HETEROSIS AND COMBINING ABILITY FOR YIELD AND YIELD ATTRIBUTING TRAITS OF PARTHENOCARPIC CUCUMBER (*Cucumis sativus* L.) UNDER POLY-NET HOUSE CONDITIONS

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
HORTICULTURE (VEGETABLE SCIENCE)
(Minor Subject: Plant Breeding and Genetics)

By

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2017

CERTIFICATE I

This is to certify that the thesis entitled **"Heterosis and combining ability for yield and yield attributing traits of parthenocarpic cucumber (*Cucumis sativus* L.) under poly-net house conditions"** submitted for the degree of **M.Sc.** in the subject of **Vegetable Science** (Minor subject: **Plant Breeding and Genetics**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Vivek Thapliyal (L-2015-A-163-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the thesis report entitled, **"Heterosis and combining ability for yield and yield attributing traits of parthenocarpic cucumber (*Cucumis sativus* L.) under poly-net house conditions"** submitted by **Vivek Thapliyal (L-2015-A-163-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Vegetable Science (**Minor subject: **Plant Breeding and Genetics**) has been approved by the Student's Advisory Committee along with Head of the Department after an oral examination on the same.

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"Anytime you deny the acknowledgement of god you are undermining the entire basis of your own existence"

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ABSTRACT

The present investigation entitled "Heterosis and combining ability for yield and yield attributing traits of parthenocarpic cucumber (*Cucumis sativus* L.) under poly-net house conditions" was carried out at Research Farm of Department of Vegetable Science, Punjab Agricultural University, Ludhiana during 2015-17. Eight parthenocarpic gynoecious inbred lines of cucumber were crossed in a diallel fashion (excluding reciprocals) to produce twenty eight cucumber hybrids. The observations were recorded for eleven traits, *viz.* fruit weight, total soluble solids, fruit length, fruit diameter, vine length, number of fruits per plant, flesh to seed cavity ratio, days to first fruit harvest, days to last fruit harvest, number of seeds per fruit and yield per plant. The analysis of variance indicated significant difference among all the genotypes for all the traits except number of seeds per fruit. The combining ability analysis revealed that mean squares due to gca and sca were significant for almost all the traits, indicating the role of both additive and non-additive gene action in inheritance of these traits. The cross combinations PBRK-4 x PBRK-12, PBRK-4 x PBRK-9 and PBRK-4 x PBRK-8 were found to exhibit high heterosis over commercial check (Multistar) for yield per plant. The parental line PBRK10 was observed to be the best general combiner for five characters, *viz*., fruit weight total soluble solids, fruit length, vine length and flesh to seed cavity ratio and second best combiner for days to last fruit harvest, whereas PBRK4 was found to be the best general combiner for number of fruits per plant, days to first fruit harvest and yield per plant. The cross combination PBRK-4 x PBRK-12 was found to be the best specific combiner for number of fruits per plant and yield per plant, PBRK-12 x PBRK-7 for fruit weight and fruit diameter and PBRK-10 x PBRK-1 for fruit length. The cross combinations PBRK4 x PBRK12, PBRK4 x PBRK9 and PBRK9 x PBRK1 exhibiting high positive heterosis for yield per plant along with high sca effects can be used for developing F_1s. The genetic components of variation revealed that most of the characters, except fruit weight, fruit length and number of fruits per plant were governed by non-additive gene action and hence can be improved through heterosis breeding.

Keywords: Heterosis, Combining ability, Parthenocarpic cucumber

Signature of Major Advisor **Signature of the student**

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ਮੌਜੂਦਾ ਜਾਂਚ "ਪੌਲੀ-ਨੈਟ ਹਾਊਸ ਵਿੱਚ ਅਨਿਸ਼ੇਕਜਨਕ ਖੀਰੇ ਦੇ ਝਾੜ ਅਤੇ ਝਾੜ ਘਟਕਾ ਲਈ ਹੈਟਰੋਸਿਸ ਅਤੇ ਮਿਲਨ ਯੋਗਤਾ" ਸਿਰਲੇਖ ਹੇਠ ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਸਬਜੀ ਵਿਭਾਗ ਦੇ ਖੋਜ ਫਾਰਮ ਉੱਪਰ 2015-17 ਦੌਰਾਨ ਕੀਤੀ ਗਈ। ਖੀਰੇ ਦੀਆਂ ਅੱਠ ਅਨਿਸ਼ੇਰਜਨਕ ਗਾਇਨੋਸ਼ੀਅਸ ਇਨਬਰਿਡ ਲਾਇਨਿਾਂ ਨੂੰ ਡਾਇਅਲੀਲ ਫੈਸ਼ਨ ਨਾਲ ਕਰਾਸ ਕਰਕੇ 28 ਖੀਰੇ ਦੇ ਹਾਇਬਰਿਡ ਪੈਦਾ ਕੀਤੇ ਗਏ। 11 ਗੁਣ ਜਿਵੇਂ ਜਿਵੇਂ ਫ਼ਲ ਭਾਰ, ਕੁੱਲ ਘੁਲਣਸ਼ੀਲ ਠੋਸ, ਫ਼ਲ ਲੰਬਾਈ, ਫ਼ਲ ਵਿਆਸ, ਵੱਲ ਦੀ ਲੰਬਾਈ, ਪ੍ਰਤੀ ਫ਼ਲ ਬੀਜਾਂ ਦੀ ਸੰਖਿਆ ਗੁੱਦੇ ਅਤੇ ਬੀਜ ਕੈਵਿਟੀ ਦਾ ਅਨੁਪਾਤ, ਫ਼ਲ ਤੋੜਨ ਲਈ ਲੱਗਣ ਵਾਲੇ ਦਿਨ ਪ੍ਰਤੀ ਿਲ ਬੀਜ ਅਤੇ ਪ੍ਰਤੀ ਪੌਦਾ ਝਾੜ ਸਬੰਧੀ ਆਂਕੜੇ ਇਕੱਠੇ ਕੀਤੇ ਗਏ। ਵੇਰੀਏਂਸ ਦਾ ਵਿਸ਼ਲੇਸ਼ਣ ਦਰਸਾਉਂਦਾ ਹੈ ਕਿ ਸਾਰੇ ਜੀਨੋਟਾਇਪ ਵਿੱਚ ਪ੍ਰਤੀਫ਼ਲ ਬੀਜਾਂ ਦੀ ਸੰਖਿਆ ਨੂੰ ਛੱਡ ਕੇ ਬਾਕੀ ਸਾਰੇ ਲੱਛਣਾਂ ਵਿਚ ਅਰਥਪੂਰਨ ਭਿੰਨਤਾ ਪਾਈ ਗਈ। ਮਿਲਨ ਯੋਗਤਾ ਵਿਸ਼ਲੇਸ਼ਣ ਦਰਸਾਉਂਦਾ ਹੈ ਕਿ ਕਰੀਬ ਸਾਰੇ ਲੱਛਣਾ ਲਈ gca ਅਤੇ sca ਦੇ ਕਾਰਨ ਔਸਤ ਸਕੂਏਅਰ ਅਰਥਪੂਰਨ ਸੀ ਜੋ ਇਨ੍ਹਾਂ ਲੱਛਣਾ ਦੇ ਪੈਤਰਿਕਤਾ ਪਿੱਛੇ ਜੀਨ ਦੇ ਐਡਿਟਿਵ ਅਤੇ ਨਾਨ ਐਡਿਟਿਵ ਕਾਰਜ ਦੀ ਭੂਮਿਕਾ ਨੂੰ ਦਰਸਾਉਂਦਾ ਹੈ। ਪ੍ਰਤੀ ਪੌਦਾ ਝਾੜ ਲਈ ਵਪਾਰਕ ਚੈੱਕ ਨਾਲੋਂ PBRK-4 x PBRK-12, PBRK-4xPBRK-9 ਅਤੇ PBRK-4xPBRK-8 ਦੇ ਕਰਾਸ ਮਿਲਨਾਂ ਵਿੱਚ ਪ੍ਰਤੀ ਪੌਦਾ ਝਾੜ ਵੱਧ ਸੀ। ਜੰਮਹੇਤੂ ਲਾਇਨ PBRK10 ਪੰਜ ਲੱਛਣ ਫ਼ਲ ਭਾਰ, ਕੁਲ ਘੁਲਣਸ਼ੀਲ ਠੋਸ, ਫ਼ਲ ਲੰਬਾਈ, ਵੱਲ ਦੀ ਲੰਬਾਈ ਅਤੇ ਗੁੱਦਾ ਬੀਜ ਕੈਵਿਟੀ ਅਨੁਪਾਤ ਲਈ ਸਭ ਤੋਂ ਵਧੀਆ ਸਾਧਾਰਨ ਕੰਬਾਇਨਰ ਸਿੱਧ ਹੋਈ ਜਦਕਿ ਆਖ਼ਰੀ ਫ਼ਲ ਤੁੜਾਈ ਤੱਕ ਤੇ ਦਿਨਾਂ ਲਈ ਇਹ ਦੂਸਰੀ ਸਭ ਤੋਂ ਵਧੀਆ ਕੰਬਾਇਨਰ ਸਾਬਿਤ ਹੋਈ, ਜਦਕਿ PBRK-4 ਪ੍ਰਤੀ ਪੌਦਾ ਫ਼ਲ, ਪਹਿਲੀ ਤੁੜਾਈ ਲਈ ਲੱਗਣ ਵਾਲੇ ਦਿਨ ਅਤੇ ਪ੍ਰਤੀ ਪੌਦਾ ਝਾੜ ਲਈ ਸਭ ਤੋਂ ਵਧੀਆਂ ਸਾਧਾਰਨ ਕੰਬਾਇਨਰ ਸਾਬਿਤ ਹੋਈ। PBRK-4 x PBRK-12 ਦੇ ਕਰਾਸ ਕੰਬੀਨੇਸ਼ਨ ਪ੍ਰਤੀ ਫਲ ਅਤੇ ਪੌਦਾ ਫ਼ਲ, ਪਹਿਲੀ ਤੁੜਾਈ ਲਈ ਲੱਗਣ ਵਾਲੇ ਦਿਨ ਅਤੇ ਪ੍ਰਤੀ ਪੌਦਾ ਝਾੜ ਲਈ ਸਭ ਤੋਂ ਵਧੀਆ ਸਾਧਾਰਨ ਕੰਬਾਇਨਰ ਸਾਬਿਤ ਹੋਈ। PBRK -4 x PBRK-12 ਦੇ ਕਰਾਸ ਕੰਬੀਨੇਸ਼ਨ ਪ੍ਰਤੀ ਪੌਦਾ ਫਲ ਅਤੇ ਪ੍ਰਤੀ ਪੌਦਾ ਝਾੜ ਲਈ, PBRK-12 x PBRK-7 ਫ਼ਲ ਭਾਰ ਅਤੇ ਫ਼ਲ ਵਿਆਸ ਲਈ PBRK-10 PBRK-1 ਫ਼ਲ ਲੰਬਾਈ ਲਈ ਸਭ ਤੋਂ ਵਧੀਆ ਵਿਸ਼ੇਸ਼ ਕੰਬਾਇਨਰ ਸਾਬਿਤ ਹੋਏ। PBRK-4 x PBRK-12, PBRK-4 x PBRK-9 ਅਤੇ PBRK-9 x PBRK-1 ਨੇ ਪ੍ਰਤੀ ਪੌਦਾ ਝਾੜ ਲਈ ਸਾਕਾਰਾਤਮਕ ਹੈਟਰੋਸਿਸ ਦਿਖਾਈ ਇਸਦੇ ਨਾਲ ਹੀ ਜ਼ਿਆਦਾ sca ਪ੍ਰਭਾਵ ਨੂੰ F_1s ਤਿਆਰ ਕਰਨ ਲਈ ਵਰਤਿਆ ਜਾ ਸਕਦਾ ਹੈ। ਵਿਭਿੰਨਤਾ ਦੇ ਜੈਨੇਟਿਕ ਘਟਕ ਦਰਸਾਉਂਦੇ ਹਨ ਕਿ ਫ਼ਲ ਭਾਰ, ਫ਼ਲ ਲੰਬਾਈ ਅਤੇ ਪ੍ਰਤੀ ਪੌਦਾ ਫ਼ਲ ਦੀ ਸੰਖਿਆ ਨੂੰ ਛੱਡ ਬਾਕੀ ਸਾਰੇ ਲੱਛਣ ਜੀਨ ਦੇ ਨਾਲ-ਅਡੈਟਿਵ ਕਾਰਜ ਕਰਕੇ ਸੰਚਾਲਿਤ ਹੁੰਦੇ ਸਨ ਇਸ ਕਰਕੇ ਹੈਟਰੋਸਿਸ ਬਰੀਡਿੰਗ ਰਾਹੀਂ ਸੁਧਾਰੇ ਜਾ ਸਕਦੇ ਹਨ।

ਮੁੱਖ ਸ਼ਬਦ: ਹੈਟਰੋਸਿਸ, ਮਿਲਨ ਯੋਗਤਾ, ਅਨਿਸ਼ੇਰਜਕ ਖੀਰਾ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ | **ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER - I

INTRODUCTION

Cucumber (*Cucumis sativus* L.) is one of the most important cucurbitaceous vegetable crops grown extensively in tropical and sub-tropical parts of India. It belongs to the family Cucurbitaceae, comprising of 118 genera and 825 species (Jeffrey 1990). Its primary centre of origin is India (Zeven and Deweb 1982) and secondary centre of diversification is China (De Candolle 1882). The crop is grown throughout the world and is the fourth most important vegetable crop after tomato, cabbage and onion (Tatlioglu 1993). In India, it is grown in an area of 64 thousand hectares with an annual production of 1024 thousand MT (Anonymous 2016).

Cucumber is a rich source of vitamin B, C, iron, calcium and phosphorus (Yawalkar 1985). Besides being primarily consumed as a salad vegetable, it is also used in cosmetic industry. It has a cooling effect and is thus helpful in causing relief from sun burns. The fruits possess medicinal properties and are used in the treatment of jaundice, constipation and arthritis.

Parthenocarpy (seedless fruit) is an economically important yield attributing trait in cucumber (Sun *et al* 2006). Yield of parthenocarpic cucumber varieties is often higher than that of conventional seeded varieties due to association with gynoecious trait. Parthenocarpic cucumber varieties can be successfully grown under poly-house conditions as these do not require pollination for fruit set. Since pollination is not a pre-requisite for fruit set as in seeded cucumber, and all the flowers that appear are female (gynoecy), there is an increase in overall yield, which is the ultimate goal of any breeding programme. Moreover economic returns are high as the seedless fruits fetch higher prices than the usual seeded fruits.

Heterosis in cucumber is of commercial importance as the hybrids produced have higher yield and desirable quality. The term heterosis was first coined by Shull (1914) and is defined as the deviation of F_1 hybrid from both of its parents. Heterosis in cucumber was first reported by Hayes and Jones (1916) and they observed 24-30 percent increase in yield over the high yielding parents. At national level, F_1 hybrid Pusa Sanyog has been released by IARI, Katrain (Gill *et al* 1973) by crossing gynoecious line (isolated from a Japanese variety Kaga Aomaga Fushinavi) with Green Long of Naples (an Italian variety) which out yielded the recommended variety by 128.78 per cent. However its performance is confined to cooler and sub-tropical conditions. Kumar *et al* (2010) reported significant heterosis over better, top and standard parents for all the characters studied. Singh *et al* (2015) also observed significant economic heterosis for most of the characters studied.

The information regarding *per se* performance of parents is not enough to predict the success of a hybrid. In other words, the superior performance of the parents does not assure

the superiority of their hybrid. The estimation of combining ability, thus, becomes important in heterosis breeding, as it helps in determining the ability of an inbred line to combine with other inbred lines to produce a hybrid. The concept of combining ability was first given by Sprague and Tatum (1942), who coined two terms, namely general combining ability (gca) and specific combining ability (sca). The estimates of gca and sca effects helps in the selection of parents for producing superior hybrids.

In any crop improvement programme, the selection of the breeding method plays a very important role, which in turn depends upon the type of gene action involved in the inheritance of a trait. Thus, the study of genetic components of variation is important as it helps in selection of an appropriate breeding method to get higher gains in yield and its component characters.

Although, much work has been done on heterosis and combining ability in monoecious cucumber lines, the information on heterosis and combining ability of parthenocarpic cucumber inbred lines has been limited in India. Thus there is a need to obtain information on new parthenocarpic cucumber hybrid combinations possessing high yield and desirable yield attributing traits for poly-net house cultivation.

Keeping in view the above facts, the present investigation entitled "Heterosis and combining ability for yield and yield attributing traits of parthenocarpic cucumber (*Cucumis sativus* L.) under poly-net house conditions" was initiated with following objectives:

1. To estimate the extent of heterosis present in crosses
2. To estimate general combining ability effects of parents and specific combining ability effects of crosses
3. To estimate the genetic components of variation

CHAPTER-II

REVIEW OF LITERATURE

The available literature pertaining to the present study is briefly reviewed under the following sub headings:

2.1 Heterosis

2.2 Combining ability

2.3 Genetic component of variation

HETEROSIS

The term heterosis was first coined by Shull (1914) and is defined as the deviation of F_1 hybrid from both of its parents. The superiority over the mid parent is called relative heterosis while that over the better parent is known as heterobeltiosis. Superiority of F_1 over the standard check variety is known as standard heterosis or commercial heterosis.

Heterosis in cucumber was first reported by Hayes and Jones (1916) and they found 24-30 percent increase in yield over the high yielding parents. In cucumber, heterosis can be exploited commercially as many traits are under the control of non- additive gene action and therefore can be improved by hybrid development.

More (2002) developed two types of lines from a complex cross [(Table Green 68 x SC3) x Poona Khira] F_3 x [(Gy-14 x Table Green 68) x Poona Khira] F_3. First set included lines PKG-1-2, 1-11, 1-12 and 1-15 having yellow skinned fruits, gynoecy and parthenocarpy, whereas second set comprised of PKH-1-21, 1-23 and 1-24 having green fruit skin colour, gynoecy and parthenocarpy. Two hybrids Phule Champa and Phule Prachi were found to show great promise for yield potential (hence, they were released for common utilization in 2001).

Pandey *et al* (2005) studied ten cucumber hybrids for estimation of heterosis and concluded that there was wide variation in magnitude and direction of heterosis for all the characters. Heterosis over better parent up to 100.08% was observed for fruit weight. Positive heterosis was reported for fruit diameter, average fruit weight and number of fruits, which ranged between 100.83-10.83. DC-1 x B-159 and VRC-11-2 x Bihar-10 were found to be the best heterotic combinations.

Bairagi *et al* (2005) while evaluating 28 non-reciprocal hybrids derived from eight diverse cucumber genotypes found that nine crosses manifested significant heterobeltiosis for number of fruits per plant. The best heterotic hybrid was PCUC-83 x PCUC-25 (67.7%), followed by PCUC-83 x PCUC-15 (58.2%), PCUC-25 x PCUC- 15 (56.1%) and PCUC-8 x PCUC-15 (42.4%).

Godoy *et al* (2008) estimated heterosis in relation to superior parents using 27 treatments in a randomized complete block design. Positive heterosis was obtained with

hybrids H35 and H43 showing maximum heterosis for yield per plant.

Appreciable heterosis over better parent and mid parent in desirable direction was found for all the characters studied (Hanchinamani and Patil 2009). F_1 hybrid BGDL x Hot Season was found to be the best performing hybrid recording a significant increase of 94.03 and 31.73 per cent in yield over mid and better parents, respectively.

Kumar *et al* (2010) evaluated fifteen F_1 hybrids obtained by crossing six diverse parental lines through half-diallel method to study the extent of heterosis for yield and its attributing characters. Significant heterosis was observed over better parents, top parents and standard parents for all the characters studied. The extent of heterosis for total yield per plant ranged from 0.53 to 44.82 over better parent, 2.85 to 44.81% over standard as well as top parent (Pusa Uday). The cross combinations CRC-8 x Pusa Uday, CHC-2 x Pusa Uday and G-338 x Pusa Uday were found to be the three best performing hybrids for yield per plant.

Singh *et al* (2010) studied heterosis for yield and contributing characters through diallel method using ten parents. They observed significant heterosis over better parent for yield per plant (80.95%) followed by vine length (33.1%), average fruit weight (30.1%), number of branches per plant (29.0%), polar diameter (27.8%) and equatorial diameter of fruit (27.3%). The cross combinations VRC-18-2 x Patna -3 showed maximum heterosis for yield per plant.

Dogra and Kanwar (2011) crossed eight parents in a half diallel fashion to obtain 28 F_1 hybrids. These hybrids along with eight parents and one check were grown in a randomized complete block design for estimation of heterosis for yield and horticultural traits. Maximum heterobeltiosis and standard heterosis for earliness were expressed by the cross EC173934 x LC-40 and G_2 x Gyn1, respectively. The cross K-90 x G_2 exhibited maximum heterobeltiosis and standard heterosis for yield and number of fruits.

Rabou and Hamed (2011) while studying ten F_1 hybrids for estimation of heterosis for some economic characters observed that seven out of ten evaluated hybrids showed significant positive heterosis over the better parent ranging from 18.24% to 138.39% for total yield per plant. The cross combination *Cus* 2-11-519 x *Cus* 2-23-576 showed maximum heterosis (138.39%) followed by *Cus* 2-11-519 x *Cus* 1-12-26 (60.26%) and *Cus* 3-2-14 x *Cus* 1-12-26 (49.80%).

Twenty one F_1 hybrids were produced by Kushwaha *et al* (2011) by crossing seven parental lines in diallel cross excluding reciprocals. The cross combination BC-11 x BC-12 was observed to show significant desirable heterosis for nodal position of first female flower, BC-16x Poinsette for fruit length, BC-14 x BC-16 for fruit diameter, BC-15 x BC-16 for fruit weight and BC-11 x BC-16 for number of fruits per plant and fruit yield per vine.

Singh *et al* (2012) observed considerable amount of heterosis for yield and related characters in cucumber. The heterosis value for yield per plant ranged from -43.77% (CH-20 x CHC-1) to 70.81% (BSC-1 x CC-5) over standard variety and 0.87% (CH-6 x CC-5) to

34.45% (BSC-1 x CC-5) over better parent. Hybrids BSC-1 x BSC-2, BSC-1 x CHC-1, VRC-11-2 x CC-5 and CC-7 x CHC-1 were found to exhibit high heterosis over standard variety and better parent.

Mule *et al* (2012) estimated heterosis for fruit yield and its component by crossing twelve diverse parents in a line x tester design to obtain 27 F_1 hybrids. They found that the hybrids varied in magnitude and direction of heterosis for most of the characters. Highest heterobeltiosis for number of fruits per vine was exhibited by by hybrid Sheetal x SPP-44 (66.67%) followed by Sheetal x CC-9 (75.00%) and Pilibhit Local x K-90 (33.33%). These three hybrids were found to be most promising considering the overall performance in respect of fruit yield per vine.

Airina *et al* (2013) evaluated twelve F_1 hybrids obtained from a top cross involving twelve monoecious parents and a gynoecious parent. They observed significant relative heterosis and heterobeltiosis for days to first harvest, number of fruits per plant, yield per plant, fruit length and fruit girth. Hybrid EC 709119 x IC 538155 was observed to exhibit maximum relative heterosis (347.62%) and heterobeltiosis (271.05%) with respect to number of fruits per plant. Maximum relative heterosis (560.73%) and heterobeltiosis (44.82%) for yield per plant were also expressed by the same hybrid.

Singh *et al* (2014) conducted an experiment to estimate heterosis for yield and its component traits in a 8x8 parent diallel cross excluding reciprocals and observed that maximum heterosis for yield per vine was expressed by the cross combinations PCUC-15 x PCUC-15-1 (211.70) followed by CHC-2 x C 99-12 (177.66), PCUC-15 x CHC 2 (97.35), PCUC 15-1 x BIHAR (69.84) and EC 43342 x C 99-12 (62.10). The cross CHC 2 x C 99-12 also showed significant heterosis for fruit weight, number of fruits per vine and vine length and was found to be one of the best crosses for yield per vine.

Jat *et al* (2015) developed twenty one F_1 hybrids by using seven parental lines including two gynoecious lines in a half diallel mating design to determine heterosis for earliness, yield and yield related traits. PPC-2 x Pusa Uday, GPC-1 x Pusa Uday and PPC-2 x Punjab Naveen were the three best heterotic hybrids for yield per plant, showing 64.51, 55.61 and 54.57% heterosis, respectively, over standard check Pusa Uday.

Singh *et al* (2015) studied heterosis for yield and its related traits in an 8x8 parent diallel cross excluding reciprocals and observed wide range of economic heterosis for most of the characters studied. Heterosis over better parent for yield per vine ranged from -66.16 to 162.43%. Maximum heterosis for yield per vine was shown by the cross combinations PCUC 15 x PCUC 15-1, PCUC 15-1 x BIHAR 1, EC 43342 x C 98-6, EC 43342 x C 99-10 and PCUC 15-1 x C 98-6.

Singh *et al* (2016) while evaluating eight parental lines and their 28 hybrids along with a standard check reported that the extent of heterosis varied from -14.31 to 18.27 over

better parent and -21.26 to 2.24 over standard check. Hybrid ACC-2 x ACC-6 and ACC-5 x ACC-7 were found to exhibit maximum heterosis over better parent and standard check, respectively. For number of fruits per vine, the extent of heterosis ranged from -28.15 to 32.15 over better parent and -17.80 to 35.17 over standard check. Maximum heterosis over better parent and standard check was exhibited by ACC-3 x ACC-4 and ACC-2 x ACC-8, respectively.

Kaur *et al* (2016) crossed eight diverse cucumber genotypes in a half diallel mating design to obtain 21 F_1 hybrids for estimation of heterosis for quality attributing traits. JLG x NCH-1 was found to exhibit maximum heterosis for flesh to seed cavity ratio over better parent (16.67%) and standard check NS-404 (11.11%), while that for total soluble solids was shown by JLG x Summer Kheera over better parent (31.06%) and standard check (34.39%).

COMBINING ABILITY

The estimation of combining ability plays an important role in heterosis breeding as it helps in determining the ability of an inbred line to combine with other inbreds to produce a hybrid. The knowledge of only heterosis is not enough to determine the superiority of a hybrid. A hybrid will be superior only if its parents have a good combing ability among each other. The concept of combining ability was first given by Sprague and Tatum (1942), who coined two terms, namely general combining ability (gca) and specific combining ability (sca). They defined gca as the average performance of a line in hybrid combinations. Sca is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved (Sprague and Tatum 1942).

Sushir *et al* (2005) estimated combining ability effects in cucumber using eight cultivars and their 28 hybrides obtained through half-diallel mating design. They found that the parents Sheetal, Shubhangi and Talegaon Local were good general combiners for yield per vine, gca effects being 107.70, 81.03 and 19.00, respectively. Cross combinations Improved Long Green x Himangi and Poona Khira x Junnar Local were found to exhibit high sca effects for yield per vine (247.30 and 229.39, respectively) and were identified as the best hybrids.

Yadav *et al* (2007) studied 45 F_1 hybrids developed through line x tester technique (15 lines and 3 testers) for analysis of combining ability for yield and its contributing characters. The parent 2020 was found to exhibit significant general combining ability followed by 2017, 2231 and 2336. The best crosses showing high sca effects for fruit yield per plant and related traits were found to be 2015 x 2014, 2229 x 2226, 2237 x 2238, 2016 x 2238, 2237 x 2226 and 2028 x 2238 which can be exploited through heterosis breeding programme.

Yoshioka *et al* (2010) crossed eight cucumber genotypes in a half-diallel mating design to produce 28 F_1 hybrids to estimate the gca and sca of fruit texture related traits. They

found that the gca effect was more significant than the sca effect. Moreover, the gca of a parent was highly correlated with the performance of the parental genotypes. Therefore, the traits related to fruit texture can be improved by selection at the level of parental genotype.

Singh *et al* (2010) while studying 10 diverse inbred lines for combining ability analysis found that Peelibheet Local and PCUC-28 was best general combiner for yield and yield attributing traits. The cross PCUC-28 x Peelibheet Local showed high sca effect for yield, vine length, polar and equatorial diameter of fruit and average fruit weight. Both gca and sca variances were found to play a role for various traits and thus concluding that improvement in yield and its related traits can be brought out through recurrent selection and hybridization.

A study was made in a 10x10 diallel cross (excluding reciprocals) by Sarkar and Sirohi (2010) to analyze combining ability for yield and its contributing characters. The hybrids PCUC-28 x VRC-11-1, DC-1 x PCUC-28 and CH-20 x Himangi were found to be the top performing hybrids over top parent for total yield per plant. The parents which gave the highest yield (DC-2, followed by PCUC-28 and DC-1) also showed high gca with respect to yield and yield contributing characters. These results suggest that it will be useful to select the parental lines having high gca *w.r.t* yield and yield contributing characters for obtaining F_1 hybrids (Sarkar and Sirohi 2010).

Singh *et al* (2011) while estimating combining ability for different characters in a line x tester design comprising 12 lines and 3 testers and their 36 F_1 hybrids found that none of the parents were good general combiner for all the characters. CHC-129, BSC-1 and CC-4 showed high gca for number of fruits per plant whereas BSC-1, CC-7 and CHC-129 for good general combiners for fruit yield per plant. The cross combinations VRC-18 x CC-5, BSC-1 x CC-5 and CC-7 x CHC-1 exhibited high specific combining ability for fruit yield and its related traits.

Kushwaha *et al* (2011) observed that the squares due to gca and sca were highly significant for all the traits, indicating the role of both additive and non-additive action. The crosses BC-11 x BC-16, BC-15 x Poinsette and BC-13 x BC-14 were found to exhibit high sca effect for yield per vine.

Mule *et al* (2012) evaluated 27 F_1 hybrid obtained from a line (3) x tester (9) method involving 12 diverse parents. They found that three parents, namely CCP-9, Gujarat Local and SPP-44 were good general combiners for fruit yield and its contributing traits. The hybrids Pilibhit Local x K-90, Sheetal x SPP-44 and Sheetal x CC-9 were found to show the highest sca effect for fruit yield per vine.

Bairagi *et al* (2013) conducted a study to estimate the general and specific combining ability effects. Eight parental lines and their 28 hybrids were evaluated for important horticultural traits. Three parental lines, namely PCUC-25, PCUC-15 and PCUC-83 were

found to be good general combiner for most of the economic traits. The cross combinations PCUC-83 x PCUC-25, PCUC-83 x PCUC-15, PCUC-25 x PCUC-15 and PCUC-8 x PCUC-15 were found to exhibit high sca effects for most of the economic traits including number of fruits and fruit yield per plant.

Kumar *et al* (2013) while analyzing the combining ability of 15 F_1 hybrids along with six parental lines in a 6 x 6 half diallel cross (excluding reciprocals) found significant gca and sca effects. The parents CRC-8, CHC-2, Pusa Uday and DC-1 were observed to show high gca for number of characters including yield per plant. The crosses CRC-8 x Pusa Uday, CHC-2 x Pusa Uday and CHC-2 x DC-1 were the best specific combiners for earliness and other desirable traits including yield per plant.

Vidhya and Kumar (2014) evaluated five genotypes namely CS-36, CS-10, CS-17, CS-37 and CS-39 for studying combining ability effects. CS-37 and CS-39 exhibited high gca for almost all the traits. High sca effects were recorded by hybrids CS-39 x CS-19, CS-37 x CS-17, CS-37 x CS-39 and CS-17 x CS-39.

Reddy *et al* (2014) conducted an experiment to estimate combining ability effects by crossing nine diverse parental cucumber lines in a half diallel mating system. The 36 F_1 hybrids along with nine parents were evaluated in a randomized complete block design with three replications. The results showed that parent CHC-1 was the best general combiner for days to first fruit harvest, whereas, Pusa Uday was the best general combiner for yield per plant and its contributing traits. The cross DC-1 x Himangi was found to exhibit high sca effect for yield per plant followed by Pusa Uday x Pant Khira.

Pati *et al* (2015) studied eight parents in a diallel set of cucumber excluding reciprocals to find out combining ability for yield and yield attributing characters. Parent P_5 (Pusa Uday) was found to exhibit highest positive gca effect for fruit length, fruit diameter and average fruit weight followed by P_6 (Punjab Naveen). The gynoecious hybrid P_1 x P_5 (GBS-1 x Pusa Uday) and P_1 x P_6 (GBS-1 x Punjab Naveen) and monoecious hybrid P_3 x P_5 (GS-4 x Pusa Uday) exhibited highest sca effects for a number of traits including yield per plant.

Kaur *et al* (2016) while studying eight diverse cucumber genotypes and their 28 F_1 hybrids for combining ability analysis for quality traits found that the parent Gy-14 (flesh to seed cavity ratio and β-carotene) and Swarna Sheetal (ascorbic acid and dry matter content) were the best general combiner. The cross combination EC-27075 x Summer Kheera showed highest sca effect for total soluble solids whereas Pant Kheera-1 x Japanese Long Green had highest sca for ascorbic acid content.

Kumar *et al* (2016) worked on the development of parthenocarpic gynoecious hybrid in cucumber. They evaluated 48 F_1 crosses developed by crossing sixteen lines and three testers along with two standard checks, namely, KH-1 and Pusa Sanyog. Lines LC-1-1, CGN-

21585, LC-28-8, CGN-20953 and testers Japanese Long Green and K-75 were found to be superior on the basis of mean performance and general combining ability. Best cross combinations exhibiting high sca effects were observed to be LC-1-1 x K-75 (monoecious), CGN-21585 x Japanese Long Green (gynoecious), CGN-19533 x K-75 (gynoecious), CGN-20953 x Poinsette (gynoecious) and LC-28-8 x K-75 (monoecious).

GENETIC COMPONENTS OF VARIATION

The choice of breeding method to be used in crop improvement programme depends upon the type of gene action involved in inheritance of various traits. Thus, it is important to study the genetic component of variation so as to formulate an appropriate breeding method for getting higher gains in yield and its component characters.

Lopez-Sese and Staub (2002) found that both gca and sca effects were significant in determination of yield related traits studied. Gca effects were found to be more important than sca effects for most of the characters, thus indicating the use of additive gene effects through selection for improvement in cucumber.

Sarkar and Sirohi (2006) observed over-dominance for almost all the characters studied namely days to first male flower opening, node number of first female flower, fruit weight and total yield per plant. The dominance component of genetic variation was found to be higher than the additive component for vine length, days to first female flower opening and days to first fruit harvest. The predominance of non-additive gene action suggested the use of heterosis breeding for crop improvement.

Munshi *et al* (2006) reported the predominance of non-additive genetic variance (over-dominance) for characters like days to first fruit harvest, number of fruits per plant and yield per plant indicating the importance of heterosis breeding for improvement of these characters. Additive genetic variance (partial dominance) was found to be predominant in fruit length which suggested the use of selection for improvement of this character.

Tiwari *et al* (2009) evaluated 15 F_1 hybrids obtained from crossing six diverse parental lines in a half-diallel fashion. The characters *viz*. days to first female flower, node number of first female flower, days to first fruit harvest, number of fruits per plant and total yield per plant exhibited higher sca effect than gca effect. Average degree of dominance was also found to be more than one for these characters, indicating the role of non-additive components of variance for improvement of these characters. However characters like fruit weight, fruit length and fruit diameter showed higher gca component than sca component (average degree of dominance less than one) indicating the role of additive gene action for character improvement.

Kumar *et al* (2010) observed dominance and over-dominance gene actions for all the quantitative traits under study. Over-dominance was observed for days to first male and female flower opening, node number of first female flower, days to first fruit set, days to first

fruit harvest, number of fruits per plant and total yield per plant. The characters like fruit weight, fruit diameter and fruit length were found to exhibit partial dominance while the vine length was observed to show nearly dominance.

Bairagi *et al* (2013) found higher gca mean squares than the sca mean squares for whole characters studied except fruit diameter, suggesting the role of additive gene action in determining most of the characters in cucumber.

Kumar *et al* (2013) while studying six diverse cucumber genotypes and their 15 F_1 hybrids obtained through half-diallel mating, found that sca component of variance was higher than the gca component of variance for traits like days to first female flower, days to first fruit harvest, number of fruits per plant and total yield per plant which can be improved through heterosis. The characters like fruit weight, fruit length and fruit diameter exhibited high gca component than the sca component of variance and can be further improved through selection.

Pati *et al* (2015) reported non-additive gene action for most of the characters, *viz.*, node number of first female flower, days to first female flower anthesis, days to fruit set from opening of the first female flower, days to first fruit harvest, number of fruits per plant and yield per plant. Hence, heterosis breeding can be used for improving these traits. However characters like fruit length, average fruit weight and vine length were found to exhibit additive gene action and can be improved through selection.

Kumar *et al* (2016) found that variances due to sca were higher in magnitude than those due to gca (average) thereby indicating the importance of non-additive gene action in inheritance of characters.

CHAPTER-III

MATERIAL AND METHODS

The present investigation was carried out at Research Farm of the Department of Vegetable Science, Punjab Agricultural University, Ludhiana during the years 2016 and 2017.

3.1 Experimental Material

The experimental material comprised of eight parthenocarpic gynoecious inbred lines of cucumber and their 28 F_1 hybrids obtained by crossing the parents in a half-diallel fashion (excluding reciprocals) and one standard check. These parthenocarpic gynoecious cucumber inbred lines were developed and maintained by the Department of Vegetable Science, PAU, Ludhiana. The list of the parental lines and check along with their source are mentioned in Table 3.1.

Table: 3.1 List of parental lines

S. No.	Genotype	Source
1	PBRK-4	PAU, Ludhiana
2	PBRK-12	PAU, Ludhiana
3	PBRK-10	PAU, Ludhiana
4	PBRK-7	PAU, Ludhiana
5	PBRK-8	PAU, Ludhiana
6	PBRK-9	PAU, Ludhiana
7	PBRK-1	PAU, Ludhiana
8	PBRK-2	PAU, Ludhiana
Standard Check		
1	Multistar	Rijk Zwan India Seeds Pvt. Ltd., Bangalore

3.2 Experimental method

3.2.1 Experiment 1: Growing of parental lines and making crosses among them

Seeds of eight parthenocarpic gynoecious inbred lines were transplanted in poly-net house during first week of February for crossing in half-diallel fashion to generate F_1s. Since all the parental lines were gynoecious in nature, male flowers were induced in selected number of plants of each genotype through application of silver thiosulphate (Nagar *et al* 2014). The sprayed plants were tagged and used as male parent. Crosses were made by hand pollinating the female flowers with the pollen of male flower of desired parent. The selfed seeds of parental lines were also obtained by pollinating the female flowers with the pollen of male flowers of the same genotype. The F_1 seeds of different crosses and selfed seeds of parents were collected during June, 2016.

3.2.2 Experiment 2: Study of heterosis and combining ability

The seeds of parents, F_1 hybrids and standard check were sown in pro-trays in first week of January, 2017. The pro-trays were filled with mixture of coco peat, perlite and vermiculite in the ratio of 3:1:1. One seed per hole was sown and kept under poly-tunnels to save the young seedlings from low temperature and frost.

Thirty days after sowing, when the seedlings attained two to three true leaves stage, these seedlings were transplanted on raised beds (1m wide and 15cm height) in the poly-net house on 10th Feb, 2017, keeping row to row distance of 60cm and plant to plant distance of 30cm. Ten plants per replication per genotype were transplanted. Data were recorded for five plants. The experiment was laid out in a Randomized Block Design (RBD) with three replications. The standard package of practices recommended for the crop was followed to raise a healthy crop (Dhall and Singh 2016). The F_1 hybrids along with eight parents and one standard check were evaluated for estimation of heterosis and combining ability during February 2017 – May 2017.

3.3 Observations recorded

Twelve characters were observed for one treatment. Five plants were randomly selected from all the treatments in each replication and then observations were recorded for all the characters.

(a) Yield and yield attributing characters

1. Fruit weight (g)

The weight of five randomly selected fruits was measured by using a weighing balance and average fruit weight was calculated.

2. Fruit length (cm)

The length of five randomly selected fruits was measured with the help of scale and average fruit length was calculated.

3. Fruit diameter (cm)

The fruit diameter of five randomly selected fruits was measured with the help of vernier caliper and average fruit diameter was calculated.

4. Vine length (cm)

The length of five randomly selected vines was measured from basal to distal end at the time of last fruit harvest and averaged to determine the vine length.

5. Number of fruits per plant

The number of fruits per plant was calculated by adding the number of fruits obtained in each picking from five randomly selected vines and averaged to determine the number of fruits per plant for each treatment.

6. Days to first fruit harvest

The number of days taken from transplanting of seedlings to first fruit picking was

calculated and averaged to record days to first fruit harvest.

7. Days to last fruit harvest

The number of days taken from transplanting of seedlings to last fruit picking was calculated and averaged to determine days to last fruit harvest.

8. Number of seeds per fruit

The number of seeds per fruit was calculated by counting the number of seeds in five randomly selected fruits and average number of seeds per fruit was calculated.

9. Yield per plant (kg)

Yield per plant (kg) was added in each picking from five randomly selected vines and averaged to determine the yield per plant.

(b) Quality characters

1. Total soluble solids (%)

The total soluble solids (TSS) content was recorded with the help of hand refractrometer by taking a drop of juice from the flesh after cutting the fruit. The observation recorded from five randomly selected fruits was averaged to determine the TSS.

2. Flesh to seed cavity ratio

$$\text{F/C ratio} = \frac{P \times E}{P' \times E'} \times 100$$

Where, P is the polar diameter of fruit, E is the equatorial diameter of fruit, P' is the polar diameter of fruit cavity, E' is the equatorial diameter of fruit cavity.

3.4 Statistical analysis

The data recorded was statistical analysis as follows:

1. Analysis of variance for experimental design
2. Estimation of heterosis
3. Combining ability analysis
4. Estimation of components of variation

The software package used for statistical analysis was TNAUSTAT- Statistical Package.

3.4.1 Analysis of variance for experimental design

The mean values of 55 genotypes (10 parents and 45 crosses) in each replication for different characters were used for the analysis of variance. The analysis of variance for randomized block design was carried out by using the following model:

$$Y_{ijk} = m + g_{ij} + b_k + e_{ijk}$$

Where,

Y_{ijk} = phenotypic value of the ij^{th} genotype grown in the kth replication

m = general population mean

g_{ij} = effect of the ij_{th} genotype, where i,j, = 1....g

b_k = effect of the k_{th} replication, where k = 1....r

e_{ijk} = random error associated with the ijk^{th} observation

Analysis of variance based on the above model led to the following components of variance:

Analysis of variance

Source of variation	**d.f.**	**S.S.**	**M.S.S**	**F-value**
Replications	r-1	Sr	$M_r = S_r$ / r-1	M_r / M_e
Genotypes	g-1	Sg	$M_g = S_g$ / g-1	M_g / M_e
Error	(r-1)(g-1)	S_e	Me = S_e / (r-1) (g-1)	
Total	gr-1	S_t		

Where

d.f. = Degree of freedom

S.S. = Sum of squares

M.S.S = Mean sum of squares

r = Number of replications

g = Number of genotypes

The standard error of difference between the genotypic means based on r replications was estimated as follows:

$$SD(d) = \pm\sqrt{\frac{2M_e}{r}}$$

Critical Difference (CD) = SE (d) x $t_{(r-1)(g-1)}$ at 5% and 1% level of significance.

3.4.2 Estimation of heterosis

Heterosis over better parent and standard check (Multistar) was calculated as follows:

$$\text{Per cent heterosis over the better parent} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Per cent heterosis over check} = \frac{\overline{F_1} - \overline{Check}}{\overline{Check}} \times 100$$

Where,

$\overline{BP}$ = mean performance of the better parent

$\overline{Check}$ = mean performance of check hybrid

3.4.2.1 Test of significance for heterosis over better parent

Test of significance was done for the numerator value for heterosis over better parent, *i.e.* $\overline{F}_1 - \overline{BP}$.

The standard error of difference was computed as under

$$\text{S.E. of heterosis} = \pm\sqrt{\frac{2M_e}{r}}$$

Where,

M_e = error mean squares

r = number of replications

The critical difference was calculated by multiplying the S.E of heterosis with table value of t at error d.f. at both 5% and 1% level of significance.

3.4.2.2 Test of significance for heterosis over standard check

Test of significance was done for the numerator value for heterosis over standard check, *i.e.* $\bar{F}_1 - \overline{Check}$.

The standard error of difference was computed as under

$$\text{S.E. of heterosis} = \pm\sqrt{\frac{2M_e}{r}}$$

Where,

M_e = error mean squares

r = number of replications

The critical difference was calculated by multiplying the S.E of heterosis with table value of t at error d.f. at both 5% and 1% level of significance.

3.4.3 Combining ability analysis

Combining ability analysis was done using Griffing (1956) Method II (parents and one set of F_1's were included but not reciprocal F_1's) and Model I (Fixed effect model). The analysis of variance for combining ability was based on the following mathematical model:

$$X_{ij} = \mu + g_i + g_j + S_{ij} + 1/bc \sum_k \sum_l e_{ijkl}$$

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)

X_{ij} = Mean performance of ith x j^{th} genotype over k and l

μ = Population mean

g_i (or g_j) = General combining ability of ith (or j^{th}) parent

S_{ij} = Specific combining ability of the crosses between the ith x j^{th} parents such that

$S_{ij} = S_{ji}$ and

e_{ijkl} = the environmental effect corresponding to the $ijkl^{th}$ observation

Restrictions imposed on the combining ability analysis are:

(i) $\sum g_i = 0$

(ii) $\sum S_{ij} + e_{ij} = 0$

Based on the above model, following are the components of variance:

Analysis of variance based on combining ability

Source of variation	Df	Sum of squares	Mean sum of squares	Expected mean sum of squares
General combining ability	p-1	Sg	$M_g = S_g/p-1$	$\sigma_e^2 + (p + 2)(1/p-1)\sum_i g_i^2$
Specific combining ability	p(p-1)/2	Ss	Ms = Ss/[p(p-1)/2]	$\sigma_e^2 + 2[1/p(p-1)] \sum_i\sum_j S_{ij}^2$ …
Error	(r-1)(g-1)	Se	M'e	σ_e^2

Where,

S_g = sum of squares due to gca= $\frac{1}{p+2}\left(\sum\left(X_i + X_{ii}\right)^2 - \left(\frac{4}{p}\right)X^2...\right)$

S_s = sum of squares due to sca= $\sum_i\sum_j X_{ij}^2 \frac{1}{p+2}\sum_i\left(X_i + X_{ij}\right)^2 + \frac{2}{(p+1)(p+2)}X^2...$

p = number of parents

$M'_e = M_e / r$ (where M_e is error mean square from RBD analysis)

X_{ii} = mean value of the ith parent

X_{ij} = the progeny mean value of the i multiply j^{th} hybrid

Estimation of gca and sca effects

General combining ability effect of the ith parent,

$$g_i = \frac{1}{p+2}\left[\left(X_{i.}+X_{ii}\right) - \frac{2}{p}X..\right]$$

Specific combining ability effects of the ith and jth cross,

$$S_{ij} = X_{ij} - \frac{1}{p+2}\left[\left(X_{i.}+X_{ii}\right) + \left(X_{.j}+X_{jj}\right) + \frac{2}{(p+1)(p+2)}X..\right]$$

Where,

p = number of parents

$X_{i.}$ = total of the array involving i^{th} parent

$X_{.j}$ = total of the array involving j^{th} parent

X_{ii} = mean value of the ith parent

X_{jj} = mean value of the jth parent

X_{ij} = progeny mean value of i x j^{th} hybrid

X..= grand total

Σ_e^2 = error variance

Standard error (SE) estimation

SE of effects was estimated as follows:

SE for gca estimates, SE (g_i) = $\pm\sqrt{\frac{(p-1)}{(p+1)(p+2)}\sigma^2 e}$

E for sca estimates, SE (S_{ij}) = $\pm\sqrt{\frac{(p^2+p+2)}{(p+1)(p+2)}\sigma^2 e}$

Where,

$\sigma^2 e$ = error variance

Critical difference (CD) of the estimates

Critical difference of the effects was calculated by multiplying the corresponding SE (d) values for difference with table value of 't' for error degree of freedom at both 5% and 1% level of significance.

3.4.4 Estimation of genetic components of variation

Following genetic parameters were estimated as suggested by Hayman (1954)

$D = V_{0L0}-E$

$H_1 = V_{0L0} - 4W_{0L01} - 4V_{1L1} - (3n-2)\ E/n$

$H_2 = 4V_{1L1} - 4V_{0L1} - 2E$

$F = 2V_{0L0} - 4W_{0L01} - 2(n-2)\ E/n$

$h^2 = 4(ML_1-ML_0)^2 - 4\ (n-1)\ E/n^2$

Where,

D = components of variance due to additive effects of genes

H_1 = components of variance due to dominance effects of genes

H_2 = components of variance due to non-additive effects of genes correlated for gene distribution

F = covariance of additive and non-additive gene effects in all the arrays

E - M'_e = environmental or non-heritable variation associated with an individual mean and it's calculated by dividing the error mean squares of the design analysis by the number of replications

h^2 = overall dominance effects of the heterosis loci accuracy of estimates of genetic parameters

W_{0L01} = covariance between the parents and the means of their offspring

ML_1 = mean of all F_1's.

ML_0 = mean of parents

V_{1L1} = means of array variance

V_{0L1} = variance of means of arrays

V_{0L0}= variance of the parents

In order to estimate the S.E. of these components, the following equations were used

$$\text{Var D} = S^2 \frac{\left(n^5+n^4\right)}{n^5}$$

$$\text{Var F} = S^2 \frac{\left(4n^5+20n^4-16n^3+16n^2\right)}{n^5}$$

$$\text{Var H}_1 = S^2 \frac{\left(n^5+41n^4-12n^3+n^2\right)}{n^5}$$

$$\text{Var H}_2 = \frac{S^2}{n^5}\left(36n^4\right)$$

$$\text{Var E} = \frac{S^2\left(n^4\right)}{n^5}$$

$$\text{Var h}^2 = \frac{S^2}{n^5}\left(16n^4+16n^2-32n+16\right)$$

Where

S^2 = ½ Var (Wr-Vr)

n = number of parents involved in the diallel i.e. ten S.E.'s were calculated by taking the square root of these equations.

The following estimates and ratios were calculated by making use of significant genetic parameters

1. **$(H_1/D)^{1/2}$**: A weighted measure of dominance of each locus. It is equal to 1 in case of full dominance, more than 1 in case of over-dominance and less than 1 in case of partial- dominance.
2. **$H_2/4H_1$**: Provides an estimate of the value of uv, where u is the proportion of positive alleles and v is the proportion of the negative alleles and u + v = 1. The maximum value of $H_2/4H_1$ will be 1/4 or 0.25 when u = v = 1/2. If the value is close to 1/4, there is symmetry at the loci exhibiting dominance otherwise genes are considered to be asymmetrically distributed.
3. **$(4DH_1)^{1/2}+F/ (4DH_1)^{1/2}-F$**: This is the ratio of total number of dominant to recessive genes in all parents. If it is near unity, it implies equality between the number of dominant and recessive alleles in the parents. This is, of course, a necessary consequence of u = v = 1/2
4. **h^2/H_2**: Number of effective factor which control the character and exhibit dominance or number of gene blocks exhibiting dominance.

These proportions are evaluated and interpreted when the relevant components are significant.

CHAPTER-IV

RESULTS AND DISCUSSION

The data collected from the present study were subjected to the following statistical analysis:-

4.1 Analysis of variance for the experimental design

4.2 Analysis of variance for combining ability

4.3 Estimation of heterosis over respective better parent (heterobeltiosis) and commercial check (standard heterosis)

4.4 Estimation of general combining ability effects

4.5 Estimation of specific combining ability effects

4.6 Estimation of genetics components of variation

4.1 Analysis of variance for experimental design

Analysis of variance for various characters, namely, fruit length, total soluble solids, fruit length, fruit diameter, vine length, number of fruits per plant, flesh to seed cavity ratio, days to first fruit harvest, days to last fruit harvest, yield per plant and number of seeds per fruit is presented in Table 4.1. Since all the inbred lines were parthenocarpic in nature, no seeds were formed in any of the genotypes as well as crosses. Hence, further analysis for this trait was not carried out. The mean squares due to genotypes were highly significant for all the characters indicating significant difference among the genotypes for all characters. Thus, further analysis of combining ability was found appropriate for these characters. Similar results were reported by Singh *et al* (2010), Dogra and Kanwar (2011) Jat *et al* (2015) and Kaur *et al* (2016).

4.2 Analysis of variance for combining ability

Analysis of variance for combining ability is shown in Table 4.2. The results revealed that the mean squares due to general combining ability were highly significant for all characters except for vine length. Mean squares due to specific combining ability were highly significant for all the characters except for days to first and last fruit harvest. The significant mean squares due to gca and sca for almost all the characters indicated the role of both additive and non-additive gene action in inheritance of these characters. These findings are in agreement with Sarkar and Sirohi (2010), Bairagi *et al* (2013), Vidhya and Kumar (2014), Pati *et al* (2015) and Singh *et al* (2016).

Table 4.1 Analysis of variance for the experimental design

Source of variation (df)	Replications (2)	Genotypes (35)	Error (70)
Fruit weight	5.63	1887.83**	57.78
Total Soluble solids	0.08	0.28**	0.03
Fruit length	0.47	39.75**	2.98
Fruit diameter	0.11	0.26**	0.62
Vine length	42.97	1170.00**	44.75
Number of fruits per plant	12.01	74.94**	4.16
Flesh to seed cavity ratio	0.04	0.20**	0.02
Days to first fruit harvest	1.22	15.14**	4.69
Days to last fruit harvest	0.01	14.53**	4.24
Yield per plant	0.12**	0.81**	0.02

*Significance at 5% level ** Significance at 1% level

Table 4.2 Analysis of variance for combining ability for different characters in cucumber

Source of variation (df)	gca (7)	sca (28)	Error (70)
Fruit weight	2467.15**	169.80**	19.26
Total Soluble solids	0.17**	0.07**	0.01
Fruit length	53.92**	3.08**	0.99
Fruit diameter	0.19**	0.06**	0.02
Vine length	42.97	1170.00**	44.75
Number of fruits per plant	106.45**	4.61**	1.39
Flesh to seed cavity ratio	0.20**	0.03**	0.01
Days to first fruit harvest	15.71**	2.38	1.56
Days to last fruit harvest	16.42**	1.97	1.41
Yield per plant	0.67**	0.17**	0.01

*Significance at 5% level ** Significance at 1% level

4.3 Estimation of heterosis over respective better parent and commercial check

The estimates of heterosis over better parent and commercial check for different characters have been presented in Table 4.3 and described as follows:

1. Fruit weight (g)

The extent of heterosis over better parent for fruit weight ranged from -33.85 to 28.29. Twelve crosses showed significant heterosis over their respective better parent. Cross combinations exhibiting high heterosis in desirable direction were observed to be PBRK-4 x PBRK-9 (28.29), PBRK-4 x PBRK-8 (22.72), PBRK-9 x PBRK-1 (20.83), PBRK-7 x PBRK-8 (18.37) and PBRK-4 x PBRK-2 (17.10).

Heterosis over check ranged from -2.18 to 53.27. Seventeen crosses showed significant positive heterosis. High positive heterosis was observed for the cross PBRK-10 x PBRK-2 (53.27), PBRK-10 x PBRK-1 (51.87), PBRK-4 x PBRK-10 (49.27), PBRK-10 x PBRK-9 (34.10) and PBRK-10 x PBRK-7 (33.42). Bairagi *et al* (2005) also identified superior hybrids showing fair amount of heterosis over better parent and check for fruit weight. Similar findings were reported by Dogra and Kanwar (2011) and Singh *et al* (2016).

2. Total soluble solids (%)

The content of total soluble solids is directly related to sweetness in cucumber. In present study, the range of heterosis over better parent for total soluble solids varied from -20.13 to 32.00. Only two crosses, namely PBRK-9 x PBRK-2 (32.00) and PBRK-4 x PBRK-9 (27.20) were found to exhibit high significant positive heterosis.

Heterosis over check ranged from -15.01 to 35.12. Significant positive heterosis was observed for ten crosses. Maximum heterosis in desirable direction was exhibited by the cross combinations PBRK-12 x PBRK-10 (35.12), PBRK-9 x PBRK-2 (32.71), PBRK-10 x PBRK-8 (32.44), PBRK-4 x PBRK-9 (27.88) and PBRK-12 x PBRK-1 (21.45). Dogra and Kanwar (2011) had also reported low heterobeltiosis and standard heterosis for total soluble solids in cucumber. However, Kaur *et al* (2016) in her study, reported high heterosis for most of the crosses.

3. Fruit length (cm)

In the present study, heterosis over better parent ranged from -43.91 to 27.70. Only two crosses showed significant positive heterosis, namely PBRK-4 x PBRK-2 (27.70) and PBRK-7 x PBRK-1 (19.21).

Extent of heterosis over check for fruit length ranged from -11.26 to 60.45. Six crosses showed significant positive heterosis. The cross combinations exhibiting high positive heterosis were observed to be PBRK-10 x PBRK-1 (60.45), PBRK-10 x PBRK-9 (47.08), PBRK-10 x PBRK-7 (36.83), PBRK-4 x PBRK-10 (35.82) and PBRK-7 x PBRK-1 (29.25). Significant heterosis for fruit length had also been reported by Singh *et al* (2010) and Airina *et al* (2013).

Table 4.3 Estimation of heterosis (%) over the respective better parent and commercial check Multistar for different characters in cucumber

Characters / Cross	Fruit weight		Total soluble solids		Fruit length		Fruit diameter	
	BP	Check	BP	Check	BP	Check	BP	Check
PBRK-4 X PBRK-12	14.87**	4.00	6.54	4.83	15.71	1.74	0.71	5.18
PBRK-4 X PBRK-10	-13.44**	49.27**	-10.32*	11.80**	-24.79**	35.82**	6.25	-5.73
PBRK-4 X PBRK-7	8.25	0.88	3.10	6.97	-1.23	7.09	17.25*	-0.74
PBRK-4 X PBRK-8	22.72**	15.64**	2.38	3.75	11.71	-1.78	-4.66	9.61
PBRK-4 X PBRK-9	28.29**	20.43**	27.20**	27.88**	5.16	-0.93	9.58	-2.77
PBRK-4 X PBRK-1	9.32	9.10	-6.64	13.14*	0.76	7.37	12.50*	3.14
PBRK-4 X PBRK-2	17.10**	24.38**	-11.94*	-15.01*	27.70**	12.28	13.36*	9.80
PBRK-12 X PBRK-10	-33.85**	14.09**	8.39	35.12**	-43.91**	1.30	-12.21*	-8.32
PBRK-12 X PBRK-7	15.06**	7.22	-8.79	-5.36	-18.16*	-11.26	9.91	14.79*
PBRK-12 X PBRK-8	3.81	-2.18	-2.12	-0.80	20.05	-7.09	-1.13	13.68*
PBRK-12 X PBRK-9	7.09	0.52	-3.20	-2.68	1.68	-4.21	-5.66	-1.48
PBRK-12 X PBRK-1	2.92	2.70	0.22	21.45**	-11.41	-5.59	-12.39*	-8.50
PBRK-12 X PBRK-2	0.86	7.12	-0.82	-2.41	19.11	-2.76	5.31	9.98
PBRK-10 X PBRK-7	-22.63**	33.42**	-8.82	13.67*	-24.23**	36.83**	7.08	-4.99
PBRK-10 X PBRK-8	-29.48**	21.62**	6.24	32.44**	-38.03**	11.91	-14.95**	-2.22
PBRK-10 X PBRK-9	-22.24**	34.10**	-14.62**	6.43	-18.56**	47.08**	11.67	-0.92
PBRK-10 X PBRK-1	-11.93**	51.87**	-6.02	17.16**	-11.15*	60.45**	3.83	-4.81
PBRK-10 X PBRK-2	-11.12**	53.27**	-11.18*	10.72	-32.42**	22.04*	5.73	2.40
PBRK-7 X PBRK-8	18.37**	11.54*	1.55	5.36	-8.30	-0.57	-13.02**	0.00
PBRK-7 X PBRK-9	10.96*	4.16	3.10	6.97	1.68	10.25	16.67*	3.51
PBRK-7 X PBRK-1	12.40*	12.16*	-11.95*	6.70	19.21*	29.25**	6.25	-2.59
PBRK-7 X PBRK-2	6.78	13.41**	5.94	9.92	-14.31	-7.09	16.22**	12.57*
PBRK-8 X PBRK-9	16.00**	9.30	4.23	5.63	6.32	0.16	-7.72	6.10
PBRK-8 X PBRK-1	13.59**	13.36**	-15.27**	2.68	0.46	7.05	-9.65	3.88
PBRK-8 X PBRK-2	7.22	13.88**	-3.70	-2.41	14.94	-6.16	-9.16	4.44
PBRK-9 X PBRK-1	20.83**	20.58**	-1.33	19.57**	5.10	11.99	8.67	-0.37
PBRK-9 X PBRK-2	10.55*	17.41**	32.00**	32.71**	14.84	8.18	10.31	6.84
PBRK-1 X PBRK-2	0.22	6.44	-20.13**	-3.22	0.76	7.37	7.44	4.07
CD 5%	12.37		0.28		2.81		0.40	
CD 1%	16.43		0.38		3.73		0.53	

Table 4.3: continued

Characters / Cross	Vine length		Number of fruits per plant		Flesh to seed cavity ratio	
	BP	Check	BP	Check	BP	Check
PBRK-4 X PBRK-12	9.75**	3.94	8.13	55.39**	9.03	6.62
PBRK-4 X PBRK-10	1.34	17.95**	-41.00**	-18.56*	-0.25	25.24**
PBRK-4 X PBRK-7	4.00	12.70**	-12.15*	21.26**	14.62**	41.01**
PBRK-4 X PBRK-8	4.25	13.56**	0.00	38.02**	-1.25	-0.63
PBRK-4 X PBRK-9	14.25**	15.95**	0.22	38.32**	16.67**	17.03**
PBRK-4 X PBRK-1	8.01**	19.34**	3.41	42.72**	-7.05	8.20
PBRK-4 X PBRK-2	11.96**	17.98**	-22.78**	6.59	-1.52	2.52
PBRK-12 X PBRK-10	-1.98	14.09**	-29.79**	0.90	-4.02	20.50**
PBRK-12 X PBRK-7	-2.18	6.00*	-20.42**	14.37	-14.87**	4.73
PBRK-12 X PBRK-8	-6.31**	2.05	-17.08**	19.16*	-1.57	-0.95
PBRK-12 X PBRK-9	-12.85**	-11.56**	-22.50**	11.38	3.77	4.10
PBRK-12 X PBRK-1	-6.30**	3.52	-17.92**	17.96*	3.25	20.19**
PBRK-12 X PBRK-2	1.74	7.22**	-32.08**	-2.40	-3.03	0.95
PBRK-10 X PBRK-7	5.35*	22.62**	-33.62**	-20.90**	7.54	35.02**
PBRK-10 X PBRK-8	-4.21*	11.49**	-18.47**	-7.49	6.53	33.75**
PBRK-10 X PBRK-9	-2.31	13.70**	-27.07**	-12.87	-14.07**	7.89
PBRK-10 X PBRK-1	2.74	19.58**	-31.37**	-23.35**	-0.75	24.61**
PBRK-10 X PBRK-2	-1.90	14.18**	-11.31	-27.25**	-2.76	22.08**
PBRK-7 X PBRK-8	8.70**	18.40**	4.27	24.25**	-10.51*	10.09
PBRK-7 X PBRK-9	4.52*	13.26**	10.28	31.74**	-9.49	11.36
PBRK-7 X PBRK-1	7.99**	19.31**	-13.32*	3.29	-3.08	19.24**
PBRK-7 X PBRK-2	6.24**	15.12**	-11.81	5.09	-8.46	12.62*
PBRK-8 X PBRK-9	7.42**	17.01**	3.01	23.05**	5.96	6.62
PBRK-8 X PBRK-1	4.43*	15.39**	7.39	21.86**	-7.32	7.89
PBRK-8 X PBRK-2	-0.41	8.48**	-17.94**	-6.89	-17.27**	-13.88*
PBRK-9 X PBRK-1	4.70*	15.68**	8.52	29.64**	-14.36**	-0.32
PBRK-9 X PBRK-2	8.23**	14.06**	-20.68**	-5.24	5.76	10.09
PBRK-1 X PBRK-2	4.89*	15.89**	-9.92	0.60	-5.69	9.78
CD 5%	10.81		3.30		0.25	
CD 1%	14.36		4.38		0.34	

Table 4.3: continued

Characters / Cross	Days to first fruit harvest		Days to last fruit harvest		Yield per plant	
	BP	Check	BP	Check	BP	Check
PBRK-4 X PBRK-12	-4.42	-6.24*	-3.10*	-3.89**	28.46**	45.90**
PBRK-4 X PBRK-10	-3.09	2.75	-1.62	2.09	-4.43	8.58*
PBRK-4 X PBRK-7	-1.62	2.96	-0.23	2.73	-2.07	11.30**
PBRK-4 X PBRK-8	-1.11	-1.22	0.41	0.35	24.41**	41.35**
PBRK-4 X PBRK-9	-3.24	-5.08	-1.40	-2.21	26.86**	44.11**
PBRK-4 X PBRK-1	-1.60	4.02	-0.45	3.02*	21.96**	38.52**
PBRK-4 X PBRK-2	-3.12	2.01	-1.36	0.75	6.13	20.49**
PBRK-12 X PBRK-10	-4.89	0.85	-2.46	1.22	3.52	0.86
PBRK-12 X PBRK-7	-4.25	0.21	-1.69	1.22	5.17	4.59
PBRK-12 X PBRK-8	-3.28	-3.39	-2.90*	-2.96*	1.54	-1.06
PBRK-12 X PBRK-9	5.96*	3.49	0.65	-0.64	-0.21	1.01
PBRK-12 X PBRK-1	-4.00	1.48	-2.02	1.39	4.17	4.48
PBRK-12 X PBRK-2	-1.01	4.23	-1.42	0.70	-5.72	-8.22*
PBRK-10 X PBRK-7	-2.50	3.39	-1.68	2.03	-4.95	-5.42
PBRK-10 X PBRK-8	-1.20	4.76	-2.68	0.99	3.74	0.91
PBRK-10 X PBRK-9	-2.00	3.92	-1.51	2.21	0.21	1.41
PBRK-10 X PBRK-1	2.79	8.99**	-0.50	3.25*	3.31	3.47
PBRK-10 X PBRK-2	-2.69	3.17	-1.57	2.15	2.31	-0.57
PBRK-7 X PBRK-8	1.62	6.35*	-1.47	1.45	26.05**	25.38**
PBRK-7 X PBRK-9	-0.10	4.55	-2.54	0.35	21.27**	22.72**
PBRK-7 X PBRK-1	-0.80	4.87	-1.85	1.57	-4.27	-4.06
PBRK-7 X PBRK-2	1.41	6.77*	-0.68	2.26	7.53	6.91
PBRK-8 X PBRK-9	-1.80	-1.90	-2.03	-2.09	27.51**	29.01**
PBRK-8 X PBRK-1	-0.40	5.29	0.67	4.18**	20.30**	20.64**
PBRK-8 X PBRK-2	-1.61	3.60	0.00	2.15	-2.30	-6.77
PBRK-9 X PBRK-1	-0.40	5.29	-1.46	1.97	38.73**	40.42**
PBRK-9 X PBRK-2	-5.03	0.00	-0.51	1.63	3.07	4.39
PBRK-1 X PBRK-2	-5.01	0.42	-2.30	1.10	-3.85	-3.69
CD 5%	3.50		3.33		0.25	
CD 1%	4.65		4.42		0.33	

*Significance at 5% level, ** Significance at 1% level

4. Fruit diameter (cm)

The extent of heterosis for better parent for fruit diameter ranged from -14.95 to 17.25. Significant positive heterosis was shown by five crosses. Maximum significant positive heterosis was observed for the cross PBRK-4 x PBRK-7 (17.25) followed by PBRK-7 x PBRK-9 (16.67), PBRK-7 x PBRK-2 (16.22), PBRK-4 x PBRK-2 (13.36) and PBRK-4 x PBRK-1 (12.50).

The range of heterosis over check for fruit diameter varied from -8.50 to 14.79. Three crosses showed significant positive heterosis. Maximum heterosis in desirable direction was observed for the cross PBRK-12 x PBRK-7 (14.79), followed by PBRK-12 x PBRK-8 (13.68) and PBRK-7 x PBRK-2 (12.57). Singh *et al* (2010) and Airina *et al* (2013) also observed significant heterosis for fruit diameter.

5. Vine length (cm)

The range of heterosis over better parent for vine length varied from -12.85 to 14.25. Significant positive heterosis was observed for fourteen crosses. The crosses exhibiting high positive heterosis were found to be PBRK-4 x PBRK-9 (14.25), PBRK-4 x PBRK-2 (11.96), PBRK-4 x PBRK-12 (9.75), PBRK-7 x PBRK-8 (8.70) and PBRK-9 x PBRK-2 (8.23).

Heterosis over check for vine length ranged between -11.56 to 22.62. Significant positive heterosis was observed for twenty four crosses. High positive heterosis was exhibited by the crosses PBRK-10 x PBRK-7 (22.62), PBRK-10 x PBRK-1 (19.58), PBRK-4 x PBRK-1 (19.34), PBRK-7 x PBRK-1 (19.31) and PBRK-7 x PBRK-8 (18.40). These results are in agreement with Singh *et al* (2010) and Mule *et al* (2012).

6. Number of fruits per plant

Number of fruits per plant is an economically important trait which contributes to the yield per plant. Heterosis over better parent for number of fruits per plant ranged from -41.00 to 10.28. However, none of the crosses showed significant positive heterosis. Similar findings were reported by Samant (2014).

The range of heterosis over check varied from -27.25 to 55.39. Twelve crosses showed significant heterosis in positive direction. The cross combinations exhibiting high heterosis in desirable directions were observed to be PBRK-4 x PBRK-12 (55.39), PBRK-4 x PBRK-1 (42.72), PBRK-4 x PBRK-9 (38.32), PBRK-4 x PBRK-8 (38.02) and PBRK-7 x PBRK-9 (31.74). Significant heterosis over better parent and check for number of fruits per plant was also reported by Pandey *et al* (2005) and Airina *et al* (2013).

7. Flesh to seed cavity ratio

The firmness of the fruit depends upon both flesh firmness and seed cavity. Therefore, flesh to seed cavity ratio affects the quality and shelf life of cucumber. Heterosis over better parent for this trait ranged from -17.27 to 16.67. Significant positive heterosis was observed for only two crosses, namely PBRK-4 x PBRK-9 (16.67) and PBRK-4 x PBRK-

7(14.62)

The extent of heterosis over check ranged from -13.88 to 41.01. Significant positive heterosis was observed for eleven crosses. The cross combinations PBRK-4 x PBRK-7 (41.01), PBRK-10 x PBRK-7 (35.02), PBRK-10 x PBRK-8 (33.75), PBRK-4 x PBRK-10 (25.24) and PBRK-10 x PBRK-1 (24.61) were observed to exhibit high positive heterosis for flesh to seed cavity ratio. Similar findings were reported by Dogra and Kanwar (2011) and Kaur *et al* (2016).

8. Days to first fruit harvest

The extent of heterosis over better parent for days to first fruit harvest ranged from -5.03 to 5.96. For this character negative value of heterosis is considered desirable. However, none of the crosses showed significant negative heterosis.

Heterosis over check for days to first fruit harvest ranged from -6.24 to 8.99. Negative value of heterosis was considered to be desirable as it indicates earliness. Only one cross, *i.e.* PBRK-4 x PBRK-12 (-6.24) was observed to show significant negative heterosis over check. Singh *et al* (2010) and Singh *et al* (2016) reported high significant heterosis in desirable direction for days to first fruit harvest. The disparity between the results of present and previous studies may be due to difference in parent material.

9. Days to last fruit harvest

Heterosis over better parent for days to last fruit harvest ranged from -3.10 to 0.67. However, none of the crosses exhibited significant positive heterosis.

The range of heterosis over check for days to last fruit harvest varied from -3.89 to 4.18. Three crosses showed significant heterosis in positive direction. The cross PBRK-8 x PBRK-1 (4.18) exhibited maximum heterosis followed by PBRK-10 x PBRK-1 (3.25) and PBRK-4 x PBRK-1 (3.02). However, Singh *et al* (2010) reported significant heterosis for days to last fruit harvest. The difference in both the results may be attributed to difference in the parental lines in both studies.

10. Yield per plant (kg)

Improvement in yield is the ultimate goal of any breeding programme. In the present study, the range of heterosis over better parent varied from -5.73 to 38.75. Significant positive heterosis was observed for nine crosses. Cross combinations exhibiting high positive heterosis were found to be PBRK-9 x PBRK-1 (38.75), PBRK-4 x PBRK-12 (28.46), PBRK-8 x PBRK-9 (27.48), PBRK-4 x PBRK-9 (26.89) and PBRK-7 x PBRK-8 (26.02).

The extent of heterosis over check ranged from -6.77 to 45.90. Significant positive heterosis was observed for twelve crosses. High heterosis in desirable direction was observed for the crosses PBRK-4 x PBRK-12 (45.90), PBRK-4 x PBRK-9 (44.11), PBRK-4 x PBRK-8 (41.35), PBRK-9 x PBRK-1 (40.42) and PBRK-4 x PBRK-1 (38.52). Significant heterosis for yield per plant had also been reported by Bairagi *et al* (2005), Dogra and Kanwar (2011),

Samant (2014), Singh *et al* (2014) and Singh *et al* (2016).

Heterosis has been used in crop production for nearly a century for developing more vigorous and high yielding cultivars (Fu *et al* 2014). Heterosis in cucumber is of commercial importance as the hybrids give higher yield and possess desired quality. In the present study, heterosis was evaluated for 28 F_1 hybrids obtained from crossing eight gynoecious parthenocarpic inbred lines in diallel fashion (excluding reciprocals). Top three cross combinations showing significant heterosis over respective better parent and commercial check for different characters are given in Table 4.4. The cross combination PBRK-4 x PBRK-12 was observed to show high heterosis for yield per plant (over better parent), number of fruits per plant and days to first fruit harvest (over check), whereas the cross PBRK-4 x PBRK-9 was observed to exhibit high heterosis for fruit weight, total soluble solids, vine length, flesh to seed cavity ratio (over better parent), number of fruits per plant (over check) and yield per plant (over both better parent and check).

Relationship between heterosis for yield and other component characters as depicted by top ten heterotic combinations for yield per plant is presented in Table 4.5. It can be seen in Table 4.5 that for almost all the cross combinations exhibiting high heterosis for yield per plant, high heterosis was also observed for number of fruits per plant, fruit weight and vine length. Hence, it was concluded that number of fruits per plant, fruit weight and vine length contributed positively towards yield per plant. Positive relation between yield and number of fruits per plant was also reported by Pandey *et al* (2005), Airina *et al* (2013) and Jat *et al* (2015). Kumar *et al* (2010) and Singh *et al* (2015) found positive contribution of fruit weight on yield per plant, whereas Bairagi *et al* (2005) and Solanki *et al* (1982) reported positive effect of vine length on yield per plant.

4.3 Estimation of general combining ability effects

Estimates of general combining ability effects for different characters are presented in Table 4.6 and presented character wise as follows:

1. Fruit weight (g)

The gca effects for fruit weight ranged from -17.98 to 35.76 and the analysis indicated significant gca for seven parents, *viz*. PBRK-12, PBRK-10, PBRK-7, PBRK-8, PBRK-9, PBRK-1 and PBRK-2. The inbred lines PBRK-10 was the best general combiner for fruit weight with gca value of 35.76, whereas PBRK-12 and PBRK-7 were poor general combiners with a gca value of -17.98 and -7.00, respectively. Significant gca effects for various characters were also reported by Sarkar and Sirohi (2010), Singh *et al* (2011) and Pati *et al* (2015.)

Table 4.4: Top three cross combinations showing significant heterosis over respective better parent and commercial check

Character	Heterosis over better parent	Heterosis over check
Fruit weight (g)	PBRK-4 x PBRK-9 PBRK-4 x PBRK-8 PBRK-9 x PBRK-1	PBRK-10 x PBRK-2 PBRK-10 x PBRK-1 PBRK-4 x PBRK-10
Total soluble solids (%)	PBRK-9 x PBRK-2 PBRK-4 x PBRK-9	PBRK-12 x PBRK-10 PBRK-9 x PBRK-2 PBRK-10 x PBRK-8
Fruit length (cm)	PBRK-4 x PBRK-2 PBRK-7 x PBRK-1	PBRK-10 x PBRK-1 PBRK-10 x PBRK-9 PBRK-10 x PBRK-7
Fruit diameter (cm)	PBRK-4 x PBRK-7 PBRK-7 x PBRK-9 PBRK-7 x PBRK-2	PBRK-12 x PBRK-7 PBRK-12 x PBRK-8 PBRK-7 x PBRK-2
Vine length (cm)	PBRK-4 x PBRK-9 PBRK-4 x PBRK-2 PBRK-4 x PBRK-12	PBRK-10 x PBRK-7 PBRK-10 x PBRK-1 PBRK-4 x PBRK-1
Number of fruits per plant	-	PBRK-4 x PBRK-12 PBRK-4 x PBRK-1 PBRK-4 x PBRK-9
Flesh to seed cavity ratio	PBRK-4 x PBRK-9 PBRK-4 x PBRK-7	PBRK-4 x PBRK-7 PBRK-10 x PBRK-7 PBRK-10 x PBRK-8
Days to first fruit harvest	-	PBRK-4 x PBRK-12
Days to last fruit harvest	-	PBRK-8 x PBRK-1 PBRK-10 x PBRK-1 PBRK-4 x PBRK-1
Yield per plant (kg)	PBRK-9 x PBRK-1 PBRK-4 x PBRK-12 PBRK-8 x PBRK-9	PBRK-4 x PBRK-12 PBRK-4 x PBRK-9 PBRK-4 x PBRK-8

Table 4.5: Relationship between heterosis for yield and other component characters as depicted by top ten heterotic combinations for yield per plant

Rank	Top ten heterotic combinations for yield per plant	Other characters for which heterosis is significant in desirable direction
1	PBRK-4 x PBRK-12	Number of fruits per plant Days to first fruit harvest
2	PBRK-4 x PBRK-9	Fruit weight Total soluble solids Vine length Flesh to seed cavity ratio Number of fruits per plant
3	PBRK-4 x PBRK-8	Fruit weight Vine length Number of fruits per plant
4	PBRK-9 x PBRK-1	Fruit weight Total soluble solids Vine length Number of fruits per plant
5	PBRK-4 x PBRK-1	Total soluble solids Vine length Number of fruits per plant Days to last fruit harvest
6	PBRK-8 x PBRK-9	Vine length Number of fruits per plant
7	PBRK-7 x PBRK-8	Fruit weight Vine length Number of fruits per plant
8	PBRK-7 x PBRK-9	Vine length Number of fruits per plant
9	PBRK-8 x PBRK-1	Fruit weight Vine length Number of fruits per plant Days to last fruit harvest
10	PBRK-4 x PBRK-2	Fruit weight Vine length

Table 4.6: Estimation of gca effects of parents for different characters in cucumber

Character / Parent	Fruit weight	Total soluble solids	Fruit length	Fruit diameter	Vine length	Number of fruits per plant	Flesh to seed cavity ratio	Days to first fruit harvest	Days to last fruit harvest	Yield per plant
PBRK-4	-2.43	-0.07*	-0.54	-0.06	-1.23	3.73**	-0.01	-1.56**	-0.90*	0.48**
PBRK-12	-17.98**	-0.07*	-2.48**	0.11*	-23.98**	2.49**	-0.13**	-1.53**	-1.67**	-0.13**
PBRK-10	35.76**	0.25**	5.04**	-0.19**	11.32**	-6.20**	0.25**	1.25**	1.43**	-0.25**
PBRK-7	-7.00**	-0.06	0.18	-0.06	6.30**	0.56	0.17**	1.15**	0.97**	-0.07**
PBRK-8	-6.69**	-0.06*	-1.84**	0.22**	1.80	1.03**	-0.12**	-0.43	-0.59	0.05
PBRK-9	-3.79**	0.06	-0.15	-0.06	-3.43**	1.39**	-0.09**	-0.91*	-1.39**	0.19**
PBRK-1	-1.02**	0.11**	1.00**	-0.10*	7.55	0.53	0.04	1.37**	1.46**	0.05*
PBRK-2	3.15*	-0.16**	-1.20**	0.14**	1.68	-3.52**	-0.10**	0.67	0.69	-0.33**
CD 5%	2.59	0.06	0.59	0.08	2.28	0.69	0.05	0.74	0.70	0.05
CD 1%	3.44	0.08	0.78	0.11	3.03	0.92	0.07	0.98	0.93	0.07

*Significance at 5% level ** Significance at 1% level

2. Total soluble solids (%)

The gca effects for total soluble solids ranged from -0.16 to 0.25. Six parents namely, PBRK-4, PBRK-12, PBRK-10, PBRK-8, PBRK-1 and PBRK-2 exhibited significant gca effects,. The best combiners were observed to be PBRK-10 and PBRK-1 with gca values of 0.25 and 0.11, respectively. The lines PBRK-2 (-0.16), PBRK-4 (-0.07) and PBRK-12 (-0.07) were found to be poor combiners, whereas, PBRK-9 was found to be an average combiner. Similar findings were also reported by Vidhya and Kumar (2014) and Kaur *et al* (2016).

3. Fruit length (cm)

The gca effects for fruit length ranged from -2.48 to 5.04 and the analysis indicated significant gca for five parents, viz., PBRK-12, PBRK-10, PBRK-8, PBRK-1 and PBRK-2. The best general combiners were found to be PBRK-10 and PBRK-1, with a gca value of 5.04 and 1.00, respectively. The line PBRK-12 (-2.48) and PBRK-8 (-1.84) were observed to be poor combiners whereas PBRK-7 was observed to be an average combiner for fruit length.

These results are in agreement with Bairagi *et al* (2013), Reddy *et al* (2014) and Pati *et al* (2015).

4. Fruit diameter (cm)

The gca effects for fruit diameter ranged from -0.19 to 0.22. Five parents, namely, PBRK-12, PBRK-10, PBRK-8, PBRK-1 and PBRK-2 showed significant gca effects. The lines PBRK-8 (0.22), PBRK-2 (0.14) and PBRK-12 (0.11) were found to be among the best combiners, whereas PBRK-10 and PBRK-1 were observed to be poor combiners with a gca value of -0.19 and -0.10, respectively. Significant gca effects for fruit diameter were also reported by Sarkar and Sirohi (2010), Bairagi *et al* (2013) and Vidhya and Kumar (2014).

5. Vine length (cm)

The gca effects for vine length ranged from -23.98 to 11.32. Four parents viz., PBRK-12, PBRK-10, PBRK-7 and PBRK-9 showed significant gca effects. The best general combiners were observed to be PBRK-10 and PBRK-7 with a gca value of 11.32 and 6.30, respectively. The line PBRK-12 (-23.98) was found to be poor combiner followed by PBRK-9 (-3.43). These results are in agreement with Singh *et al* (2010), Jat *et al* (2011) and Mule *et al* (2012).

6. Number of fruits per plant

The gca effects for number of fruits per plant ranged from -6.20 to 3.73 and the analysis indicated significant gca for six parents namely, PBRK-4, PBRK-12, PBRK-10, PBRK-8, PBRK-9 and PBRK-2. The best general combiners were observed to be PBRK-4 and PBRK-12 with a gca value of 3.73 and 2.49, respectively. PBRK-10 (-6.20) and PBRK-2 (-3.52) were found to be poor combiners, whereas, PBRK-7 (0.56) and PBRK-1(0.53) were observed to be average combiners. Similar findings were also reported by Singh *et al* (2011), Bairagi *et al* (2013) and Pati *et al* (2015).

7. Flesh to seed cavity ratio

The gca effects for flesh to seed cavity ratio ranged from -0.13 to 0.25. Six parents exhibited significant gca effects namely, PBRK-12, PBRK-10, PBRK-7, PBRK-8, PBRK-9 and PBRK-2. The lines PBRK-10 and PBRK-7 were the best general combiner with a gca value of 0.25 and 0.17, respectively. PBRK-12 (-0.13) and PBRK-8 (-0.12) were observed tobe poor combiners. Kaur *et al* (2016) observed significant gca effects for flesh to seed ratio in cucumber.

8. Days to first fruit harvest

For days to first fruit harvest, negative gca effects were considered to be desirable as it indicates earliness. The gca effects ranged from -1.56 to 1.37 and analysis indicate significant gca effects for six parents viz., PBRK-4, PBRK-12, PBRK-10, PBRK-7, PBRK-9 and PBRK-2. The best general combiner for days to first fruit harvest was PBRK-4 followed by PBRK-12 with a gca value of -1.56 and -1.53, respectively. The inbred line PBRK-1 (1.37) was poor combiner followed by PBRK-10 (1.25). These results were in agreement with Reddy *et al* (2014) and Jat *et al* (2015).

9. Days to last fruit harvest

The gca effects for days to last fruit harvest ranged from -1.67 to 1.46 and analysis indicate significant gca effects for six parents namely, PBRK-4, PBRK-12, PBRK-10, PBRK-7, PBRK-9 and PBRK-1. The best general combiner was PBRK-1 with a gca value of 1.46 followed by PBRK-10 with a gca value of 1.43 whereas PBRK-12 and PBRK-9 were poor combiners with a gca value of -1.67 and -1.39, respectively.

10. Yield per plant (kg)

The gca effects for yield per plant ranged from -0.33 to 0.48. Seven parents showed significant gca effects *viz*., PBRK-4, PBRK-12, PBRK-10, PBRK-7, PBRK-9, PBRK-1 and PBRK-2. PBRK-4 was the best general combiner with a gca value of 0.48 followed by PBRK-9 with a gca value of 0.19. PBRK-2 and PBRK-10 were poor combiners with a gca value of -0.33 and -0.25, respectively. Significant gca effects for yield per plant were also observed by Singh *et al* (2010), Mule *et al* (2012), Bairagi *et al* (2013), Pati *et al* (2015) and Jat *et al* (2015).

In general, PBRK-10 was observed to be the best general combiner for five characters, *viz*., fruit weight, total soluble solids, fruit length, vine length and flesh to seed cavity ratio and second best combiner for days to last fruit harvest. PBRK-4 was found to be the best general combiner for number of fruits per plant, days to first fruit harvest and yield per plant, whereas PBRK-1 was found to be the best combiner for days to last fruit harvest and second best for total soluble solids and fruit length. For fruit diameter PBRK-8 was observed to be the best combiner followed by PBRK-2 and PBRK-12. PBRK-12 was found to be a poor combiner for fruit weight, total soluble solids, fruit length, vine length, flesh to seed

cavity ratio and days to last fruit harvest, whereas PBRK-10 was found to exhibit the lowest gca effects for fruit diameter, number of fruits per plant. PBRK-1 was observed to be a poor combiner for days to first fruit harvest, whereas PBRK-2 was found to be a poor combiner for yield per plant. Hence, on the basis of high gca effects in desirable direction for maximum characters, PBRK-10 and PBRK-4 may be considered as the best general combiners.

Top parents on the basis of gca in desirable direction and *per se* performance for different characters are presented in Table 4.7. It can be seen that for most of the characters, the parents showing high gca effects were also observed to give high *per se* performance for that character. Thus it can be inferred that *per se* performance of a parent can be taken into consideration for estimating its general combining ability, which is in agreement with Balliu and Hallidri (2000). Similar findings were also reported by Kumar *et al* (2013), Reddy *et al* (2014) and Pati *et al* (2015).

4.4 Estimation of specific combining ability effects

The results pertaining to the estimates of specific combining ability effects for different characters are presented in Table 4.8.The mean values of crosses for different characters are given in tables in Appendix II. Character wise description is given as follows:

1. Fruit weight (g)

The sca effects for fruit weight ranged from -18.98 to 16.61. Twenty five crosses showed significant sca effects out of which 19 were in positive direction. High positive sca effect was recorded for the cross PBRK-12 x PBRK-7 (16.6), PBRK-4 x PBRK-9 (14.78) and PBRK-10 x PBRK-1 (14.16). Significant sca effects for fruit weight were also observed by Singh *et al* (2010), Rabou and Hamed (2011) and Reddy *et al* (2014).

The range of mean value varied from 125.47 to 196.60. Cross PBRK-10 x PBRK-2 (196.60) was found to exhibit highest magnitude of fruit weight, whereas PBRK-12 x PBRK-8 (125.47) recorded the lowest fruit weight.

2. Total soluble solids (%)

The sca effects for total soluble solids ranged from -0.36 to 0.71. Nineteen crosses exhibited significant sca effects out of which ten were in positive direction. Promising crosses exhibiting significant high sca effects in desirable direction were PBRK-9 x PBRK-2 (0.71) PBRK-12 x PBRK-10 (0.48) and PBRK-4 x PBRK-9 (0.50). Kaur *et al* (2016) also reported significant sca effects for this character.

The mean values ranged from 2.11 to 3.36. Highest estimates of TSS were found for the cross PBRK-12 x PBRK-10 (3.36), whereas PBRK-4 x PBRK-2 was observed to exhibit lowest value for TSS.

3. Fruit length (cm)

The range of sca effects for fruit length varied from -3.63 to 2.62. Significant sca

Table 4.7: Top parents on the basis of gca in desirable direction and *per se* performance for different characters in cucumber

Character	Top parents on the basis of gca performance	Top parents on the basis of *per se* performance
Fruit weight	PBRK-10, PBRK-2	PBRK-10, PBRK-2, PBRK-1
Total soluble solids	PBRK-10, PBRK-1	PBRK-10, PBRK-1, PBRK-7
Fruit length	PBRK-10, PBRK-1	PBRK-10, PBRK-7, PBRK-1
Fruit diameter	PBRK-8, PBRK-2, PBRK-12	PBRK-8, PBRK-12, PBRK-2
Vine length	PBRK-10, PBRK-7	PBRK-10, PBRK-1, PBRK-8
Number of fruits per plant	PBRK-4, PBRK-12, PBRK-9	PBRK-12, PBRK-4, PBRK-9
Flesh to seed cavity ratio	PBRK-10, PBRK-7	PBRK-10, PBRK-7, PBRK-1
Days to first fruit harvest	PBRK-4, PBRK-12, PBRK-9	PBRK-12, PBRK-9, PBRK-4
Days to last fruit harvest	PBRK-1, PBRK-10, PBRK-7	PBRK-10, PBRK-1, PBRK-7
Yield per plant	PBRK-4, PBRK-9, PBRK-1	PBRK-4, PBRK-9, PBRK-1

Table 4.8: Estimation of sca effects of cross combinations for different characters in cucumber

Characters / Crosses	Fruit weight	Total soluble solids	Fruit length	Fruit diameter	Vine length
PBRK-4 X PBRK-12	7.91**	0.05	2.02**	0.12**	9.94**
PBRK-4 X PBRK-10	12.24**	-0.10**	0.11	0.02	6.30**
PBRK-4 X PBRK-7	-7.07**	0.10*	0.24	0.07	-0.54
PBRK-4 X PBRK-8	11.55**	0.02	0.80*	0.17**	5.90**
PBRK-4 X PBRK-9	14.78**	0.50**	-0.74	0.00	16.52**
PBRK-4 X PBRK-1	-2.52	0.08*	-0.53	0.25**	13.21**
PBRK-4 X PBRK-2	12.91**	-0.35**	2.48**	0.26**	16.01**
PBRK-12 X PBRK-10	-17.35**	0.48**	-3.63**	-0.24**	20.32**
PBRK-12 X PBRK-7	16.61**	-0.21**	-0.84*	0.46**	7.08**
PBRK-12 X PBRK-8	4.23*	-0.09*	1.87**	0.15**	2.65
PBRK-12 X PBRK-9	4.80**	-0.26**	0.66	-0.12**	-22.86**
PBRK-12 X PBRK-1	4.83**	0.28**	-0.72	-0.34**	0.23
PBRK-12 X PBRK-2	6.32**	-0.04	1.95**	0.09	14.45**
PBRK-10 X PBRK-7	-3.53*	-0.06	-0.45	0.04	9.31**
PBRK-10 X PBRK-8	-18.98**	0.41**	-2.52**	-0.13*	-11.32**
PBRK-10 X PBRK-9	-5.88**	-0.36**	-1.58**	0.19**	-1.10
PBRK-10 X PBRK-1	14.16**	-0.14**	2.62**	0.09	1.19
PBRK-10 X PBRK-2	11.78**	-0.04	-1.50**	0.11*	-5.14**
PBRK-7 X PBRK-8	10.85**	0.05	0.28	-0.18**	9.30**
PBRK-7 X PBRK-9	-1.52	-0.03	0.37	0.22**	2.93
PBRK-7 X PBRK-1	5.98**	-0.09*	2.35**	0.04	5.62**
PBRK-7 X PBRK-2	3.41	0.26**	-1.43**	0.35**	2.02
PBRK-8 X PBRK-9	4.77**	-0.06	0.74	0.04	15.90**
PBRK-8 X PBRK-1	7.20**	0.19**	0.72	-0.00	1.25
PBRK-8 X PBRK-2	3.70*	-005	0.75	-0.22**	-8.48**
PBRK-9 X PBRK-1	13.57**	0.11**	-0.16	0.12*	7.14**
PBRK-9 X PBRK-2	5.33**	0.71**	1.42**	0.15*	9.35**
PBRK-1 X PBRK-2	-11.50**	-0.24**	0.13	0.08	2.50
CD 5%	3.45	0.08	0.78	0.11	3.04
CD 1%	4.58	0.11	1.04	0.15	4.03

Table 4.8: (continued)

Characters / Crosses	Number of fruits per plant	Flesh to seed cavity ratio	Days to first fruit harvest	Days to last fruit harvest	Yield per plant
PBRK-4 X PBRK-12	3.83**	0.04	-2.25**	-3.05**	788.11**
PBRK-4 X PBRK-10	-3.94**	0.06	0.64	0.72	-253.00**
PBRK-4 X PBRK-7	-1.84**	0.48**	0.86	1.90**	-345.39**
PBRK-4 X PBRK-8	1.42**	-0.12**	-0.19	0.73	467.87**
PBRK-4 X PBRK-9	1.13*	0.23	-2.14**	-1.40**	411.19**
PBRK-4 X PBRK-1	2.97**	-0.10**	1.32**	1.75**	378.24**
PBRK-4 X PBRK-2	-1.03*	-0.07	0.74	-0.08	204.15**
PBRK-12 X PBRK-10	1.63**	0.07*	-0.59	0.49	114.09**
PBRK-12 X PBRK-7	-2.13**	-0.18**	-0.89	0.94*	53.03
PBRK-12 X PBRK-8	-1.54**	-0.01	-1.58**	-2.30**	-244.97**
PBRK-12 X PBRK-9	-3.63**	0.07	3.24**	1.17*	-323.25**
PBRK-12 X PBRK-1	-1.30**	0.27**	-0.31	0.66	-74.00*
PBRK-12 X PBRK-2	-1.79**	0.01	2.12**	0.63	-82.09*
PBRK-10 X PBRK-7	-1.29**	0.09*	-1.67**	-1.22*	-137.75**
PBRK-10 X PBRK-8	1.22*	0.35**	0.78	-0.86	-62.89
PBRK-10 X PBRK-9	-0.34	-0.23**	0.73	1.34**	-189.96**
PBRK-10 X PBRK-1	-1.81**	-0.01	1.65**	-0.31	15.02
PBRK-10 X PBRK-2	1.37**	0.08*	-1.33**	-0.80	277.66**
PBRK-7 X PBRK-8	1.52**	-0.07	1.87**	0.12	521.79**
PBRK-7 X PBRK-9	2.83**	-0.07*	1.22**	-0.34	296.11**
PBRK-7 X PBRK-1	-2.64**	-0.04	-0.86	-1.79**	-396.24**
PBRK-7 X PBRK-2	1.81**	-0.03	1.03*	-0.22	332.33**
PBRK-8 X PBRK-9	0.42	0.12**	-1.26*	-1.58**	369.97**
PBRK-8 X PBRK-1	1.02*	0.01	0.99*	2.77**	250.42**
PBRK-8 X PBRK-2	-1.34**	-0.31**	0.62	1.21*	-215.47**
PBRK-9 X PBRK-1	2.40**	-0.20**	1.47**	-0.90	723.48**
PBRK-9 X PBRK-2	-1.33**	0.17**	-1.17*	1.41**	-10.81
PBRK-1 X PBRK-2	0.84	0.03	-3.18**	-2.04**	-121.43**
CD 5%	0.93	0.07	0.98	0.93	69.71
CD 1%	1.23	0.09	1.31	1.24	92.57

*Significance at 5% level ** Significance at 1% level

effects were shown by fourteen crosses out of which eight were in positive direction. High positive sca effects were observed for the crosses PBRK-10 x PBRK-1 (2.62), PBRK-4 x PBRK-2 (2.48) and PBRK-7 x PBRK-1 (2.35). Sarkar and Sirohi (2010) and Mule *et al* (2012) also observed significant sca effects for fruit length.

The mean values ranged from 14.60 to 26.40 with crosses PBRK-10 x PBRK-1 (26.40) and PBRK-12 x PBRK-7 (14.60) exhibiting the highest and the lowest value for fruit length, respectively.

4. Fruit diameter (cm)

The sca effects for fruit diameter ranged from -0.34 to 0.46. Eighteen crosses showed significant sca effects out of which twelve were in positive direction. Crosses exhibiting high postive sca effects were found to be PBRK-12 x PBRK-7 (0.46), PBRK-7 x PBRK-2 (0.35) and PBRK-4 x PBRK-2 (0.26). These results are in agreement with Mule *et al* (2012), Reddy *et al* (2014) and Pati *et al* (2015).

The range of mean values varied from 3.30 to 4.14. Maximum value was observed for the cross PBRK-12 x PBRK-7 (4.14), whereas PBRK-12 x PBRK-1(3.30) was found to show the least value for fruit diameter.

5. Vine length (cm)

The range of sca effects for vine length varied from -22.86 to 20.32. Significant sca effects were exhibited by nineteen crosses out of which fifteen were in positive direction. High positive sca effects were observed for the crosses PBRK-12 x PBRK-10 (20.32), PBRK-4 x PBRK-9 (16.52) and PBRK-4 x PBRK-2 (16.01). Singh *et al* (2011) and Bairagi *et al* (2013) also found significant sca effects for vine length.

The estimates for vine length for different crosses ranged from 199.80 to 277, with cross PBRK-10 x PBRK-7 (277) and PBRK-12 x PBRK-9 (199.80) exhibiting the maximum and minimum values, respectively.

6. Number of fruits per plant

The sca effects for number of fruits per plant ranged from (-3.94 to 3.83). Twenty five crosses showed significant sca effects out of which twelve were in positive direction. Promising cross combinations exhibiting high positive sca effects were observed to be PBRK-4 x PBRK-12 (3.83), PBRK-7 x PBRK-9 (2.83) and PBRK-4 x PBRK-1 (2.97). Similar findings were also reported by Sarkar and Sirohi (2010), Vidhya and Kumar (2014) and Jat *et al* (2015).

The mean values for number of fruits per plant ranged from 16.20 to 34.60. Cross combination PBRK-4 x PBRK-12 (34.60) was observed to exhibit highest number of fruits, whereas cross PBRK-10 x PBRK-2 recorded the least number of fruits per plant.

7. Flesh to seed cavity ratio

The sca effects for flesh to seed cavity ratio ranged from -0.31 to 0.48. Fifteen crosses showed significant sca effects out of which eight were in positive direction. High sca effects in desirable direction were recorded for the cross combinations PBRK-4 x PBRK-7 (0.48), PBRK-12 x PBRK-1 (0.27) and PBRK-10 x PBRK-8 (0.35). Kaur *et al* (2016) observed significant sca effects for this character.

The estimates for flesh to seed cavity ratio ranged from 1.82 to 2.98 with cross PBRK-4 x PBRK-7 (2.98) and PBRK-8 x PBRK-2 (1.82) exhibiting the highest and lowest value, respectively.

8. Days to first fruit harvest

The range of sca effects for days to first fruit harvest varied from -3.18 to 3.24. Negative sca effects were considered to be desirable as it indicates earliness. Significant sca effects were recorded for seventeen crosses out of which eight were in negative direction. High negative sca effects were observed for the crosses PBRK-1 x PBRK-2 (-3.18), PBRK-4 x PBRK-12 (-2.25) and PBRK-4 x PBRK-9 (-2.14). Similar findings were reported by Reddy *et al* (2014) and Pati *et al* (2015) for days to first fruit harvest.

The range of mean values for days to first fruit harvest varied from 59.07 to 68.67. The best cross combination showing the least value was found to be PBRK-4 x PBRK-12 (59.07) whereas the poorest cross with highest value was observed to be PBRK-10 x PBRK-1 (68.67).

9. Days to last fruit harvest

The range of sca effects for days to last fruit harvest ranged from -3.05 to 2.77. Fifteen crosses showed significant sca effects out of which eight were in positive direction. Crosses exhibiting high sca effects in desirable direction were observed to be PBRK-8 x PBRK-1 (2.77), PBRK-4 x PBRK-7 (1.90) and PBRK-4 x PBRK-1 (1.75).

The mean values for days to last fruit harvest ranged from 110.40 to 119.67 with cross PBRK-8 x PBRK-1 (119.67) and PBRK-4 x PBRK-12 (110.40) showing the maximum and minimum value for days to last fruit harvest.

10. Yield per plant (kg)

The sca effects for yield per plant ranged from -0.40 to 0.79. Twenty four crosses showed significant sca effects out of which thirteen were in positive direction. Promising crosses showing high positive sca effects were found to be PBRK-4 x PBRK-12 (0.79) PBRK-9 x PBRK-1 (0.72) and PBRK-7 x PBRK-8 (0.52). Sarkar and Sirohi (2010), Singh *et al* (2010), Bairagi *et al* (2013) and Pati *et al* (2015) had also reported significant sca effects for yield per plant.

The estimates of mean value ranged from 2.86 to 4.54. The cross exhibiting highest yield per plant was found to be PBRK-4 x PBRK-12 (4.54) whereas minimum value was

observed for the cross PBRK-12 x PBRK-2.

It was observed that the cross combination PBRK-4 x PBRK-12 exhibited highest sca effects for yield per plant and number of fruits per plant. The cross combination PBRK-4 x PBRK-9 was the second best specific combiner for fruit weight, total soluble solids and vine length. The cross PBRK-4 x PBRK-2 was found to show high sca effects for fruit length, fruit diameter and vine length, PBRK-12 x PBRK-7for fruit weight and fruit diameter and PBRK-10 x PBRK-1 for fruit length.

The entries in Table 4.9 suggests that most of the crosses exhibiting high sca effects for different characters were also found to give high per se performance for that character. Thus it can be concluded that, *per se* performance of a cross is related to its sca effects. These results are in agreement with Munshi *et al* (2006), Kumar *et al* (2013) and Reddy *et al* (2014).

Moreover, most of the crosses having high sca effect had at least one of the parents as high or an average general combiner (Table 4.10). Hence, high gca of a parent is an indication of high sca of the cross containing it in that cross. Similar results were also reported by Bairagi *et al* (2013) and Singh *et al* (2016). However, cross containing parents having low gca can exhibit high sca due to complementary gene action. Mule *et al* (2012) also reported similar findings.

4.6 Estimation of genetic components of variation

The estimates of genetic components of variation for different characters are presented in Table 4.11 and described character wise as follows:

1. Fruit weight (g)

The estimates of additive and non-additive components were found to be significant, suggesting the importance of both genes for this trait. However, the magnitude of D component (1400.12) was higher than H_1 component (571.29) which indicates that the additive component was comparatively more important than dominant one. The degree of dominance $(H_1/D)^{1/2}$ was found to be 0.64, indicating the presence of partial dominance. The F value was found to be positive (594.82), indicating more frequency of dominant genes in the parents.

Moreover, the proportion of dominant and recessive gene as depicted by the formula $[(4DH_1)^{1/2}+ F]/ [(4DH_1)^{1/2}-F]$ was found to be 1.20, suggesting more number of dominant genes. The proportion of genes with positive and negative effects in the parents ($H_2/4 H_1$) was found to be less (0.21) than the expected value of 0.25, suggesting the asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio of h^2/H_2 was found to be 1.92, indicating the presence of two groups of genes showing dominance for this trait.

2. Total soluble solids (%)

The estimates of both additive (D) and non-additive (H_1 and H_2) components were found to be significant. However, the magnitude of H_1 component was higher than D

Table 4.9: Top cross combinations on the basis of sca effects and *per se* performance in desirable direction for different characters in cucumber

Character	Top cross combination on the basis of sca performance	Top cross combination on the basis of *per se* performance
Fruit weight (g)	PBRK-12 x PBRK-7 PBRK-4 x PBRK-9 PBRK-10 x PBRK-1	PBRK-10 x PBRK-2 PBRK-10 x PBRK-1 PBRK-4 x PBRK-10
Total soluble solids (%)	PBRK-9 x PBRK-2 PBRK-4 x PBRK-9 PBRK-12 x PBRK-10	PBRK-12 x PBRK-10 PBRK-9 x PBRK-2 PBRK-10 x PBRK-8
Fruit length (cm)	PBRK-10 x PBRK-1 PBRK-4 x PBRK-2 PBRK-7 x PBRK-1	PBRK-10 x PBRK-1 PBRK-10 x PBRK-9 PBRK-10 x PBRK-7
Fruit diameter (cm)	PBRK-12 x PBRK-7 PBRK-7 x PBRK-2 PBRK-4 x PBRK-2	PBRK-12 x PBRK-7 PBRK-12 x PBRK-8 PBRK-7 x PBRK-2
Vine length (cm)	PBRK-12 x PBRK-10 PBRK-4 x PBRK-9 PBRK-4 x PBRK-2	PBRK-10 x PBRK-7 PBRK-10 x PBRK-1 PBRK-4 x PBRK-1
Number of fruits per plant	PBRK-4 x PBRK-12 PBRK-4 x PBRK-1 PBRK-7 x PBRK-9	PBRK-4 x PBRK-12 PBRK-4 x PBRK-1 PBRK-4 x PBRK-9
Flesh to seed cavity ratio	PBRK-4 x PBRK-7 PBRK-10 x PBRK-8 PBRK-12 x PBRK-1	PBRK-4 x PBRK-7 PBRK-10 x PBRK-7 PBRK-10 x PBRK-8
Days to first fruit harvest	PBRK-1 x PBRK-2 PBRK-4 x PBRK-12 PBRK-4 x PBRK-9	PBRK-4 x PBRK-12 PBRK-4 x PBRK-9 PBRK-12 x PBRK-8
Days to last fruit harvest	PBRK-8 x PBRK-1 PBRK-4 x PBRK-7 PBRK-4 x PBRK-1	PBRK-8 x PBRK-1 PBRK-10 x PBRK-1 PBRK-4 x PBRK-1
Yield per plant (kg)	PBRK-4 x PBRK-12 PBRK-9 x PBRK-1 PBRK-7 x PBRK-8	PBRK-4 x PBRK-12 PBRK-4 x PBRK-9 PBRK-4 x PBRK-8

Table 4.10: Top cross combinations with consistent significant sca effects for different characters along with ranking of parents on the basis of gca effects in cucumber

Character	Top cross combination on sca basis	Ranking of parents based on gca basis
Fruit weight (g)	PBRK-12 x PBRK-7 PBRK-4 x PBRK-9 PBRK-10 x PBRK-1	Low x Low Low x Low High x Low
Total soluble solids (%)	PBRK-9 x PBRK-2 PBRK-4 x PBRK-9 PBRK-12 x PBRK-10	Average x Low Low x Low Low x High
Fruit length (cm)	PBRK-10 x PBRK-1 PBRK-4 x PBRK-2 PBRK-7 x PBRK-1	High x High Low x Low Low x High
Fruit diameter (cm)	PBRK-12 x PBRK-7 PBRK-7 x PBRK-2 PBRK-4 x PBRK-2	High x Low Low x High Low x High
Vine length (cm)	PBRK-12 x PBRK-10 PBRK-4 x PBRK-9 PBRK-4 x PBRK-2	Low x High Low x High Low x High
Number of fruits per plant	PBRK-4 x PBRK-12 PBRK-4 x PBRK-1 PBRK-7 x PBRK-9	High x High High x Average Average x High
Flesh to seed cavity ratio	PBRK-4 x PBRK-7 PBRK-10 x PBRK-8 PBRK-12 x PBRK-1	Low x High High x Low Low x Average
Days to first fruit harvest	PBRK-1 x PBRK-2 PBRK-4 x PBRK-12 PBRK-4 x PBRK-9	Low x Average High x High High x High
Days to last fruit harvest	PBRK-8 x PBRK-1 PBRK-4 x PBRK-7 PBRK-4 x PBRK-1	Low x High Low x High Low x High
Yield per plant (kg)	PBRK-4 x PBRK-12 PBRK-9 x PBRK-1 PBRK-7 x PBRK-8	High x Low High x High Low x Average

Table 4.11: Estimation of genetic components of variation

Characters	Additive (D)	Dominance (H_1)	Non-additive (H_2)	F	E	$(H_1/D)^{1/2}$	$H_2/4H_1$	$(4DH_1)^{1/2}+F/(4DH_1)^{1/2}-F$	h^2/H_2
Fruit weight (g)	1400.12**	571.29**	481.68**	594.82**	18.78	0.64	0.21	1.20	1.92
Total soluble solids (%)	0.08**	0.27**	0.25**	0.03	0.01	1.85	0.23	1.19	0.152
Fruit length (cm)	31.18**	10.76**	8.44**	14.21**	0.97**	0.59	0.20	2.27	0.64
Fruit diameter (cm)	0.13**	0.20**	0.14**	0.12**	0.02**	1.24	0.18	2.21	1.81
Vine length (cm)	566.39**	627.18**	542.34**	195.77	14.90	1.05	0.21	1.39	2.44
Number of fruits per plant	35.49**	16.31**	14.24**	-6.69	1.46	0.68	0.22	0.76	-0.03
Flesh to seed cavity ratio	0.06**	0.12**	0.11**	-0.13	0.01**	1.41	0.22	0.85	0.26
Days to first fruit harvest	4.47**	6.31**	6.82**	-2.24	1.53**	1.19	0.27	0.65	-0.07
Days to last fruit harvest	4.97**	4.19**	5.07**	-2.19	1.37**	0.92	0.30	0.61	-0.10
Yield per plant (g)	0.07	0.67**	0.52**	-0.13	0.01	3.19	0.20	0.52	1.13

*Significance at 5% level, ** Significance at 1% level

component indicating that the dominant component was comparatively more important than the additive one. Further, the degree of dominance was also found to be more (1.85) than unity, suggesting the preponderance of over-dominance. The F value was found to be slightly positive (0.03), indicating more frequency of dominant genes in the parents. Moreover, the proportion of dominant to recessive gene was found to be more (1.19) than unity, which also suggests presence of more number of dominant genes. The ratio $H_2/4H_1$ was found to be less (0.23) than the expected value of 0.25, suggesting asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was found to be 0.15, which means that only one group of genes control this character and exhibit dominance.

3. Fruit length (cm)

Both additive and non-additive components were found to be significant. However, the magnitude of D component was higher than the H_1 component. This indicates that the additive component was of more importance than the non-additive components. The degree of dominance was observed to be less (0.59) than unity, indicating partial dominance. The F value was found to be positive (14.2) indicating more frequency of dominant genes in the parents. Moreover, the proportion of dominant and recessive genes was observed to be more (2.27) than unity, thus indicating the presence of more number of dominant genes. The ratio $H_2/4H_1$ was found to be less (0.20) than the expected value of 0.25, which suggests asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was found to be 0.64, which indicates that one group of genes showed dominance for this trait.

4. Fruit diameter (cm)

Estimates of both additive and non-additive components were found to be significant. However, the magnitude of H_1 was higher than D component indicating that the dominant component was comparatively more important than the additive component. The degree of dominance was observed to be more (1.24) than unity, indicating the presence of over-dominance. The F value was found to be positive (0.12), indicating more frequency of dominant genes in the parents. Moreover, the proportion of dominant and recessive genes was observed to be more (2.21) than unity, which indicates the presence of more number of dominant genes. The ratio $H_2/4H_1$ was found to be less (0.18) than the expected value of 0.25, suggesting an asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was found to be 1.81, which means that two groups of genes control this character and exhibit dominance.

5. Vine length (cm)

Estimates of both additive and non-additive components were found to be highly significant. However, the magnitude of H_1 component was higher than D component indicating the importance of dominant component over additive component. The degree of

dominance was found to be more (1.05) than unity, indicating the role of over-dominance. The F value was found to be positive (195.77), which indicates more frequency of dominant genes in the parents. Moreover, the proportion of dominant and recessive genes was observed to be more (1.39) than unity, indicating the presence of more number of dominant genes. The ratio $H_2/4H_1$ was observed to be less (0.21) than the expected value of 0.25, suggesting an asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was found to be 2.44, which indicates that three groups of genes showed dominance for this trait.

6. Number of fruits per plant

Significance of both additive and non-additive components indicates the role of both genes in inheritance of this trait. The magnitude of D component was higher than the H_1 component indicating that the additive component was comparatively more important than the dominant component. The degree of dominance was found to be less (0.68) than unity, indicating the presence of partial dominance. The F value was observed to be negative (-6.69), indicating more frequency of recessive genes in the parents. Moreover, the proportion of dominant and recessive genes was observed to be less (0.76) than unity, indicating the presence of more number of recessive genes. The ratio $H_2/4H_1$ was found to be less (0.22) than the expected value of 0.25, which suggests an asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was found to be -0.03, suggesting that one group of genes showed dominance for this trait.

7. Flesh to seed cavity ratio

Both additive and non-additive components were found to be significant for this trait. The magnitude of H_1 component was higher than the D component and H_2 indicating the importance of dominant component over additive component. The degree of dominance was found to be more (1.41) than unity, indicating the presence of over-dominance. The F value was observed to be negative (-0.13), which indicates more frequency of recessive genes in the parents. Moreover, the proportion of dominant and recessive genes was found to be less (0.85) than unity, suggesting the presence of more number of recessive genes. The ratio $H_2/4H_1$ was found to be less (0.22) than the expected value of 0.25, which suggests an asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was observed to be 0.26, suggesting that one group of genes control this character and exhibit dominance.

8. Days to first fruit harvest

Significance of both additive and non-additive components indicates the role of both genes in inheritance of this trait. The magnitude of H_1 component was higher than the D component indicating the importance of dominant component over additive component. The degree of dominance was found to be more (1.19) than unity, indicating the presence of over-

dominance. The F value was found to be negative (-2.24), suggesting more frequency of recessive genes in the parents. Moreover, the proportion of dominant and recessive genes was found to be less (0.65) than unity, which indicates the presence of more number of recessive genes. The ratio $H_2/4H_1$ was found to be more (0.27) than the expected value of 0.25, indicating an asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was observed to be -0.07, which indicates that one group of genes showed dominance for this trait.

9. Days to last fruit harvest

Both additive and non-additive components were found to be significant for this trait. The magnitude of H_1 component was higher than the D component indicating the importance of dominant over additive component. The degree of dominance was found to be less (0.92) than unity, indicating the presence of partial dominance. The F value was found to be negative (-2.19), which indicates more frequency of recessive genes in the parents. Moreover, the proportion of dominant and recessive genes was found to be less (0.61) than unity, indicating the presence of more number of recessive genes. The ratio $H_2/4H_1$ was found to be more (0.30) than the expected value of 0.25, suggesting an asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was found to be -0.10, which indicates that one group of genes showed dominance for this trait.

10. Yield per plant

The dominant and non-additive component was found to be significant while the additive component was non-significant. The degree of dominance was found to be more (3.19) than unity, indicating the role of over-dominance. The F value was found to be negative (-0.13), suggesting more frequency of recessive genes in the parents. Moreover, the proportion of dominant and recessive genes was found to be less (0.52) than unity, indicating the presence of more number of recessive genes. The ratio $H_2/4H_1$ was found to be less (0.20) than the expected value of 0.25, indicating an asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio h^2/H_2 was observed to be 1.13, which suggests that two group of genes control this character and exhibit dominance.

The study of genetic component of variation revealed that dominant variances were higher than additive variance for most of the characters, viz., total soluble solids, fruit diameter, vine length, flesh to seed cavity ratio, days to first fruit harvest, days to last fruit harvest and yield per plant. This shows the role of non-additive gene action for inheritance of these traits. However, the additive variance was higher for characters, viz., fruit weight, fruit length and number of fruits per plant, indicating the role of additive gene action for their inheritance. Predominant role of non-additive gene action for most of the characters was also reported by Kumar *et al* (2013), Reddy *et al* (2014) and Singh *et al* (2016).

The degree of dominance $(H_1/D)^{1/2}$ was found to be more than unity for total soluble

solids, fruit diameter, vine length, flesh to seed cavity ratio and yield per plant, indicating the presence of over-dominance, whereas, it was less than one for fruit weight, fruit length, number of fruits per plant and days to last fruit harvest, suggesting the presence of partial dominance. F value was found to be positive for fruit weight, total soluble solids, fruit length, fruit diameter and vine length, indicating more frequency of dominant genes than recessive genes in the parents. The proportion of dominant and recessive genes $[(4DH_1)^{1/2}+ F]/ [(4DH_1)^{1/2}-F]$ was also found to be more than unity, which also suggested more number of dominant genes than recessive genes. The negative value of F for number of fruits per plant, flesh to seed cavity ratio, days to first fruit harvest, days to last fruit harvest and yield per plant indicated more frequency of recessive genes than dominant genes in the parents. The proportion of dominant to recessive genes was also observed to be less than one for these characters. Sarkar and Sirohi (2006) and Kumar *et al* (2010) also observed over-dominance for most of the characters including yield per plant.

The ratio of $H_2/4H_1$ was found to be less than the expected value of 0.25 for all characters except days to first fruit harvest, days to last fruit harvest and yield per plant, suggesting an asymmetrical distribution of favourable and unfavourable gene for those characters. The number of group of dominant genes (h^2/H_2) was found to be one for total soluble solids, fruit length, number of fruits per plant, flesh to seed cavity ratio, days to first fruit harvest and days to last fruit harvest. Similar findings were reported by Sarkar and Sirohi (2006) and Kumar *et al* (2010).

CHAPTER-V

SUMMARY

The present investigation entitled "Heterosis and combining ability for yield and yield attributing traits of parthenocarpic cucumber (*Cucumis sativus* L.) under poly-net house conditions" was carried out at Research Farm Department of Vegetable Science, Punjab Agricultural University, Ludhiana, India. The major objectives of the study were to estimate the extent of heterosis, ombining ability for crosses and genetic components of variation.

The study included eight parthenocarpic gynoecious inbred lines, *viz.* PBRK-4, PBRK-12, PBRK-10, PBRK-7, PBRK-8, PBRK-9, PBRK-1 and PBRK-2. The commercial hybrid 'Multistar' was used as a standard check for estimation of standard heterosis. The parthenocarpic gynoecious parental lines were crossed in a diallel fashion (without reciprocals) to produce twenty eight F_1 hybrids. Since all the parental lines were gynoecious in nature, male flowers were induced in selected plants of all genotypes by external application of Silver thiosulfate at 2-4 true leaf stage. The parental lines along with twenty eight F_1 hybrids and one check were grown in a randomized complete block design with three replications. Observations were recorded for eleven namely, fruit weight, total soluble solids, fruit length, fruit diameter, vine length, number of fruits per plant, flesh to seed cavity ratio, days to first fruit harvest, days to last fruit harvest and yield per plant.

Analysis of variance for various characters revealed that the mean sum of squares due to genotypes were highly significant for all the characters, indicating significant difference among the genotypes for these characters. The analysis of variance for combining ability showed that the mean sum of squares due to general combining ability were highly significant for all the characters except for vine length, whereas mean sum of squares due to specific combining ability were highly significant for all the characters except for days to first and last fruit harvest. The significant mean sum of squares due to gca and sca for almost all the characters indicated the presence of both additive and non-additive gene action in inheritance of these traits.

The cross combination PBRK-4 x PBRK-9 showed maximum heterosis over better parent for fruit weight, whereas for heterosis over check, cross PBRK-10 x PBRK-2 showed maximum heterotic value. For fruit length, maximum heterosis over better parent was shown by PBRK-4 x PBRK-2, while that over check was observed for the cross PBRK-10 x PBRK-1. The cross combination PBRK-4 x PBRK-7 was found to exhibit maximum heterobeltiosis for fruit diameter, whereas maximum heterosis over check was shown by PBRK-12 x PBRK-7. For number of fruits per plant, none of the crosses were found to exhibit significant positive heterosis over better parent, whereas, high heterosis over check for this trait was observed for the cross PBRK-4 x PBRK-12. For yield per plant, maximum heterosis over

better parent was observed for PBRK-9 x PBRK-1, while that over check was observed for the cross PBRK-4 x PBRK-12.

The estimation of combining ability effects revealed that in general, PBRK-10 was the best general combiner for five characters, viz., fruit weight total soluble solids, fruit length, vine length and flesh to seed cavity ratio and second best combiner for days to last fruit harvest. The genotype PBRK-4 was observed to be the best general combiner for number of fruits per plant, days to first fruit harvest and yield per plant, whereas PBRK-1 was observed to be the best combiner for days to last fruit harvest and second best for total soluble solids and fruit length. Hence, on the basis of high gca effects in desirable direction for maximum characters, PBRK-10 and PBRK-4 may be considered as the best general combiners.

It was seen that for most of the characters, the parents which showed high gca effects were also observed to give high *per se* performance for that character. Thus it can be inferred that *per se* performance of a parent can be taken into consideration for estimating its general combining ability.

It was observed that the cross combination PBRK-12 x PBRK-7 exhibited high sca effects for two characters, *viz*., fruit weight and fruit diameter. Cross combination PBRK-10 x PBRK-1 exhibited maximum sca effects for fruit length, whereas PBRK-12 x PBRK-10 were found to show high sca for vine length. The cross combination PBRK-4 x PBRK-12 was found to exhibit maximum sca effects for number of fruits per plant and yield per plant.

Most of the crosses which showed high sca effects for different characters were also found to give high per se performance for that character. Thus it was concluded that, high *per se* performance was related to high sca effect. Moreover, most number of crosses having high sca effect consisted of at least one of the parents as high or an average general combiner. Hence, high gca of a parent is an indication of high sca of the cross containing it in that cross. However, cross containing parents with low gca can exhibit high sca effects due to complementary gene action.

The study of genetic component of variation revealed that dominant variances were higher than additive variances for most of the characters, except fruit weight, fruit length and number of fruits per plant. This shows the role of non-additive gene action for inheritance of these traits. However, the additive variances were higher than dominant variances for rest of the characters indicating the role of additive gene action for inheritance.

The degree of dominance $(H_1/D)^{1/2}$ was found more than one for total soluble solids, fruit diameter, vine length, flesh to seed cavity ratio and yield per plant, which indicated the presence of over-dominance, whereas, it was less than one for fruit weight, fruit length, number of fruits per plant and days to last fruit harvest, suggesting the presence of partial dominance.

F value was found to be positive for fruit weight, total soluble solids, fruit length, fruit diameter and vine length, indicating more frequency of dominant genes than recessive genes, present in the parents. The proportion of dominant and recessive genes $[(4DH_1)^{1/2}+ F]/[(4DH_1)^{1/2}-F]$ was also found to be more than unity, which also suggested more number of dominant genes than that of recessive genes. The negative F value for number of fruits per plant, flesh to seed cavity ratio, days to first fruit harvest, days to last fruit harvest and yield per plant indicated more frequency of recessive genes than dominant genes in the parents. The proportion of dominant and recessive genes was also observed to be less than one for these characters.

The ratio of $H_2/4H_1$ was found to be less than the expected value of 0.25 for all characters except for days to first and last fruit harvest and yield per plant, suggesting an asymmetrical distribution of favourable and unfavourable gene for those characters. The number of group of dominant genes (h^2/H_2) was found to be one for most of the characters, *viz.*, total soluble solids, fruit length, number of fruits per plant, flesh to seed cavity ratio, days to first fruit harvest and days to last fruit harvest.

From the present investigation, it is concluded that the cross combinations PBRK-4 x PBRK-12, PBRK-4 x PBRK-9 and PBRK-4 x PBRK-8 were found to exhibit high heterosis over commercial check 'Multistar'. The inbred line PBRK-10 was the best general combiner for seven characters followed by PBRK-4 for three and PBRK-1 for one character. Most of the characters, except fruit weight, fruit length and number of fruits per plant were observed to be governed by non-additive gene action. Hence, heterosis breeding can be used for improving yield and yield attributing traits. The cross combinations PBRK-4 x PBRK-12, PBRK-4 x PBRK-9 and PBRK-9 x PBRK-1 exhibiting high heterosis in desirable direction along with high sca effects for yield per plant and can be used for developing F_1s.

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Appendix 1: Mean values of parents for three replications

Character / Parents	Fruit weight (g)	Total soluble solids (%)	Fruit length (cm)	Fruit diameter (cm)	Vine length (cm)	Number of fruits per plant	Flesh to seed cavity ratio	Days to first fruit harvest	Days to last fruit harvest	Yield per plant (kg)	Number of seeds per fruit
PBRK-4	116.13	2.40	14.47	3.05	213.93	30.73	2.07	61.80	113.93	3.54	0.00
PBRK-12	96.27	2.45	12.13	3.77	186.20	32.00	1.96	61.47	113.40	3.03	0.00
PBRK-10	221.20	3.10	29.71	3.20	262.93	13.73	2.65	66.80	119.20	3.02	0.00
PBRK-7	119.53	2.58	17.84	3.01	244.80	26.53	2.60	65.93	118.27	3.10	0.00
PBRK-8	120.87	2.52	12.73	4.15	246.07	25.27	2.13	62.93	114.80	2.96	0.00
PBRK-9	120.40	2.50	15.50	3.20	229.27	26.60	2.12	61.53	113.40	3.15	0.00
PBRK-1	128.00	3.01	17.53	3.31	249.60	24.87	2.46	66.60	118.87	3.12	0.00
PBRK-2	136.23	2.25	13.43	3.49	238.07	18.27	2.20	66.33	117.33	2.54	0.00
Multistar (Check)	128.27	2.49	16.45	3.61	225.91	22.27	2.11	63.00	114.87	3.11	0.00

Appendix II: Mean values of crosses for three replications

Characters / Crosses	Fruit weight	Total soluble solids	Fruit length	Fruit diameter	Vine length	Number of seeds per fruit
PBRK-4 X PBRK-12	133.40	2.61	16.74	3.79	234.80	0.00
PBRK-4 X PBRK-10	191.47	2.78	22.35	3.40	266.47	0.00
PBRK-4 X PBRK-7	129.40	2.66	17.62	3.58	254.60	0.00
PBRK-4 X PBRK-8	148.33	2.58	16.16	3.95	256.53	0.00
PBRK-4 X PBRK-9	154.47	3.18	16.30	3.51	261.93	0.00
PBRK-4 X PBRK-1	139.93	2.81	17.67	3.72	269.60	0.00
PBRK-4 X PBRK-2	159.53	2.11	18.47	3.96	266.53	0.00
PBRK-12 X PBRK-10	146.33	3.36	16.67	3.31	257.73	0.00
PBRK-12 X PBRK-7	137.53	2.35	14.60	4.14	239.47	0.00
PBRK-12 X PBRK-8	125.47	2.47	15.29	4.10	230.53	0.00
PBRK-12 X PBRK-9	128.93	2.42	15.76	3.55	199.80	0.00
PBRK-12 X PBRK-1	131.73	3.02	15.53	3.30	233.87	0.00
PBRK-12 X PBRK-2	137.40	2.43	16.00	3.97	242.22	0.00
PBRK-10 X PBRK-7	171.13	2.83	22.51	3.43	277.00	0.00
PBRK-10 X PBRK-8	156.00	3.29	18.41	3.53	251.87	0.00
PBRK-10 X PBRK-9	172.00	2.65	24.20	3.57	256.87	0.00
PBRK-10 X PBRK-1	194.80	2.91	26.40	3.43	270.13	0.00
PBRK-10 X PBRK-2	196.60	2.75	20.08	3.69	257.93	0.00
PBRK-7 X PBRK-8	143.07	2.62	16.36	3.61	267.47	0.00
PBRK-7 X PBRK-9	133.60	2.66	18.14	3.73	255.87	0.00
PBRK-7 X PBRK-1	143.87	2.65	21.27	3.51	269.53	0.00
PBRK-7 X PBRK-2	145.47	2.73	15.29	4.06	260.07	0.00
PBRK-8 X PBRK-9	140.20	2.63	16.48	3.83	264.33	0.00
PBRK-8 X PBRK-1	145.40	2.55	17.61	3.75	260.67	0.00
PBRK-8 X PBRK-2	146.07	2.43	15.44	3.77	245.07	0.00
PBRK-9 X PBRK-1	154.67	2.97	18.43	3.59	261.33	0.00
PBRK-9 X PBRK-2	150.60	3.30	17.80	3.85	257.67	0.00
PBRK-1 X PBRK-2	136.53	2.41	17.67	3.75	261.80	0.00

Appendix II (continued)

Characters / Crosses	Number of fruits per plant	Flesh to seed cavity ratio	Days to first fruit harvest	Days to last fruit harvest	Total yield per plant
PBRK-4 X PBRK-12	34.60	2.25	59.07	110.40	4.54
PBRK-4 X PBRK-10	18.13	2.65	64.73	117.27	3.38
PBRK-4 X PBRK-7	27.00	2.98	64.87	118.00	3.46
PBRK-4 X PBRK-8	30.73	2.10	62.23	115.27	4.40
PBRK-4 X PBRK-9	30.80	2.47	59.80	112.33	4.49
PBRK-4 X PBRK-1	31.78	2.29	65.53	118.33	4.31
PBRK-4 X PBRK-2	23.73	2.17	64.27	115.73	3.75
PBRK-12 X PBRK-10	22.47	2.55	63.53	116.27	3.14
PBRK-12 X PBRK-7	25.47	2.21	63.13	116.27	3.26
PBRK-12 X PBRK-8	26.53	2.09	60.87	111.47	3.08
PBRK-12 X PBRK-9	24.80	2.20	65.20	114.13	3.14
PBRK-12 X PBRK-1	26.27	2.54	63.93	116.47	3.25
PBRK-12 X PBRK-2	21.73	2.13	65.67	115.67	2.86
PBRK-10 X PBRK-7	17.61	2.85	65.13	117.20	2.94
PBRK-10 X PBRK-8	20.60	2.83	66.00	116.00	3.14
PBRK-10 X PBRK-9	19.40	2.28	65.47	117.40	3.16
PBRK-10 X PBRK-1	17.07	2.63	68.67	118.60	3.22
PBRK-10 X PBRK-2	16.20	2.58	65.00	117.33	3.10
PBRK-7 X PBRK-8	27.67	2.33	67.00	116.53	3.90
PBRK-7 X PBRK-9	29.33	2.35	65.87	115.27	3.82
PBRK-7 X PBRK-1	23.00	2.52	66.07	116.67	2.99
PBRK-7 X PBRK-2	23.40	2.38	67.27	117.47	3.33
PBRK-8 X PBRK-9	27.40	2.25	61.80	112.47	4.02
PBRK-8 X PBRK-1	27.13	2.28	66.33	119.67	3.76
PBRK-8 X PBRK-2	20.73	1.82	65.27	117.33	2.90
PBRK-9 X PBRK-1	28.87	2.11	66.33	117.13	4.37
PBRK-9 X PBRK-2	21.10	2.33	63.00	116.73	3.25
PBRK-1 X PBRK-2	22.40	2.32	63.27	116.13	3.00

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