirable and highly preferred by consumers as compare to small and very long fruits. Fruit length of the parents varied from 11.62 to 21.56 cm and the parent PBRK-10 produced highest fruit length which was significantly different from both the checks and also followed parents PBRK-1 and PPC-6. Among the crosses, its varied from 12.04 to 20.96 cm and highest fruit length was recorded in PBRK-15 × PBRK-10 which was significantly different from both the checks but at par with followed crosses PBRK-16 × PBRK-10 and PBRK-9

Source of variance	df	FYPP	NFPP	FW	FL	FD	NFFFA	DFFA	TSS	FSCR	WC
Analysis of variance for the experimental design for different characters in parthenocarpic cucumber over two environments											
E1											
Replication	2	0.005	0.989	79.133*	0.040	0.023	1.431	2.536	0.003	0.001	0.195
Genotype	40	0.457**	20.761**	1370.580**	14.934**	0.099**	6.325**	25.422**	0.242**	0.162**	0.472**
Error		0.037	1.556	24.357	0.656	0.065	0.709	3.640	0.003	0.002	0.097
E2											
Replication	2	0.003	0.745	42.219	0.601**	0.178**	0.460	1.862	0.003	0.001	0.195
Genotype	40	0.355**	29.460**	3593.880**	21.573**	0.271**	1.464**	21.731**	0.242**	0.162**	0.472**
Error		0.056	2.774	14.976	0.113	0.030	0.209	3.676	0.003	0.002	0.097
Pooled											
Replication	2	0.007	1.621	118.334	0.475	0.163	0.136	4.304	0.006	0.002	0.389
Genotype	40	0.597**	42.870**	3668.168**	31.710**	0.275**	4.611**	25.731**	0.226**	0.261**	0.533**
Environment	1	16.001**	1033.979**	5916.558**	17.879**	0.288**	82.905**	176.428**	9.358**	1.777**	10.849**
Genotype × Environment	40	0.215**	7.354**	1296.296**	4.797**	0.095	3.178**	21.422**	0.258**	0.063**	0.411**
Pooled Error	200	0.081	3.194	274.992	1.267	0.057	1.003	7.211	0.054	0.014	0.160
Combining ability in line × tester design for different traits in parthenocarpic cucumber over two environments											
E1											
Parents	10	0.230**	25.356**	1218.589**	14.842**	0.127*	3.207**	28.385**	0.137**	0.062**	0.191*
Lines	3	0.107	6.103*	104.735**	2.443*	0.013	0.729	44.238**	0.078**	0.047**	0.027
Testers	6	0.295**	38.092**	1303.291**	20.902**	0.187*	4.205**	22.451**	0.165**	0.060**	0.304**
Lines vs. Testers	1	0.216*	6.705*	4051.941**	15.678**	0.114	4.654	16.429*	0.145**	0.125**	0.000
Parents vs. Crosses	1	0.000	7.943*	2069.002**	0.697	0.121	1.614	0.786	0.406**	0.288**	0.034
SCA Crosses	27	0.556**	19.801**	1490.283**	16.450**	0.094	7.565**	25.189**	0.292**	0.206**	0.556**
GCA Lines	3	0.454	12.392	946.851	2.676	0.049	9.712	43.235	0.283	0.068	0.094
GCA Tester	6	0.347	41.666*	3364.428*	58.830**	0.052	16.785**	24.829	0.025	0.195	0.297
Error	76	0.039	1.628	24.520	0.647	0.063	0.743	3.533	0.003	0.002	0.096
E2											
Parents	10	0.201**	33.921**	3862.700**	35.624**	0.239**	2.788**	28.841**	0.436**	0.061**	0.610**
Lines	3	0.196*	1.912	1084.110**	3.843**	0.158**	0.743*	39.757**	0.841**	0.065**	0.732**
Testers	6	0.215**	54.973**	5147.938**	53.739**	0.272**	3.575**	28.167**	0.292**	0.050**	0.626**
Lines vs. Testers	1	0.136	3.634	4487.044**	22.280**	0.284**	4.203**	0.133	0.083**	0.123**	0.152
Parents vs. Crosses	1	2.764**	61.528**	1973.317**	2.412**	0.001	2.796**	0.291	0.631**	0.119**	0.014
SCA Crosses	27	0.315**	26.804**	3794.506**	18.550**	0.300**	0.966**	21.474**	0.161**	0.211**	0.473**
GCA Lines	3	0.306	0.107	6491.522*	29.412*	0.117	1.392	11.089	0.053	0.306	1.134*
GCA Tester	6	0.376	82.200**	8204.948**	48.288**	0.171	1.591	23.554	0.235	0.097	0.530
Error	76	0.058	2.851	15.318	0.119	0.031	0.216	3.564	0.003	0.002	0.102
Pooled											
Parents	10	0.320**	54.409**	4362.644**	44.711**	0.326**	4.321**	19.940**	0.338**	0.038**	0.545**
Lines	3	0.291**	5.823	859.998**	5.798**	0.131*	1.111	18.803 **	0.530**	0.014**	0.273*
Testers	6	0.330**	86.085**	5418.834**	65.342**	0.415**	5.171**	22.205 **	0.261**	0.056**	0.759**
Lines vs. Testers	1	0.347**	10.106*	8533.438**	37.669**	0.379**	8.852**	9.761	0.223**	0.000	0.079
Parents vs. Crosses	1	1.376**	56.197**	0.566	0.258	0.073	0.081	0.060	0.012*	0.389**	0.045
SCA Crosses	27	0.648**	38.169**	3803.999**	30.148**	0.281**	5.021**	29.962**	0.201**	0.357**	0.551**
GCA Lines	3	0.692	6.267	5394.997*	21.724	0.111	6.541	30.140	0.109	0.303	0.872
GCA Tester	6	0.650	113.735**	10196.560**	102.035**	0.141	12.938**	23.242	0.117	0.230	0.426
Env × Parents	10	0.112*	4.868*	718.645**	5.755**	0.040	1.675**	37.285**	0.235**	0.086**	0.255**
Env × Crosses	27	0.223**	8.448**	1480.789**	4.852**	0.113**	3.510**	16.702**	0.252**	0.059**	0.478**
Env × L × T effect	18	0.299**	8.106**	1423.014**	3.856**	0.133**	2.692 **	12.642**	0.293**	0.056**	0.524**
Pooled Error	152	0.048	2.229	19.919	0.383	0.047	0.479	3.548	0.003	0.002	0.099

Table 2. Analysis of variance for the experimental design and combining ability for different traits in parthenocarpic gynoecious cucumber in pooled across the two environments. Data are mean sums of squares; *significant at $p \leq 0.05$ and **significant at $p \leq 0.01$. **df**: degree of freedom, **FYPP**: fruit yield per plant; **NFPP**: number of fruits per plant; **FW**: fruit weight; **FL**: fruit length; **FD**: fruit diameter; **NFFFA**: node at which first female flower appears; **DFFP**: days to first fruit picking; **TSS**: total soluble solids; **FSCR**: flesh to seed cavity ratio; **WC**: water content; **E1**: Environment 1 (Winter season); **E2**: Environment 2 (Summer season).

[a]Traits	FYPP	NFPP	FW	FL	FD	NFFFA	DFFP	TSS	FSCR	WC
PK- 1	2.32	17.18	134.27^{efghijk}	14.28	3.66^{fgh}	3.68^{fg}	45.78^{bcdefghij}	2.85	1.88^{cdefgh}	97.27^{bcd}
PBRK-9	2.24	16.82	133.39	13.63	3.48	4.01^{cdefg}	47.45^{bcdefghij}	2.98	1.78^{h}	97.06^{d}
PBRK-15	2.21	19.03^{defgh}	126.09	15.61^{efghi}	3.58^{h}	3.75^{fg}	47.70^{bcdefghij}	3.29^{abcdef}	1.77^{h}	96.89
PBRK-16	2.69^{defgh}	17.33	154.04^{efghijk}	15.58^{fghi}	3.83^{cdefgh}	3.00	43.87^{bcdefghij}	3.50^{a}	1.82^{efgh}	97.37^{bcd}
PBRK-1	2.18	12.50	185.96^{bc}	19.52^{cd}	3.44	3.84^{efg}	47.04^{bcdefghij}	3.08^{ef}	1.86^{cdefgh}	97.19^{d}
PBRK-8	2.76^{def}	23.19^{ab}	121.56	11.62	3.75^{defgh}	5.25^{a}	46.29^{bcdefghij}	2.80	1.67	97.25^{bcd}
PBRK-10	2.41^{h}	12.53	209.71^{a}	21.56^{a}	3.54	5.17^{a}	49.73^{abcd}	3.07^{ef}	1.73	97.69^{ab}
PBRK-14	2.83^{cde}	18.14^{ghij}	165.16^{def}	14.28	4.25a	4.00^{cdefg}	45.47^{bcdefghij}	3.33^{abcde}	1.97^{c}	96.94
PBRK-17	2.52^{efgh}	17.08	151.78^{efghijk}	15.57^{fghi}	3.89^{bcdefg}	2.67	44.56^{bcdefghij}	3.09^{def}	1.84^{cdefgh}	96.94
PBRK-18	2.61^{defgh}	18.81^{defghi}	133.74	15.42^{fghi}	3.90^{bcdefg}	4.75^{abcdef}	49.39^{bcde}	2.72	1.82^{defgh}	97.00^{d}
PPC-6	2.32	15.19	156.18^{defghij}	16.48^{efg}	3.81^{cdefgh}	4.92^{abcde}	46.52^{bcdefghij}	3.16^{cdef}	1.79^{h}	96.53
PK-1 × PBRK-1	2.63^{defgh}	17.38^{hij}	157.60^{defghi}	15.05^{hi}	3.81^{cdefgh}	4.00^{cdefg}	46.04^{bcdefghij}	3.10^{def}	2.21^{b}	97.65^{abc}
PK-1 × PBRK-8	2.51^{efgh}	20.38^{cde}	124.68	12.04	3.84^{cdefgh}	3.17	45.07^{bcdefghij}	3.34^{abcd}	1.94^{cdef}	96.74
PK-1 × PBRK-10	2.50^{fgh}	16.65	152.30^{efghijk}	16.64^{ef}	3.60^{h}	3.01	46.20^{bcdefghij}	3.14^{cdef}	1.69	96.66
PK-1 × PBRK-14	2.92^{bcd}	19.60^{defg}	144.60^{efghijk}	15.05^{hi}	3.68^{fgh}	3.57^{g}	44.45^{bcdefghij}	3.10^{def}	2.21^{b}	97.26^{bcd}
PK-1 × PBRK-17	2.48^{fgh}	18.59^{efghij}	135.67^{efghijk}	15.93^{efghi}	4.13^{ab}	3.67^{fg}	43.57^{bcdefghij}	3.04^{f}	2.39^{a}	97.26^{bcd}
PK-1 × PBRK-18	2.24	18.12^{ghij}	120.56	14.64	3.35	2.09	45.71^{bcdefghij}	3.09^{def}	1.75	97.32^{bcd}
PK-1 × PPC-6	2.82^{cde}	18.38^{efghij}	153.43^{efghijk}	15.25^{ghi}	3.41	5.34	47.12^{bcdefghij}	2.75	1.78^{h}	97.30^{bcd}
PBRK-9 × PBRK-1	2.42^{gh}	16.72^{j}	151.63^{efghijk}	15.98^{efghi}	3.73^{efgh}	3.18	43.47^{bcdefghij}	2.84	1.43	97.23^{cd}
PBRK-9 × PBRK-8	2.54^{efgh}	20.73^{cd}	122.98	13.52	3.53	4.43^{abcdefg}	52.49^{a}	2.87	2.35^{a}	96.94
PBRK-9 × PBRK-10	2.45^{fgh}	13.72	199.79^{ab}	20.69^{abc}	3.69^{fgh}	3.83^{efg}	44.48^{bcdefghij}	3.40^{abc}	1.77	97.30^{bcd}
PBRK-9 × PBRK-14	2.77^{def}	21.95^{abc}	123.81	13.54	3.60^{h}	4.09^{bcdefg}	46.59^{bcdefghij}	3.14^{def}	2.35^{a}	97.30^{bcd}
PBRK-9 × PBRK-17	2.49^{fgh}	18.32^{f}	137.39^{efghijk}	14.80^{i}	3.51	4.33^{abcdefg}	49.07^{bcdefg}	3.18^{bcdef}	1.95^{cde}	97.41^{abcd}
PBRK-9 × PBRK-18	2.39	18.71^{defghij}	148.98^{efghijk}	14.72^{i}	3.72^{efgh}	3.93^{defg}	49.16^{bcdef}	3.05^{f}	1.89^{cdefgh}	96.80
PBRK-9 × PPC-6	2.45^{fgh}	16.36	162.01^{defgh}	15.99^{efghi}	4.03^{abc}	5.17^{ab}	46.46^{bcdefghij}	2.72	1.74	97.21^{cd}
PBRK-15 × PBRK-1	2.74^{defg}	16.13	173.63^{cd}	19.51^{cd}	3.50	3.67^{fg}	45.53^{bcdefghij}	3.42^{ab}	1.96^{cd}	97.24^{bcd}
PBRK-15 × PBRK-8	3.25^{a}	23.79^{a}	131.82	13.69	3.59^{h}	4.25^{abcdefg}	47.19^{bcdefghij}	3.10^{def}	1.80^{gh}	97.09^{d}
PBRK-15 × PBRK-10	2.28	13.58	187.89^{bc}	20.96^{ab}	3.63^{gh}	4.01^{cdefg}	45.07^{bcdefghij}	2.86	1.82^{defgh}	96.98^{d}
PBRK-15 × PBRK-14	2.46^{f}	17.80^{ghij}	145.28^{efghijk}	15.20^{ghi}	3.99^{abcde}	4.00^{cdefg}	48.50^{bcdefghij}	3.11^{def}	1.83^{defgh}	96.98^{d}
PBRK-15 × PBRK-17	2.56e^{fgh}	18.40^{fghij}	147.03^{efghijk}	15.52^{fghi}	3.89^{bcdefg}	4.01^{cdefg}	45.48^{bcdefghij}	3.00	1.80^{fgh}	97.16^{d}
PBRK-15 × PBRK-18	2.40	19.49^{defg}	121.19	14.37	3.64^{gh}	3.16	49.99^{abc}	3.27^{abcdef}	2.38^{a}	96.67
PBRK-15 × PPC-6	2.76^{def}	20.19^{cdef}	134.84^{efghijk}	15.41^{fghi}	3.31	5.09^{abc}	46.07^{bcdefghij}	3.21^{bcdef}	1.72	96.38
PBRK-16 × PBRK-1	3.26^{a}	16.83^{hi}	212.35^{a}	18.98^{d}	4.04^{abcd}	3.50	47.35^{bcdefghij}	3.24^{abcdef}	1.71	97.18^{d}
PBRK-16 × PBRK-8	3.33^{a}	22.90^{abc}	132.26	13.00	3.92^{bcdef}	3.83^{efg}	44.96^{bcdefghij}	3.29^{abcdef}	1.79^{h}	97.40^{abcd}
PBRK-16 × PBRK-10	2.77^{def}	15.35	203.24^{ab}	19.77^{bcd}	3.93^{bcdef}	5.16^{ab}	48.59^{bcdefghij}	3.20^{bcdef}	1.88^{cdefgh}	97.83^{a}
PBRK-16 × PBRK-14	2.07	15.00	140.33^{efghijk}	15.43	3.47	5.02^{abcd}	45.04^{bcdefghij}	2.84	1.73	97.26^{bcd}
PBRK-16 × PBRK-17	2.24	15.30	163.86^{defg}	15.87^{efghi}	3.68^{fgh}	3.25	45.05^{bcdefghij}	3.04^{f}	1.72	97.02^{d}
PBRK-16 × PBRK-18	3.23^{ab}	18.71^{def}	171.35^{cde}	16.26	3.84^{cdefgh}	4.01^{cdefg}	46.74^{bcdefghij}	3.10^{def}	1.77^{h}	97.03^{d}
PBRK-16 × PPC-6	2.76^{def}	19.49^{def}	152.12^{efghijk}	16.00^{efghi}	3.54	6.75	51.41^{ab}	3.20^{bcdef}	1.93^{cdefg}	97.16^{d}
PKH-11 (Check)	2.63^{de}	17.76^{ghij}	160.08^{defgh}	16.87^{e}	3.69^{fgh}	3.25	45.73^{bcdefghij}	3.05^{f}	1.83^{defgh}	96.72
Emirstar (Check)	3.14^{abc}	21.64^{abc}	152.55^{efghijk}	16.20^{efgh}	3.60^{h}	3.50	45.03^{bcdefghij}	3.28^{abcdef}	1.82^{efgh}	97.10^{d}
LSD ($P \leq 0.05$)	0.32	2.03	18.88	1.28	0.27	1.14	3.06	0.26	0.13	0.45

Table 3. Mean performance of parents, hybrids and checks for various yield and quality attributes evaluated in pooled across the two environments. Means compared using least significance difference (LSD) test at $p \leq 0.05$.[a]Traits acronyms given under Table 2.

× PBRK-10. Fruit diameter is another important trait which has great contribution towards total yield but in cucumber, it has been observed that there is less preference of fruits having more diameter. The fruit diameter of the parents varied from 3.44 to 4.25 cm and parent PBRK-14 had highest fruit diameter which was significantly different from both the checks and also followed parents PBRK-18 and PBRK-17. Among crosses, its ranged from 3.31 to 4.13 cm and cross PK-1 × PBRK-17 showed highest fruit diameter was significantly different from both the checks but at par with followed crosses PBRK-16 × PBRK-1 and PBRK-9 × PPC-6.

For earliness, node at which first female flower appears directly help to select early maturing genotype and such genotypes got higher price in the market due to early yield. It ranged from 2.67 – 5.25 among parents and parent PBRK-17 bear female flower at the lowest node which was significantly at par with both the checks and followed parent PK-1 (3.68). Among hybrids, it varied from 2.09 – 6.75 nodes and hybrid PK-1 × PBRK-18 produced female flower at lowest node which was at par with both the checks and followed crosses and

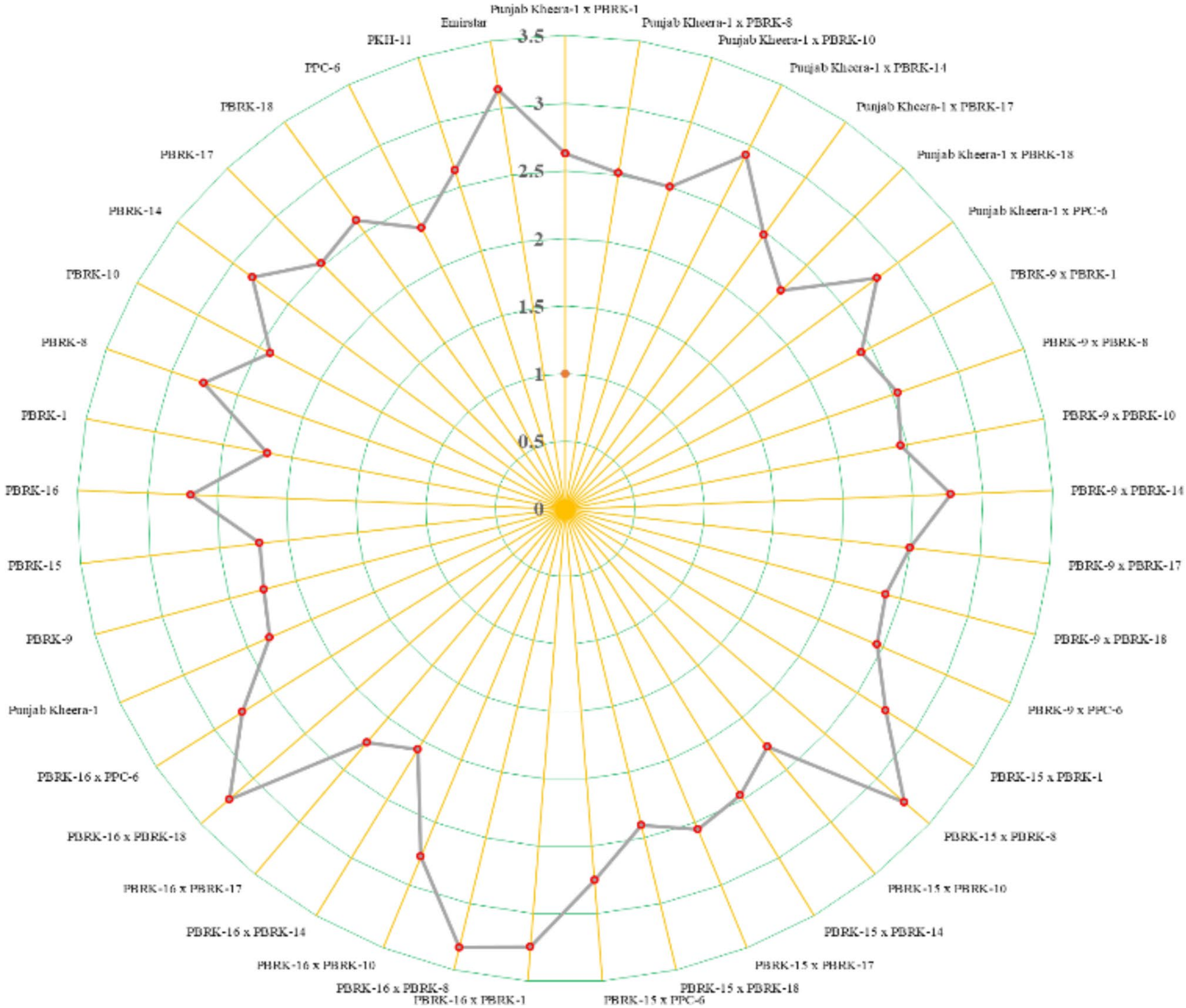

Fig. 3. Pooled mean comparisons of parents, commercial checks and F_1 hybrids for fruit yield per plant.

PK-1 × PBRK-10PBRK-15 × PBRK-18. Days to first fruit picking are also a key component which has great contribution on earliness and early yield. It varied from 43.87 – 49.73 among parents and PBRK-16 took least days to first picking which was significantly at par with both the checks and followed parents PBRK-17 and PBRK-14. Among the F_1 hybrids, early harvest varied from 43.47 – 52.49 days and cross combination PBRK-9 × PBRK-1 took minimum days to first fruit picking which was statistically similar with both the checks and followed crosses PK-1 × PBRK-17 and PK-1 × PBRK-14.

Among quality traits, total soluble solids (TSS) is an important trait for consumer preference and TSS of the parents varied from 2.72 – 3.50ºB and parent PBRK-16 exhibited highest TSS which was at par with check (Emirstar) and followed parents PBRK-14 and PBRK-15 but significantly different from check (PKH-11). In case of hybrids, it varied from 2.72 – 3.42ºB and cross combination PBRK-15 × PBRK-1 exhibit highest TSS which was at par with check (Emirstar) and followed crosses PBRK-9 x PBRK-10 and PBRK-16 × PBRK-8 but significantly different from check (PKH-11). The flesh to seed cavity ratio (FSCR) of the parents varied from 1.67 – 1.97 and it was observed that parent PBRK-14 exhibited highest FSCR which was significantly different from both the checks but at par with followed parents PK-1 and PBRK-1. In the case of crosses, FSCR varied from 1.43 – 2.39 and highest FSCR was observed in PK-1 × PBRK-17 which was significantly different from both the checks but at par with followed crosses PBRK-15 × PBRK-18, PBRK-9× PBRK-18 and PBRK-9× PBRK-14. Water content is one of the important traits which direct contribute in fruit quality. It was observed that parthenocarpic fruits having more water content as compared to open field condition. It ranged in parents from 96.53 – 97.69% and PBRK-10 exhibited highest water content which was significantly different from both the checks but at par with followed parents PBRK-16 and PK-1. Among the hybrids, water content varied from 96.38 – 97.83% and higher water content was shown by cross PBRK-16 x PBRK-10 which was significantly different from both the checks but at par with followed crosses PK-1 × PBRK-17 and PBRK-9 × PBRK-17. The less water content fruits have better shelf life.

Estimation of combining ability effects of parents and hybrids pooled across the two environments

General combining ability (GCA) effects of parents

Estimates of general combining ability (GCA) effects of 11 parents (four lines and seven testers) for yield and quality attributes in pooled environments are given in Table 4. Estimates of GCA effects of individual parental lines in the F_1 generation were found to be highly significant for most of the studied traits. Three parents viz., PBRK-16, PBRK-1 and PBRK-8 exhibited highly significantly and positive GCA effects for fruit yield per plant whereas parents PBRK-8 and PBRK-18 exhibited highly significantly and positive GCA effects for number of fruits per plant. For fruit weight, PBRK-16 and testers PBRK-1, PBRK-10 showed significantly positive GCA effects while lines PBRK-15, PBRK-16 and testers PBRK-1 and PBRK-10 observed to be good general combiners for fruit length. For fruit diameter, the line PBRK-16 and tester PBRK-17 found to be best general combiner.

For earliness, the line PK-1 and testers PBRK-1 and PBRK-18 were indicated as good general combiner due to their high and significant negative GCA effects for node at which first female flower appears and days to first fruit picking. For TSS, the lines PBRK-15 and PBRK-16 and testers PBRK-1, PBRK-8, PBRK-10 and PBRK-18 found to be the best general combiners. The lines PK-1 and PBRK-9 and testers PBRK-8, PBRK-14, PBRK-17 and PBRK-18 showed significantly positive GCA effects for fruit to seed cavity ratio whereas line PBRK-16 and tester PBRK-1 were observed to be the good general combiner for water content.

Specific combining ability (SCA) of hybrids

Estimates of specific combining ability (SCA) effects of hybrids for yield and quality attributes within and across the environments for all observed traits are displayed in Fig. 4. Out of 28 crosses, eight cross – combinations showed significantly positive SCA effects for fruit yield per plant and three crosses viz., PK – 1 × PBRK – 14, PBRK – 16 × PBRK – 1 and PBRK – 16 × PBRK – 18 were found to be best specific combiners. For number of fruits per plant, significant and positive SCA effects were observed in six crosses and only one cross combination PBRK – 9 × PBRK – 14 indicated as good specific combiner due to its high and significantly positive SCA effects. However, 11 cross combinations showed significantly positive SCA effects for fruit weight and four crosses viz. PK – 1 × PBRK – 8, PK – 1 × PBRK – 14, PK – 1 × PPC – 6 and PBRK – 16 × PBRK – 1 were best specific combiners. For fruit length, significant and positive SCA effects were observed for 11 cross – combinations and five cross combinations (PK – 1 × PBRK – 14, PK – 1 × PBRK – 17, PBRK – 9 × PBRK – 10, PBRK – 15 × PBRK – 1 and PBRK – 15 × PBRK – 10) indicated as good specific combiner. It was observed that six crosses showed significant and positive SCA effects for fruit diameter and two cross-combinations (PK – 1 × PBRK – 17, PBRK – 15 × PBRK – 14) found to be the best specific combiners.

For node at which first female flower appears, three crosses exhibited significant negative SCA effects and out of them, two crosses PK – 1 × PBRK – 18 and PBRK – 16 × PBRK – 17 were indicated as good specific combiner due to its high and significant negative SCA effects. Five cross – combinations exhibited significant negative SCA effects for days to first fruit picking. For total soluble solids, ten crosses showed significant positive SCA effects and one cross combination, PBRK – 9 × PBRK – 10, was observed as good specific combiner due to its high and significant positive SCA effects. Nine crosses showed significant positive SCA effects for fruit to seed cavity ratio.

Parents	FYPP	NFPP	FW	FL	FD	NFFFA	DFFP	TSS	FSCR	WC
Lines										
PK – 1	−0.05	0.28	−10.62**	−0.91**	−0.01	−0.51**	−1.22**	−0.01	0.09**	0.04
PBRK – 9	−0.13**	−0.09	−2.37**	−0.24**	−0.01	0.08	0.72*	−0.07**	0.02**	0.04
PBRK – 15	0.004	0.32	−3.07**	0.53**	−0.05	−0.03	0.16	0.05**	0.00	−0.21**
PBRK – 16	0.17**	−0.51*	16.05**	0.62**	0.07*	0.45**	0.35	0.04**	−0.11**	0.13**
LSD ($P \le 0.05$)	0.06	0.40	1.40	0.18	0.07	0.19	0.58	0.02	0.01	0.09
LSD ($P \le 0.01$)	0.08	0.52	1.85	0.24	0.09	0.25	0.76	0.03	0.02	0.12
SE	0.03	0.20	0.71	0.09	0.04	0.10	0.29	0.01	0.01	0.05
Testers										
PBRK – 1	0.128**	−1.40**	21.92**	1.53**	0.07	−0.46**	−1.08**	0.06**	−0.08**	0.19**
PBRK – 8	0.28**	3.79***	−23.94**	−2.79**	0.02	−0.14	0.75	0.06**	0.07**	−0.09
PBRK – 10	−0.132**	−3.34**	33.93**	3.67**	0.02	−0.05	−0.59	0.06**	−0.11**	0.06
PBRK – 14	−0.08	0.42	−13.37**	−1.05**	−0.02	0.12	−0.53	−0.05**	0.13**	0.07
PBRK – 17	−0.19**	−0.51	−5.89**	−0.32**	0.10*	−0.24	−0.88*	−0.03**	0.06**	0.08
PBRK – 18	−0.07	0.59*	−11.36**	−0.85**	−0.06	−0.76**	1.23**	0.032 **	0.05**	−0.18**
PPC – 6	0.06	0.44	−1.28	−0.19	−0.12*	1.53**	1.09**	−0.12**	−0.11**	−0.12
LSD ($P \le 0.05$)	0.08	0.52	1.85	0.24	0.10	0.25	0.76	0.02	0.02	0.12
LSD ($P \le 0.01$)	0.10	0.69	2.45	0.31	0.12	0.33	1.01	0.03	0.03	0.16
SE	0.04	0.26	0.94	0.12	0.05	0.13	0.38	0.01	0.01	0.06

Table 4. General combining ability (GCA) effects of parents for various yield and quality attributes evaluated across the two environments. *, **Significance at $p \le 0.05$ and $p \le 0.01$ level of probability, respectively. SE = standard error. [a] Traits acronyms given under Table 2.

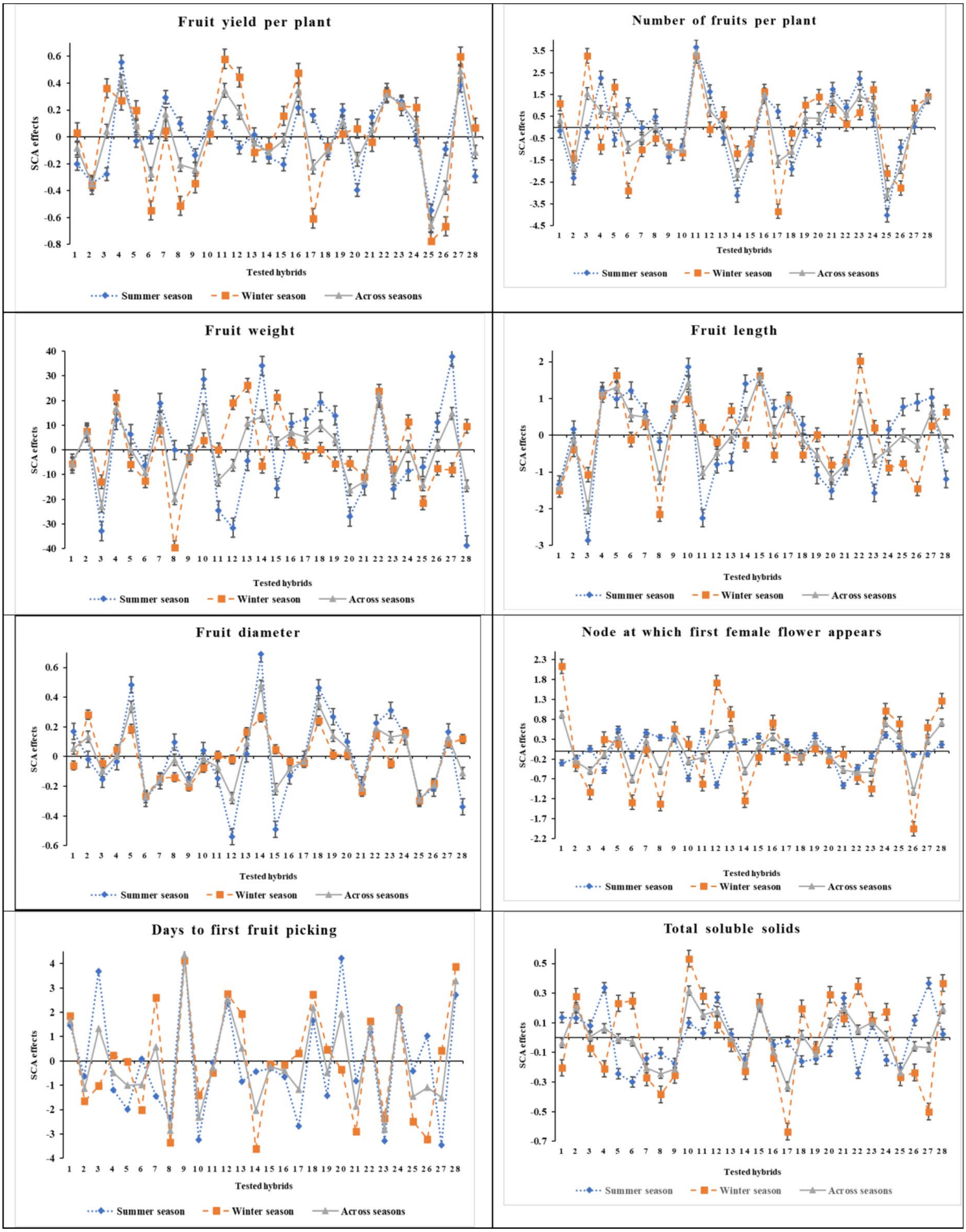

Fig. 4. Estimates of specific combining ability (SCA) effects for yield and quality attributes of F_1 hybrids of parthenocarpic gynoecious cucumber generated in line × tester mating design evaluated in sets of winter season, summer season, and across two seasons.

For water content, five crosses showed significant positive SCA effects and cross PBRK – 16 × PBRK – 10 had maximum water content. It is concluded that the cross-combinations showing good SCA effects for various yield and quality attributes traits elaborate all possible combinations between parents with good, average and poor general combining ability.

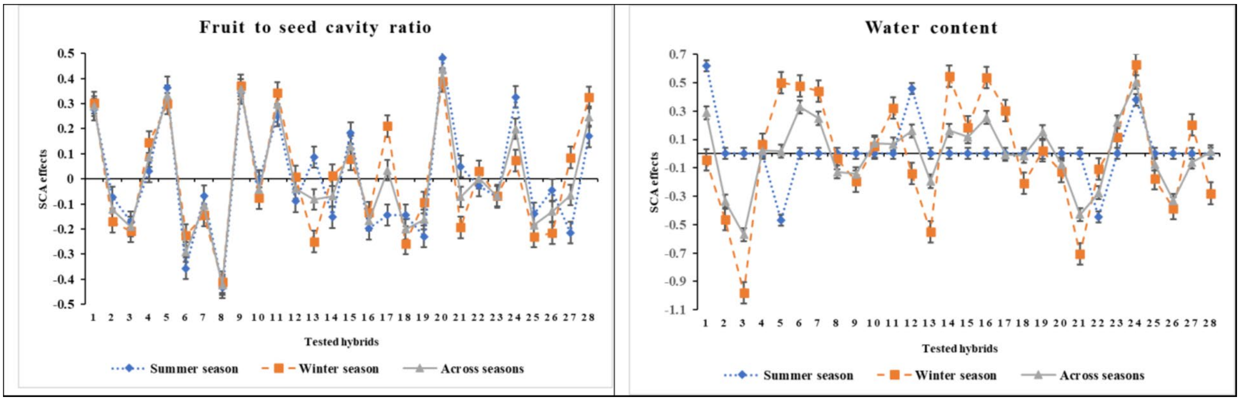

Figure 4. (continued)

Estimation of heterosis over two commercial check hybrids

Heterosis was estimated for each trait as a percentage of increase in F_1 hybrid over two commercial checks (standard heterosis) in pooled across the environments (Table 5). For fruit yield per plant, standard heterosis over both checks (PKH – 11 and Emirstar) varied from – 21.27 to 26.86% over PKH – 11 and – 34.18–6.05% over Emirstar. Out of 28 F_1 hybrids, four crosses showed high and significantly positive heterosis over check 'PKH – 11', however, none of hybrids showed highly significantly and positive heterosis over the check 'Emirstar' for fruit yield per plant but four hybrids showed positive and non-significant heterosis over check 'Emirstar'. The cross PBRK – 16 × PBRK – 8 was the top best performing hybrid for fruit yield per plant over check 'PKH – 11' having standard heterosis of 26.86%. In case of number of fruits per plant, a varied range of standard heterosis was found over both checks (– 23.52–34.01% over PKH – 11 and – 37.25–9.96% over Emirstar). Among the F_1 hybrids, six crosses over check 'PKH – 11' and one cross over check 'Emirstar' showed high and significantly positive standard heterosis for number of fruits per plant. The cross – combination PBRK – 15 × PBRK – 8 was observed to be top performed over both the standard checks for number of fruits per plant.

A wide range of standard heterosis (– 24.69 to 32.65% over PKH – 11 and – 20.97 to 39.20% over Emirstar) was observed for fruit weight. Among all the cross combinations, five crosses over check 'PKH – 11' and eight crosses over check 'Emirstar' exhibited high and significantly positive heterosis for fruit weight. The F_1 hybrid PBRK – 16 × PBRK – 1 was found to be top-ranking hybrid over standard checks for fruit weight. For fruits length, heterosis over standard checks ranged from (– 28.65 to 24.23% over PKH – 11; –25.67 to 29.42% over Emirstar), respectively. Amongst all hybrids, five crosses over both standard checks exhibited high and significantly positive heterosis. The cross, PBRK – 15 × PBRK – 10, was found as the top performing hybrid over both standard checks for fruit length. For fruit diameter, standard heterosis ranged from – 14.12 to 10.88%, – 18.34 to 7.33% and (– 10.17 to 11.89% over PKH – 11; – 8.09 to 14.48% over Emirstar), respectively. One cross over check 'PKH – 11' and four crosses over check 'Emirstar' exhibited high and significantly positive heterosis. The cross PK – 1 × PBRK – 17 was found top performing hybrid over both standard checks due to positive and highly significant heterosis for fruit diameter.

A diverse range of heterosis was observed over standard checks (– 35.83 to 107.59% over PKH – 11 and – 40.38 to 92.86% over Emirstar) for node at which first female flower appears. Only one cross exhibited high and significantly negative heterosis over both standard checks for node at which first female flower appears. The cross – combination, PK – 1 × PBRK – 18, bear female flowers at the lowest node w.r.t to both the standard checks hybrids. For days to first fruit picking, a diverse range of standard heterosis (– 4.94 to 14.78% over PKH – 11 and – 3.46 to 16.56% over Emirstar) was noted and two crosses showed significant and negative heterosis over standard check 'PKH – 11' but four crosses showed non – significant standard heterosis over commercial check 'Emirstar'. The cross PBRK – 9 × PBRK – 1 was the top – ranking hybrid over both standard checks in desirable directions for days to first fruit picking.

For TSS, a diverged range of standard heterosis (– 10.67 to 12.37% over PKH – 11 and – 16.99 to 4.43% over Emirstar) was identified among the F_1 hybrids, and observed that 11 crosses over commercial check 'PKH – 11' and two crosses over commercial check 'Emirstar' exhibited high and significantly positive heterosis for TSS. The cross combination PBRK – 15 × PBRK – 1 exhibited highest value of standard heterosis for TSS. A wide range in standard heterosis (– 22.20 to 30.39% over PKH – 11; – 21.56 to 31.47% over Emirstar) was observed for fruit to seed cavity ratio. Among all the F_1 hybrids, 10 crosses over check 'PKH – 11' and 11 crosses over standard check 'Emirstar' exhibited high and significantly positive heterosis for fruit to seed cavity ratio. The F_1 PBRK – 15 × PBRK – 18 was found to be top – ranking hybrid over both standard checks for fruit to seed cavity ratio. For water content, a diverged range of standard heterosis (– 0.36 to 1.14% over PKH – 11and – 0.75 to 0.74% over Emirstar) was identified among all the F_1 hybrids, and it was observed that 14 crosses over commercial check 'PKH – 11' and two crosses over standard check 'Emirstar' exhibited high and significantly positive heterosis. The cross combination, PBRK – 16 × PBRK – 10 exhibited highest heterosis for water content over both check hybrids.

Traits	FYPP		NFPP		FW		FL		FD		NFFFA		DFFP		TSS		FSCR		WC	
Hybrids	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar	PKH – 11	Emirstar
PK – 1 × PBRK – 1	0.13	−16.30 **	−2.14	−19.70 **	−1.55	3.31	−10.80 **	−7.07 **	3.30	5.69	23.01 *	14.29	0.67	2.23	1.92	−5.29 **	20.47 **	21.47 **	0.96 **	0.56 **
PK – 1 × PBRK – 8	−4.32	−20.01 **	14.77 **	−5.83	−22.11 **	−18.27 **	−28.65 **	−25.67 **	4.07	6.48	−2.97	−9.86	−1.44	0.09	9.74 **	1.98 *	5.73 **	6.61 **	0.02	−0.37 *
PK – 1 × PBRK – 10	−4.95	−20.54 **	−6.25	−23.08 **	−4.86 **	−0.16	−1.38	2.74	−2.26	0	−7.53	−14.1	1.02	2.59	3.12 **	−4.17 **	−7.73 **	−6.97 **	−0.07	−0.46 *
PK – 1 × PBRK – 14	11.30 *	−6.95	10.39 *	−9.42 **	−9.67 **	−5.21 **	−10.83 **	−7.10 **	−0.23	2.08	9.79	2.00	−2.80	−1.30	1.64	−5.54 **	20.47 **	21.47 **	0.55 **	0.16
PK – 1 × PBRK – 17	−5.65	−21.13 **	4.70	−14.09 **	−15.25 **	−11.06 **	−5.58 **	−1.64	11.89 **	14.48 **	12.76	4.76	−4.72 *	−3.25	−0.05	−7.12 **	30.39 **	31.47 **	0.56 **	0.16
PK – 1 × PBRK – 18	−14.73 **	−28.72 **	2.05	−16.27 **	−24.69 **	−20.97 **	−13.24 **	−9.61 **	−9.13 *	−7.03	−35.83 **	−40.38 **	−0.05	1.50	1.31	−5.85 **	−4.37 **	−3.58 *	0.61 **	0.22
PK – 1 × PPC – 6	7.37	−10.24 **	3.53	−15.05 **	−4.16 *	0.57	−9.62 **	−5.85 **	−7.55 *	−5.41	64.17 **	52.52 **	3.04	4.64	−9.69 **	−16.07 **	−3.09 *	−2.29	0.59 **	0.20
PBRK – 9 × PBRK – 1	−7.75	−22.88 **	−5.85	−22.75 **	−5.28 **	−0.6	−5.29 *	−1.34	1.27	3.61	−2.20	−9.14	−4.94 *	−3.46	−6.62 **	−13.22 **	−22.20 **	−21.56 **	0.53 **	0.13
PBRK – 9 × PBRK – 8	−3.30	−19.16 **	16.77 **	−4.19	−23.18 **	−19.39 **	−19.85 **	−16.50 **	−4.39	−2.17	36.24 **	26.57 *	14.78 **	16.56 **	−5.69 **	−12.36 **	28.12 **	29.17 **	0.22	−0.17
PBRK – 9 × PBRK – 10	−6.60	−21.92 **	−22.74 **	−36.61 **	24.81 **	30.97 **	22.65 **	27.78 **	0	2.31	17.89	9.52	−2.73	−1.22	11.66 **	3.76 **	−3.46 *	−2.66	0.59 **	0.20
PBRK – 9 × PBRK – 14	5.59	−11.73 **	23.61 **	1.42	−22.66 **	−18.84 **	−19.74 **	−16.38 **	−2.26	0	25.63 *	16.71	1.88	3.46	2.96 **	−4.32 **	28.12 **	29.17 **	0.60 **	0.21
PBRK – 9 × PBRK – 17	−5.02	−20.59 **	3.20	−15.32 **	−14.17 **	−9.94 **	−12.28 **	−8.61 **	−4.75	−2.54	33.06 **	23.62 *	7.30 **	8.97 **	4.32 **	−3.05 **	6.28 **	7.16 **	0.71 **	0.31
PBRK – 9 × PBRK – 18	−9.14 *	−24.04 **	5.40	−13.52 **	−6.94 **	−2.34	−12.75 **	−9.11 **	0.81	3.15	20.71	12.14	7.50 **	9.17 **	0.27	−6.82 **	3.28 *	4.13 **	0.07	−0.32
PBRK – 9 × PPC – 6	−6.54	−21.87 **	−7.88	−24.41 **	1.20	6.20 **	−5.21 *	−1.25	9.63 *	12.16 **	58.89 **	47.62 **	1.59	3.16	−10.67 **	−16.99 **	−4.82 **	−4.04 **	0.50 **	0.11
PBRK – 15 × PBRK – 1	4.38	−12.74 **	−9.15 *	−25.46 **	8.46 **	13.82 **	15.66 **	20.49 **	−5.2	−3.01	12.92	4.90	−0.44	1.11	12.37 **	4.43 **	6.82 **	7.71 **	0.53 **	0.14
PBRK – 15 × PBRK – 8	24.19 **	3.82	34.01 **	9.96 **	−17.65 **	−13.59 **	−18.89 **	−15.50 **	−2.76	−0.51	30.55 **	21.29 *	3.20	4.80 *	1.86	−5.34 **	−1.64	−0.83	0.38 *	−0.01
PBRK – 15 × PBRK – 10	−13.14 **	−27.39 **	−23.52 **	−37.25 **	17.37 **	23.16 **	24.23 **	29.42 **	−1.45	0.83	23.22 *	14.48	−1.45	0.08	−5.97 **	−12.61 **	−0.45	0.37	0.26	−0.13
PBRK – 15 × PBRK – 14	−6.16	−21.55 **	0.23	−17.75 **	−9.25 **	−4.77 **	−9.89 **	−6.12 **	8.14 *	10.64 **	22.86 *	14.14	6.06 *	7.71 **	2.08 *	−5.14 **	−0.27	0.55	0.26	−0.13
PBRK – 15 × PBRK – 17	−2.60	−18.58 **	3.65	−14.95 **	−8.15 **	−3.62 *	−8.01 **	−4.17	5.56	8.00 *	23.27 *	14.52	−0.54	1.00	−1.64	−8.60 **	−1.55	−0.73	0.45 *	0.06
PBRK – 15 × PBRK – 18	−8.57	−23.57 **	9.75 *	−9.94 **	−24.29 **	−20.56 **	−14.84 **	−11.28 **	−1.22	1.06	−2.92	−9.81	9.32 **	11.01 **	7.39 **	−0.2	30.39 **	31.47 **	−0.05	−0.44 *
PBRK – 15 × PPC – 6	4.95	−12.26 **	13.71 **	−6.69	−15.77 **	−11.61 **	−8.67 **	−4.86 *	−10.17 **	−8.09 *	56.54 **	45.43 **	0.74	2.30	5.53 **	−1.93 *	−6.10 **	−5.32 **	−0.36	−0.75 **
PBRK – 16 × PBRK – 1	23.81 **	3.50	−5.19	−22.21 **	32.65 **	39.20 **	12.49 **	17.19 **	9.18 *	11.70 **	7.74	0.10	3.55	5.16 *	6.46 **	−1.07	−6.46 **	−5.69 **	0.48 *	0.08

Continued

Traits	FYPP		NFPP		FW		FL		FD		NFFFA		DFFP		TSS		FSCR		WC	
Hybrids	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**	**PKH – 11**	**Emirstar**
PBRK – 16 × PBRK – 8	26.86 **	6.05	28.96 **	5.82	−17.38 **	−13.30 **	−22.97 **	−19.75 **	6.33	8.79 *	17.89	9.52	−1.69	−0.17	8.05 **	0.41	−2.55	−1.74	0.70 **	0.30
PBRK – 16 × PBRK – 10	5.65	−11.68 **	−13.53 **	−29.05 **	26.96 **	33.23 **	17.16 **	22.05 **	6.69	9.16 *	58.69 **	47.43 **	6.25 **	7.90 **	4.93 **	−2.49 *	2.37	3.21 *	1.14 **	0.74 **
PBRK – 16 × PBRK – 14	−21.27 **	−34.18 **	−15.54 **	−30.69 **	−12.34 **	−8.01 **	−8.56 **	−4.74 *	−5.97	−3.79	54.38 **	43.43 **	−1.51	0.02	−6.62 **	−13.22 **	−5.55 **	−4.77 **	0.55 **	0.16
PBRK – 16 × PBRK – 17	−14.79 **	−28.77 **	−13.85 **	−29.31 **	2.36	7.41 **	−5.92 **	−1.99	−0.23	2.08	−0.10	−7.19	−1.48	0.05	−0.22	−7.27 **	−6.01 **	−5.23 **	0.30	−0.09
PBRK – 16 × PBRK – 18	22.92 **	2.76	5.35	−13.56 **	7.04 **	12.32 **	−3.63	0.4	4.07	6.48	23.27 *	14.52	2.20	3.78	1.64	−5.54 **	−3.18 *	−2.39	0.31	−0.08
PBRK – 16 × PPC – 6	5.08	−12.15 **	9.77 *	−9.93 **	−4.97 **	−0.28	−5.18 *	−1.21	−4.07	−1.85	107.59 **	92.86 **	12.41 **	14.16 **	5.15 **	−2.29 *	5.10 **	5.96 **	0.45 *	0.06
Average	0.27	−16.17	2.29	−16.06	−5.12	−0.44	−6.05	−2.13	0.33	2.65	24.63	15.78	2.06	3.64	1.62	−5.57	3.86	4.72	0.42	0.03
Minimum	−21.27	−34.18	−23.52	−37.25	−24.69	−20.97	−28.65	−25.67	−10.17	−8.09	−35.83	−40.38	−4.94	−3.46	−10.67	−16.99	−22.2	−21.56	−0.36	−0.75
Maximum	26.86	6.05	34.01	9.96	32.65	39.2	24.23	29.42	11.89	14.48	107.59	92.86	14.78	16.56	12.37	4.43	30.39	31.47	1.14	0.74
LSD at $p = 0.05$	0.23	0.23	1.48	1.48	5.24	5.24	0.68	0.68	0.27	0.27	0.72	0.72	2.15	2.15	0.06	0.06	0.05	0.05	0.35	0.35
LSD at $p = 0.01$	0.31	0.31	1.96	1.96	6.93	6.93	0.90	0.90	0.36	0.36	0.96	0.96	2.85	2.85	0.08	0.08	0.06	0.06	0.46	0.46

Table 5. Standard heterosis (%) over two commercial check hybrids exhibited by 28 F_1 hybrids for yield and quality attributes traits in pooled across the two environments. **LSD**: least significant difference; *, ** significant at $P \leq 0.05$ and $P \leq 0.01$ level of probability, respectively; [a] Traits acronyms given under Table 2.

Estimation of potence ratio

Potence ratio estimated the nature and degree of dominance among the F_1 hybrids. The potence ratio of 28 cross combinations for different traits in pooled across the environments is presented in Table 6. In present investigation, it was observed that maximum potence ratio for fruit yield per plant was observed in hybrid PBRK – 15 × PBRK – 1 (31.29) and 19 hybrids showed over-dominance (> ± 1) and nine hybrids showed partial dominance (–1 to + 1). For number of fruits per plant, 12 hybrids exhibited over-dominance (> ± 1) and 16 hybrids showing partial dominance (– 1 to + 1) but maximum potence ratio was observed in hybrid PBRK – 1 × PBRK – 17 (29.79). Maximum potence ratio for fruit weight was observed in hybrid PBRK – 9 × PBRK – 18 (34.83) and 11 hybrids exhibited over-dominance (> ± 1) and 17 hybrids showed partial dominance (–1 to + 1). For fruit length, maximum potence was observed in hybrid PBRK – 16 × PBRK – 17 (51.14) and seven hybrids showed over-dominance (> ± 1), 17 hybrids showed partial dominance (–1 to + 1) and one hybrid PBRK – 15 × PBRK – 1 showed complete dominance. For fruit weight, maximum potence ratio was observed in hybrid PBRK – 9 × PBRK – 1 (13.26) and 16 hybrids showed over-dominance (> ± 1), 11 crosses exhibited partial dominance (– 1 to + 1) and one hybrid (PBRK – 15 × PBRK – 17) showed complete dominance. For node at which first female flower appearance, maximum potence ratio was observed in hybrid PBRK – 9 × PBRK – 14 (24.24) and 20 hybrids exhibited over-dominance (> ± 1) and eight hybrids exhibited partial dominance (–1 to + 1). Maximum potence ratio for days to first fruit picking was observed in hybrid PBRK – 9 × PBRK – 8 (9.73) and 18 hybrids showed over-dominance (> ± 1) and ten hybrids showed partial dominance (–1 to + 1). For total soluble solids, maximum potence was observed in hybrid PK – 1 × PBRK – 8 (21.57) and 16 hybrids showed over-dominance (> ± 1) and 12 hybrids showed partial dominance (–1 to + 1). For flesh to seed cavity ratio, maximum potence ratio was observed in hybrid PK – 1 × PBRK – 8 (36.87) and 24 hybrids showed over-dominance (> ± 1) and four hybrids showed partial dominance (–1 to + 1). For water content, maximum potence was observed in hybrid PK – 1 × PBRK – 8 (10.42) and 19 hybrids showing over-dominance (> ± 1) and 11 hybrids showing partial dominance (–1 to + 1).

Estimation of genetic components of variance

Gene action plays a crucial role in the genetic improvement of quantitative traits in any breeding program, as it aids in selecting appropriate breeding methods. In the present study, the σ^2SCA was higher than the σ^2GCA (average) for all traits except fruit weight and length (Table 7), indicating that most traits, except fruit weight

Traits[a]	FYPP	NFPP	FW	FL	FD	NFFFA	DFFP	TSS	FSCR	WC
PK – 1 × PBRK – 1	5.11	1.09	−0.10	−0.71	2.30	2.92	−0.59	1.23	36.87	10.42
PK – 1 × PBRK – 8	−0.13	0.06	−0.51	−0.68	2.82	−1.66	−3.78	21.57	1.58	−44.16
PK – 1 × PBRK – 10	3.04	0.77	−0.52	−0.35	0.03	−1.90	−0.79	1.62	−1.52	−3.96
PK – 1 × PBRK – 14	1.39	4.02	−0.33	0.77	−0.94	−1.66	−7.59	0.03	6.07	0.90
PK – 1 × PBRK – 17	0.53	29.79	−0.84	1.56	3.03	0.98	−2.61	0.64	30.23	0.95
PK – 1 × PBRK – 18	−1.60	0.15	−50.39	−0.38	−3.75	−3.97	−1.04	4.94	−3.68	1.33
PK – 1 × PPC – 6	0.50	2.22	−0.95	−0.12	−4.38	1.68	2.64	−1.61	−1.35	1.06
PBRK – 9 × PBRK – 1	15.94	0.95	−0.31	−0.20	13.26	−8.94	−18.71	−3.91	−9.83	1.01
PBRK – 9 × PBRK – 8	2.94	0.23	−0.76	0.89	−0.66	−0.32	9.73	−0.19	11.50	−2.30
PBRK – 9 × PBRK – 10	−0.54	−0.45	0.74	0.78	5.57	−1.30	−3.60	8.47	0.60	−0.24
PBRK – 9 × PBRK – 14	−0.24	6.77	−1.60	−1.29	−0.67	24.24	0.13	−0.12	4.93	4.97
PBRK – 9 × PBRK – 17	1.24	10.78	−0.56	0.21	−0.84	1.47	2.12	2.71	4.31	6.83
PBRK – 9 × PBRK – 18	−0.14	0.90	34.83	0.22	0.16	−1.23	0.77	1.55	4.04	−7.78
PBRK – 9 × PPC – 6	12.40	0.43	1.51	0.66	2.38	1.56	−1.13	−3.67	−6.98	1.58
PBRK – 15 × PBRK – 1	31.29	0.11	0.59	1.00	−0.20	4.00	−5.61	2.21	3.32	1.84
PBRK – 15 × PBRK – 8	2.83	1.29	3.53	0.04	−0.98	2.67	0.28	0.23	1.55	0.22
PBRK – 15 × PBRK – 10	−0.29	−0.68	0.48	0.80	3.40	−0.64	−3.59	−2.86	3.22	−0.99
PBRK – 15 × PBRK – 14	−0.18	−1.77	−0.02	0.39	0.22	0.95	1.72	−10.58	−0.46	1.04
PBRK – 15 × PBRK – 17	1.21	0.36	0.63	−3.15	1.00	1.47	−0.41	−1.89	−0.12	4.07
PBRK – 15 × PBRK – 18	−0.05	5.06	−3.28	−12.10	−0.62	−2.19	1.72	0.92	23.60	−9.08
PBRK – 15 × PPC – 6	9.06	1.60	−0.42	−1.48	−3.38	1.30	−1.76	−0.15	−7.38	−1.85
PBRK – 16 × PBRK – 1	3.19	0.79	2.65	0.73	2.00	0.20	1.20	−0.22	−6.57	−1.10
PBRK – 16 × PBRK – 8	17.33	0.90	−0.34	−0.30	3.45	−0.26	−0.10	0.40	0.53	1.50
PBRK – 16 × PBRK – 10	1.61	0.18	0.77	0.40	1.73	0.99	0.61	−0.42	2.20	1.87
PBRK – 16 × PBRK – 14	−10.09	−6.78	−3.47	0.77	−2.74	3.03	0.46	−6.67	−2.20	0.49
PBRK – 16 × PBRK – 17	−4.47	−14.87	9.69	51.14	−5.73	2.49	2.46	−1.23	−10.06	−0.64
PBRK – 16 × PBRK – 18	14.46	0.85	3.71	9.68	−0.72	0.15	0.04	−0.04	−29.30	−0.86
PBRK – 16 × PPC – 6	1.38	3.02	−2.79	−0.07	−34.13	2.92	4.70	−0.73	8.00	0.50

Table 6. Estimation of potence ratio of F_1 hybrids for various yield and quality attributes traits in pooled across the two environments. [a] Traits acronyms given under Table 2.

and length, are governed by non-additive gene action, therefore, heterosis breeding can be effectively utilized to improve these traits in cucumber. In contrast, fruit weight and length exhibited additive gene action, suggesting that selection in advanced generations would be more effective for improving these traits. Furthermore, σ^2SCA × Env is greater than σ^2GCA × Env., it indicates that the interaction of SCA with the environment has a larger influence on the traits studied compared to the GCA, emphasizes the role of non-additive gene action for studied traits under variable environmental conditions. These findings were further supported by the values of σ^2A (additive variance) and σ^2D (dominant variance), where σ^2D was higher than σ^2A for all traits except fruit weight and length. Additionally, the variance ratio (σ^2A / σ^2D) was less than one for all traits except fruit weight and length, further confirming the predominance of non-additive gene action for most traits. The degree of dominance for all traits, except fruit weight and length, was greater than one, indicating the significant role of dominance variance in governing these traits. The low narrow-sense heritability was observed for all the traits except fruit length, indicating that non-additive gene action predominated for most traits. In contrast, fruit length exhibited high narrow-sense heritability, suggesting the influence of additive gene action.

Discussions

In present investigation, pooled mean square due to genotypes for all the traits was significant indicating the presence of genetic variability among the genotypes. The significant genetic variation present in the genotypes is the cornerstone of any crop breeding program[30]. The analysis of variance for the experimental design for different traits showed that the mean square due to environments were also significant for all the traits which clearly showed that the environment effected the performance of the hybrids and parents whereas mean square due to the genotype × environment interaction was also significant which indicated the differential response of genotypes with change in the environment. This suggested that there is need to pursue environment specific breeding strategy to identify hybrids for summer, winter season and both seasons cultivation. In present study, it was observed that yield and its contributing traits were most affected by environment. Therefore, it is important to select parents and hybrids suitable for specific environments and those stable over the environments. Identification of the suitable parental lines or F_1 hybrids over the environments will potentially assist in production of the high yielding parthenocarpic gynoecious cucumber plants in both the environments or throughout the year.

The success of any hybrid breeding program depends on the right choice of parents. Estimating combining ability is essential because it evaluates an inbred line's potential to mate with testers to produce a hybrid. The genetic worth of parents is assessed by the per se performance and general combining ability. Determining the GCA of parents and SCA aids in selecting the appropriate parents for hybridization facilitates the creation of superior crosses. The analysis of variance for combining ability in line × tester for different traits showed that MS due parents, SCA crosses, environment × parents, environment × crosses and environment × line × tester were significant for almost all the traits which impacted performance of hybrids and parents. It was observed that the best parent per se was not necessarily associated with the GCA of the parents. For example, PBRK – 14 had the highest per se for fruit yield per plant and fruit diameter but the GCA effects were negatively in summer season and pooled across the environment. Besides parents mean performance, parents having high GCA effects as well as both nature (direction or sign) and magnitude (size) of GCA are considered in choice of parents for production of superior F_1 hybrids. The parents having good GCA can be useful for the prediction of yield potential of the cross[31]. However, Griffing[26] pointed out that the per se performance and combining ability did not always give similar inferences. Hence, choice of the parents should be based on actual combining ability effects with some emphasis on per se performance of the parents for production of superior F_1 hybrids. Such common information with respect to combining ability in parthenocarpic cucumber genotypes will help the breeders to develop high yielding parthenocarpic gynoecious hybrids[32].

Based on the pooled results of GCA and mean performance, the line PBRK – 16 found to be the best for fruit yield per plant, fruit weight, fruit length, fruit diameter and water content whereas tester PBRK – 8 was best for fruit yield per plant, number of fruits per plant and TSS. It is suggested that the line PBRK – 16 and tester PBRK – 8 can be used as female and male parents, respectively in hybridization program to develop high yielding parthenocarpic F_1 hybrids of cucumber. Earliness has great effect on yield by increasing the duration of fruit production or pickings and also indicates the genotype adaption to current and new environments. Among parents, PK – 1 (line) and PBRK – 1 (tester) exhibited higher GCA and mean performance for earliness, therefore, these can be used for development of early maturing parthenocarpic gynoecious cucumber hybrids. In cucumber, fruit weight and fruit length played a significant role in total yield. It was observed that the tester 'PBRK – 10' showed significantly positive GCA effects and mean performance for fruit length and fruit weight over the environments and pooled across the environments. The line PK – 1 and tester PBRK – 14 had significantly positive GCA effects and mean performance for flesh to seed cavity ratio. These results are consistent with the findings of previous studies; Bhutia et al.[33] identified parent Pusa Uday, DC – 1 and Kalyanpur Green as good general combiner for total yield per plant and number of fruits per plant, and fruit length and average fruit weight, and earliness traits, respectively. Ene et al.[34] identified Beit Alpha and Straight 8, and Kumar et al.[35] revealed CRC – 8, CHC – 2, Pusa Uday and DC – 1 as best general combiners for total fruit yield. Mule et al.[36] reported CCP – 9, Gujarat local and SPP – 44, and Naik et al.[37] identified US – 640, Himangi and Haveri Local parents as good combiners for fruit yield and its contributing traits. Ranga et al.[38] discovered UHFO – 6 to be a good general combiner for pod yield per plant in okra. Line GBS – 1 was found to be the best general combiner for days to first fruit picking and node number at which first female flower appears reported by Pati et al.[39]. Kumari et al.[40] discovered good general combiner for TSS, ascorbic acid, water content and flesh to seed cavity ratio. The best general combiners for rind thickness, β – carotene content, flesh thickness, firmness, ascorbic acid and TSS reported in muskmelon[21]. Similar results were also in agreement with previous findings[41–44]. In terms of best general combiners, the line PBRK – 16 and tester PBRK – 1 (Fig. 5) were observed to be the best for most of

[a]Traits	σ^2 Line	σ^2 Tester	σ^2 GCA (Average)	σ^2 SCA	σ^2 GCA × Env.	σ^2 SCA × Env.	σ^2 A	σ^2 D	σ^2 A / σ^2 D (Variance Ratio)	Degree of Dominance	Heritability (Narrow sense) %	Genetic Advance 5%
FYPP	0.015	0.025	0.019	0.100	0.002	0.086	0.076	0.399	0.191	2.287	16.289	0.162
NFPP	0.109	4.669	1.767	2.771	0.403	2.144	7.070	11.082	0.638	1.252	37.07	2.358
FW	127.953	423.982	235.600	231.167	102.250	467.345	942.400	924.667	1.019	0.991	34.202	26.151
FL	0.509	4.237	1.864	1.206	0.447	1.167	7.458	4.823	1.546	0.804	52.860	2.892
FD	0.001	0.004	0.002	0.050	0.001	0.026	0.009	0.200	0.043	4.848	4.683	0.029
NFFFA	0.146	0.523	0.283	0.289	0.279	0.766	1.133	1.155	0.981	1.010	25.228	0.779
DFFA	0.633	0.820	0.701	4.770	1.279	3.030	2.805	19.080	0.147	2.608	11.352	0.822
TSS	0.003	0.005	0.003	0.040	0.011	0.097	0.013	0.161	0.083	3.480	4.003	0.034
FSCR	0.007	0.009	0.008	0.068	0.004	0.018	0.032	0.271	0.118	2.912	14.539	0.099
WC	0.019	0.014	0.017	0.074	0.017	0.143	0.067	0.296	0.227	2.098	11.179	0.126

Table 7. Estimation of genetic components of variance across the two environments. [a] Traits acronyms given under Table 2.

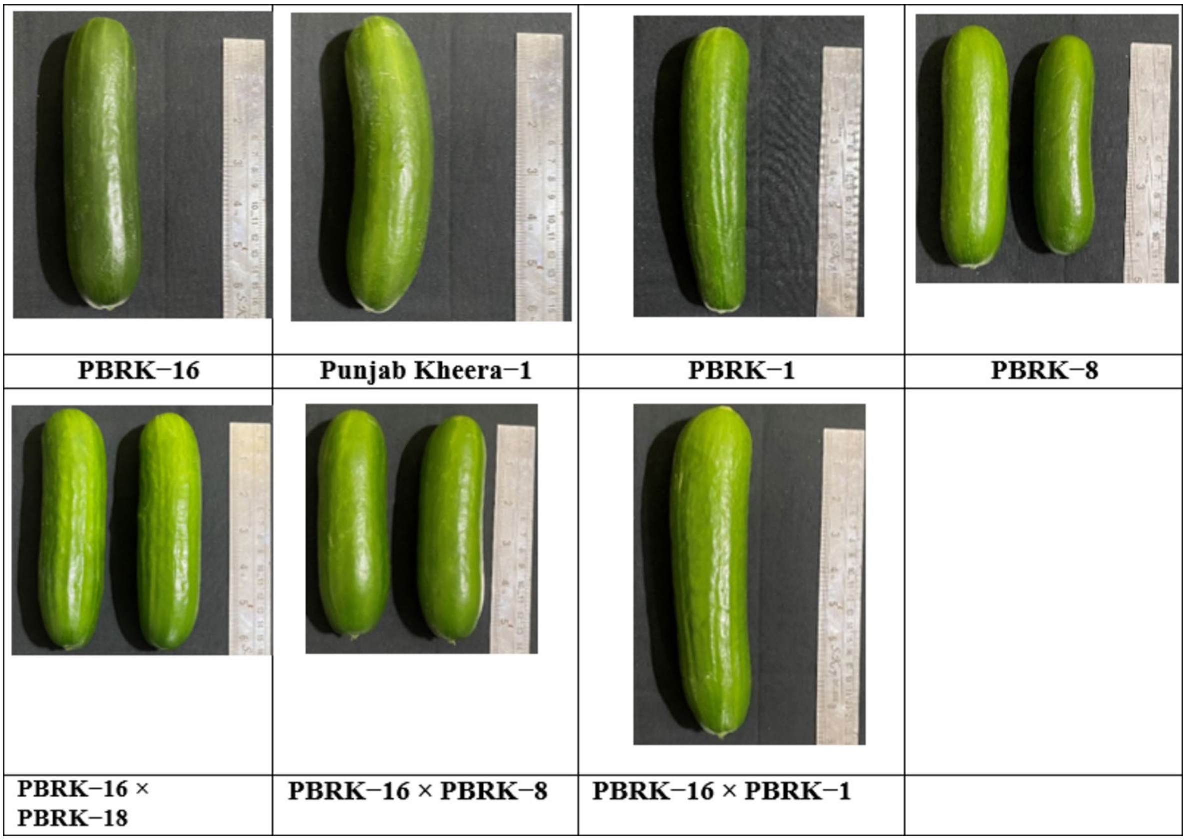

Fig. 5. Top performing parental lines and F_1 hybrids for yield and quality attributes selected on the basis of both winter and summer seasons evaluation.

the traits studied and both parents can give its best potential when used as female and male parent, respectively in F_1 development programme for improvement of yield and its attributing traits in cucumber.

Specific combining ability (SCA) is the performance of parental genotypes in specific cross combination that are governed by non – additive gene effects in case of hybrids. In general, non – additive SCA effects of crosses are reflected due to non – fixable effects of dominant and epistatic interactions of genes[45]. Information regarding SCA effects is of great importance in any breeding programme for species which are responsible for the development of F_1 hybrid cultivars. Present SCA result revealed that cross combinations PBRK – 16 × PBRK – 18 (good × average) and PK – 1 × PBRK – 14 (average × average) found to be the best for fruit yield per plant; PBRK – 9 × PBRK – 10 (poor × good) for fruit length and fruit weight; PBRK – 16 × PBRK – 17 (poor × good) for earliness traits; PBRK – 16 × PBRK – 10 (poor × poor) for flesh to seed cavity ratio and water content (good × poor); PBRK – 9 × PPC – 6 for fruit diameter (average × poor). Similarly, the crosses US – 640 × Haveri Local, DWD × Haveri Local and Sabra × Bagalkot Local as good specific combiners involving poor × good and poor × average combiners for yield and its attributing traits[37]. Shafike and Shoura[46] discovered two crosses in watermelon and Bayomi[47] identified one in tomato as good sepcifc combiners for yield related traits. Kaur et al.[21] discovered cross combination 3 M – 637 – D × 86E2143 to be a good specific combiner involving poor × good general combiners for fruit yield per plant and MM Sel – 103 × MM – 625, MS – 1 × MM – 916, MM – 1831 × Riogold and Kajri × MM – 904 for flesh thickness, rind thickness, firmness, and TSS, respectively in muskmelon. Hybrid Poona Khira × Sel. 97 – 7 to be a good specific combiner for earliness traits (days to first female flower anthesis, node number of first female flower and days to first fruit harvest)[48]. The cross EC – 27,075 × Summer Kheera, Pant Kheera – 1 × Japanese Long Green and Pant Kheera – 1 × Summer Kheera were good specific combiners for total soluble solids, ascorbic acid, and mineral content, respectively[43]. Cross combination AVCU – 1303 × Swarna Sheetal was best specific combiner for flesh to seed cavity ratio, ascorbic acid and fruit weight; PBRK – 11 × CMVR – 1 for fruit length; AVCU – 1303 × AVCU – 1202 for TSS and water content[40]. These results also corroborate the findings of studies conducted on bitter gourd by Triveni et al.[49], cabbage by Chander et al.[50], and okra by Adedoyin et al.[51]. The results revealed that high and significant SCA effects of all these crosses is due to involving of average × average, good × average, good × good, good × poor and average × poor general combiners indicating non-additive gene effects which can utilize through hybrid development. This indicated that the GCA, in general, had no bearing on the SCA effects of the crosses. Besides, most cross combinations with high SCA effects had at least one parent which is good or average general combiner. The crosses involving poor × poor general combiners showed high SCA effects due to over-dominance and non-allelic complementary gene action and whereas crosses involving good × good general combiners showed high SCA effects due to presence of positive alleles and their allelic interaction in parents and progenies, respectively and these explanations also in accord with the results described[52]. Cross combinations having good × poor and average × poor general combiners results high SCA effects due to interaction of positive alleles of good or average combiners and negative alleles of poor combiners and good × poor general combiners can be used for heterosis in F_1 generation whereas crosses involving good × good general combiners would be used to get transgressive segregants in F_2 generation and crosses involving good × average general combiners may give desirable transgressive segregants in the later segregating generations[53]. The primary influence on combining ability effects for most traits came from the testers, followed by the lines and line × tester interactions. Traits with a lower ratio of GCA to SCA are predominantly controlled by non-additive genetic factors, which can be leveraged through heterosis. Conversely, traits with a higher GCA to SCA ratio are more influenced by additive genetic factors, which can be utilized through selection[54]. The findings showed that most of the cross combinations revealing highly significant SCA effects which indicates high magnitude of heterosis for various traits. The high yield of such cross combinations would be non – fixable and thus can be utilized for heterosis breeding.

The study of heterosis is very helpful in the selection of superior heterotic combinations which can utilize in the crop improvement and development of high yielding parthenocarpic gynoecious cucumber hybrids. Both positive and negative heterosis can be valuable for crop improvement, depending on the breeding objectives and ultimate goal of the breeder is to achieve heterosis in the direction that aligns with their desired outcomes. The extent of heterotic response observed in an F_1 hybrid is mainly influenced by the genetic variation and breeding value of the parent plants used in the cross, along with the environmental conditions where the hybrid is cultivated[55]. Higher yield is the main aim of any crop breeding programme mainly for production of hybrids. Cucumber showed high value of heterosis which can be used in development of high yielding parthenocarpic gynoecious cucumber hybrids. The fruit yield per plant and number of fruits per plant are key components which directly contribute towards total yield of cucumber. In present investigation, we found that F_1 hybrids viz., PBRK – 16 × PBRK – 8, PBRK – 15 × PBRK – 8, PBRK – 16 × PBRK – 18 and PBRK – 16 × PBRK – 1 (Fig. 5) produced high fruit yield per plant than standard checks whereas PBRK – 15 × PBRK – 8 and PBRK – 16 × PBRK – 8 produced higher number of fruits per plant than standard checks. The best performing hybrids can be utilized in development of high yielding parthenocarpic gynoecious cucumber hybrids for over the seasons production. The high heterosis of these hybrids is due to effect of high degree of dominance involved in inheritance of both traits which was clearly observed from the more than 1.0 value of potence ratio of both hybrids and significant dominance of same traits. The heterosis for yield has mainly been credited to heterosis for number of fruits per plant[31]. Das et al.[56] reported crosses Debstar × Pusa Barkha and Pusa Barkha × Samrat 7 Star exhibited high standard heterosis for higher fruit yield per plant and number of fruits per plant. The cross combination ISD – 006 × GRB – 5 was identified as the best performer for yield and its contributing traits in terms of superior standard heterosis in both individual and pooled environments in brinjal[57]. Patel et al.[58] identified cross Phule Prajatiti × Arka Abhay showed positive and high standard heterosis for fruit yield per plant in okra. Hybrids Narendra Agrim × Punjab Samrat and *P* – 35 – 16 × *P* – 40 – 16 revealed highest standard heterosis for fruit yield per plant and number of fruits per plants, respectively in pumpkin[59]. Similar findings of standard heterosis have also been reported in previous studies[42,60,61,62]. The fruit weight and fruit length having positive contribution in total yield in parthenocarpic cucumber[63,64]. It was observed that the F_1 hybrids PBRK – 9 × PBRK – 10, PBRK – 16 × PBRK – 10 and PBRK – 15 × PBRK – 10 produced significantly high fruit weight and fruit length than both the standard checks. In each hybrid, one of the parents (tester) have high fruit weight and fruit length so it was observed that high heterosis of these hybrids indicated varied degree of dominance involved in inheritance of both traits. Similar findings also described on cucumber by Jat et al.[16], sponge gourd by Khairiya et al.[65] and bottle gourd by Gondane et al.[66]. Fruit diameter is also an important component with direct effects on fruit appearance and hybrids PK – 1 × PRBRK – 17, PBRK – 9 × PPC – 6 and PBRK – 16 × PBRK – 1 showed highly and significant positive heterosis over both the standard checks for fruit diameter. It was observed that high thickness of cucumber fruits may not be desirable due to separation of carpels. However, the most desirable fruit diameter was observed in F_1 hybrids viz. PBRK – 16 × PBRK – 18, PBRK – 16 × PBRK – 1 and PBRK – 15 × PBRK – 14. Srinivasulu et al.[67] identified IC – 469,512 × Special Boldar and Preethi × Special Boldar combinations exhibited high standard heterosis for fruit diameter in bitter gourd. The cross – combination HB – 96 – 1 × HN exhibited highly significant heterosis for fruit diameter compared to the standard check in okra[68]. Similar results were also corroborated by Golabadi et al.[69] and Thapliyal et al.[44] in cucumber, Duradundi et al.[70] in muskmelon. To get early and higher yield, node at which first female flower appears and days to first fruit picking are important traits for development of early and high yielding parthenocarpic gynoecious cucumber varieties/hybrids. The plant bearing female flower at lower nodes give high and early yield as compare to upper nodes which helps to get high market price and also increase the fruit picking duration. The cross combinations, PK – 1 × PBRK – 18 and PBRK – 9 × PBRK – 1 produced significantly early fruits on lower nodes and minimum number of days to first fruit picking than both the standard checks. However, both crosses are best to use for development of early high yielding gynoecious parthenocarpic cucumber hybrids. Punetha et al.[71] discovered cross combination Pgyn – 5 × US – 832 showed highest negative standard heterosis for days to first female flower and days to first harvest in cucumber. These findings are also in agreement with those reported by Patel et al.[58] and Chaudhary et al.[72] in okra, Meena et al.[73] in tomato, Singh et al.[74] in bitter gourd and Phor et al.[75] in brinjal. Quality traits such as TSS, water content and flesh to seed cavity ratio had great contribution in fruit quality, appearance and shelf life in cucumber. It was observed that hybrids viz., PK – 1 × PBRK – 8, PBRK – 15 × PBRK – 18 and PK – 1 × PBRK – 1 were showing significant standard heterosis for TSS, flesh to seed cavity ratio and water content, respectively. Kaur et al.[43] identified crosses JLG × NCH – 1 and JLG × Summer Kheera showed highest standard heterosis for flesh to seed cavity ratio and total soluble solids, respectively. Similar results of standard heterosis for quality traits reported by Thapliyal et al.[44] in cucumber, Kumar et al.[76] in pumpkin, Singh et al.[77] in cabbage, Rani et al.[78] in brinjal and Sharma et al.[79] in bell pepper. Heterosis, or hybrid vigour, occurs in F_1 hybrids when the dominant alleles mask the effects of harmful recessive alleles. This means that the superiority of hybrids can be attributed to the dominant positive genes overshadowing the negative recessive ones.

The study of potence ratio helps to estimate the various degree of dominance of inherited traits. A positive potence ratio indicates varying levels of dominance, ranging from partial to overdominance in trait inheritance, while a negative potence ratio reflects varying degrees of recessiveness, from partial to under-recessiveness. Complete dominance is represented by a potence ratio of ± 1, while partial dominance is shown by a value between − 1 and + 1, excluding zero, which signifies no dominance. Over-dominance is indicated when the potence ratio is greater than > ± 1. The positive and negative signs of the potence ratio highlight the direction of dominance, providing insights into which parental traits are contributing more significantly to the hybrid performance. The result of potence ratio in pooled across the two environments illustrated that F_1 hybrids PBRK – 16 × PBRK – 18 and PBRK – 16 × PBRK – 1 showed over – dominance for fruit yield per plant and PK – 1 × PBRK – 14, PBRK – 9 × PBRK – 17 and PBRK – 15 × PBRK – 8 for number of fruits per plant (Table 6). Abd – Rabou and Zaid[80] reported over-dominance for fruit yield per plant and number of fruits per plant in five and three cucumber hybrids, respectively. The F_1 hybrid PBRK – 16 × PBRK – 17 showed over-dominance for fruit weight and fruit length whereas PBRK – 15 × PBRK – 10, PBRK – 16 × PBRK – 10 and PK – 1 × PBRK – 1 for fruit diameter. Ten hybrids exhibited over – dominance for fruit length, breadth and average fruit weight in cucumber[81]. However, for earliness traits (node at which first flower appears and days to first fruit picking) over – dominance was observed in crosses PBRK – 9 × PBRK – 17, PBRK – 16 × PPC – 6, PBRK – 16 × PBRK – 17 and PK – 1 × PPC – 6. Similar results of over – dominance for earliness traits observed in pumpkin hybrids[82]. The hybrids PK – 1 × PBRK – 1, PK – 1 × PBRK – 18 and PBRK – 9 × PBRK – 17 showed over – dominance for water content and TSS. Kumari et al.[83] reported over – dominance among nine cucumber hybrids for TSS. These results of potence ratio are in accordance with previous studies conducted by Solieman et al.[84] in tomato, Soames et al.[85] in hot pepper, Rao and Badiger[86] in bell pepper, Alhadi et al.[87] in maize and Wibowo and Sumirat[88] in coffee. The result revealed that partial to over-dominance effects are involved in the inheritance of all the studied traits and degree of dominance (potence ratio) is recorded in both positive and negative directions for various traits. The positive dominance observed in certain hybrids suggests that the traits from the higher parent have a more substantial influence on the hybrid's performance, while negative dominance indicates a stronger contribution from the lower parent. However, over-dominance effect showed the high amount of heterosis among all the studied traits which can be easily utilize in the development of stable high yielding parthenocarpic gynoecious cucumber hybrids for both the environments.

The higher σ^2SCA compared to σ^2GCA and a variance ratio (σ^2A/σ^2D) of less than one for all traits, except fruit weight and length, indicated the predominance of non-additive gene action governing these traits. Ranga et al.[89] reported high σ^2SCA than σ^2GCA for most of the traits except plant height and inter-nodal length in okra. Additionally, the degree of dominance for all traits, except fruit weight and length, was greater than one, further confirming the significant role of dominance variance in their inheritance. Kumari et al.[40] found significant degree of dominance and non-additive gene action for all traits, except fruit length. Further, higher σ^2SCA × Env. than σ^2GCA × Env. for all traits suggests that the performance of specific hybrid combinations is more sensitive to environmental changes than the average performance of lines and testers, emphasizes the role of non-additive gene action. Similar finding of environmental interaction variances for SCA and GCA was reported[90]. Narrow-sense heritability was found to be less than 0.5, indicating the predominance of non-additive gene action. Kumar et al.[91] observed low narrow-sense heritability for all the studied traits except fruit weight, length and diameter in cucumber. Ram et al.[92] also revealed low narrow-sense heritability for all the studied traits except plant height and days to 50% flowering in garden pea. Low narrow-sense heritability in cucumber indicates that a substantial portion of the observed variation in a trait is attributed to environmental factors rather than genetic factors, suggests that environmental influences play a dominant role in determining the expression of the trait, making it more challenging to achieve genetic improvement through selection alone, in such cases, hybridization (heterosis) breeding strategies may need to consider for improvement of these traits[93]. Conclusively, the dominance of non-additive gene action and low narrow-sense heritability for most key yield-contributing traits highlight the significance of heterosis breeding for achieving higher genetic gains in cucumber under variable environmental conditions.

The study, conducted under poly-net house conditions, may not fully reflect the dynamics of open-field environments, limiting its broader applicability. The use of specific parthenocarpic gynoecious *Beit Alpha* cucumber inbreds could restrict genetic diversity, potentially increasing susceptibility to environmental stresses or pathogens. Additionally, the high cost of poly-net house setups may pose challenges for small-scale farmers, affecting scalability. The limited study duration may not account for long-term environmental effects or the stability of yield and quality traits. Although the study highlights hybrids with promising traits, their commercial feasibility and acceptance among farmers and markets remain unassessed, leaving a critical gap in understanding their practical adoption and economic potential.

The utilization of parthenocarpic gynoecious cucumber inbreds provides an excellent foundation for producing high-yielding, top-quality hybrids. Future research can emphasize the incorporation of traits such as enhanced disease resistance, drought tolerance, and improved nutritional profiles to develop more resilient and adaptable cultivars[94,95]. Conducting trials across diverse geographic regions and under varying environmental conditions will be crucial to confirming the stability of heterotic effects and the adaptability of hybrids[96]. Moreover, the integration of advanced genomic tools, such as marker-assisted selection and genomic selection (Quantitative trait loci (QTL) mapping and Genome wide association mapping (GWAS)), can accelerate the identification of genomic regions linked to desirable traits, thereby facilitating targeted breeding strategies for trait improvement in cucumber[97,98]. Developing hybrids with superior yield and quality characteristics can address the growing demand for premium cucumbers in both domestic and international markets, ultimately contributing to increased profitability for producers. Future research could investigate the combination of poly-net house cultivation with integrated pest management (IPM) strategies to promote sustainable and eco-friendly cucumber production and this approach has the potential to minimize pesticide use, enhance resource efficiency, and improve crop health while maintaining high yields and quality standards[99].

Conclusion

The primary objective of the current study was to find out best hybrid combinations of beit alpha type parthenocapic gynoeious cucumber which can be grown in both the seasons in poly-net house. Based on the results of pooled across the two environments, it is concluded that parental lines PBRK – 16, PK – 1 and testers PBRK – 1, PBRK – 8 exhibited superior and stable performance on the basis of per se performance and GCA effects for yield and its contributing traits. Hence, these parents can be further utilized in the breeding programme for development of superior beit alpha type parthenocarpic gynoecious cucumber hybrids. On the bais of heterosis, mean performance and SCA effects along with consumer preference for fruits,, the F_1 hybrids PBRK – 16 × PBRK – 18 and PBRK – 16 × PBRK – 1 were found to be best and had stable performance for yield and quality traits in both the seasons.Therefore, these hybrids can be released after multi-location testing as commercial hybrid for cultivation in the state forpoly-net house conditions during both winter and summer seasons. The non-additive gene action and low narrow-sense heritability for most traits highlight the significance of heterosis breeding for achieving higher genetic gains in cucumber under variable environmental conditions. Furthermore, the year-round cultivation of these promising hybrids can significantly increase farmers' profitability, strengthen food security, and more effectively meet market demands.

Data availability

The data associated with the study has already been given in the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
The germplasm used in the present study were developed by the breeder (Dr. Rajinder Kumar Dhall) at Punjab Agricultural University, Ludhiana, Punjab, India except one variety (Pusa Parthenocarpic Cucumber – 6) and hybrid (Emirstar). All the guidelines were followed as per the University research ethics for development, characterisation and documentation of germplasm accessions. The proper breeding procedure was followed during field experiments and its details were mentioned in material and methods section. Punjab Agricultural University, Ludhiana, Punjab, India has been established in 1962 by an act of legislature and is the custodian of crop biodiversity. As a faculty member of the University and Principal Olericulturist at Vegetable Science department, Corresponding author (RKD) is fully authorised to develop, conserve and characterise the germplasm for breeding improved varieties.

Additional information
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Correspondence and requests for materials should be addressed to R.K.D.