

**STUDY ON HETEROSIS BREEDING, COMBINING
ABILITY AND GENE ACTION IN BITTER GOURD**
(*Momordica charantia* L.)

Thesis

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By

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Pantnagar
August, 2022


(Amit Nawani)
Author

CERTIFICATE – I

This is to certify that the thesis entitled “**STUDY ON HETEROSIS BREEDING, COMBINING ABILITY AND GENE ACTION IN BITTER GOURD (*Momordica charantia* L.)**” submitted in partial fulfilment of the requirements for the degree of **Master of Science in Agriculture** with major in **Horticulture (Vegetable Science)** of the College of Post Graduate Studies, G.B. Pant University of Agriculture & Technology, Pantnagar, is a record of *bona-fide* research carried out by **Mr. Amit Nawani, ID. No. 56600**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

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

Pantnagar
August, 2022



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CERTIFICATE – II


We, the undersigned, members of Advisory Committee of Mr. Amit Nawani, ID. No. 56600 a candidate for the degree of **Master of Science in Agriculture** with major in **Horticulture (Vegetable Science)** agree that the thesis entitled “**STUDY ON HETEROSIS BREEDING, COMBINING ABILITY AND GENE ACTION IN BITTER GOURD (*Momordica charantia* L.)**” may be submitted in partial fulfilment of the requirements for the degree.



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Introduction



Chapter-1

INTRODUCTION

In addition to increasing the revenue of growers and other participants in the value chain, vegetables are a necessity for human health. Producing adequate food while ensuring that they are wholesome, accessible, and inexpensive for the general public is one of the major concerns of the twenty-first century. Due to consumer awareness of the benefits of vegetables in human nutrition, the demand for vegetables has grown during the past ten years. To ensure that everyone consumes the recommended amount of vegetables per day (300 g), the demand for vegetables may rise further in the post-pandemic era. This is due to the fact that the importance of vegetables in diet, disease prevention, and environmental health has become more deeply ingrained in the global mindset (**Hong *et al.*, 2020**).

Vegetable research and development in India has advanced admirably. Vegetable production in India consistently sets new records, making it the farmers' preferred agricultural product. From a 10.4-million-hectare area, 191.77 million tonnes of production were produced in 2019-20, compared to only 20 million tonnes at the time of independence (**Anonymous, 2019-20**). According to dietitians' recommendations, with a projected 1.5 billion people by 2030, we will need to produce 210 million tonnes of vegetables to satisfy the growing need for more with fewer resources.

India produces a vast range of vegetables, accounting for 59 percent of all horticulture production (**Sagar *et al.*, 2020**). From around 5.39 percent of the country's planted area, India produces about 16.5 per cent vegetables of the world's vegetables output. Among the states of India, Uttar Pradesh is leading producer with a production of 28.31 million tonnes from the area of 1.45 million hectares and a productivity of 19.43 tonnes per hectare and West Bengal ranks second with a production of 27.69 million tonnes from an area of 1.40 million hectares and a productivity of 19.77 tonnes per hectare. Bitter melon occupies an area of 97 thousand hectares with the annual production of 1.137 million tonnes in India (**Anonymous, 2019-20**).

There are 117 genera and 825 species in the cucurbitaceae family. Cucurbits are utilized as a cultivated plant in roughly 30 species belonging to nine genera. They are frost-sensitive, tendril-bearing vines that grow in subtropical and tropical climates worldwide (**Jeffrey, 1990**). The term "cucurbits" was first coined by Liberty Hyde Bailey to describe

the cultivated species of the Cucurbitaceae family, but it is now used to describe all of the family's species. India is home to a diverse range of cucurbits, and many gourds and melons are thought to have originated there (**Choudhary, 1996**).

Bitter gourd (*Momordica charantia* L., $2n = 2x = 22$) also known as karela, balsam pear, bitter cucumber, bitter apple, bitter squash, African cucumber and bitter melon, is an economically important member of the family Cucurbitaceae that is widely cultivated in India, China, Malaysia, Africa, and South America (**Raj et al., 1993 and Singh et al., 1990**). Its primary origin is in Tropical Asia, specifically Eastern India (which includes the states of Odisha, West Bengal, Assam, Jharkhand, and Bihar) and Southern China (which includes Indo Burma) (**Zeven and Zhukovsky, 1975**).

It is an important vegetable crop and is grown for its immature tuberculate fruits which have a unique bitter taste. The crop is considered as prized vegetable because of its high nutritive values particularly ascorbic acid, vitamin A and iron. Fruits are useful against diseases like cancer, malaria, ulcer, dyslipidemia and hypertension with its anti-inflammatory, antiviral, and antibacterial properties and contains health promoting substances such as charantin and vicine (**Rao et al., 1999**). It is claimed that the fruit powder is used for healing wounds, leprosy and malignant ulcers (**Prasad et al., 2006**). It is reported for its usefulness in snakebites. The roots have abortifacient activity. It has been reported that protein of bitter gourd inhibited the growth of immune deficiency virus (HIV-1) in human beings (**Singh et al., 1990**).

Fruits are used after cooking and many delicious dishes can be prepared after frying or stuffing. However, a large number of value-added products can be made out of it like juice, pickle, chips etc. During the off season the fruits can be made available in the market in the form of sliced, partially boiled or dried forms (**Hassan and Umar, 2006**). Agricultural and processed food products exports development authority (APEDA) have identified bitter gourd as one of the potent vegetables for export among cultivated cucurbitaceous vegetables.

India is endowed with a wide range of diversity for various morphological traits of bitter gourd i.e., sex expression, growth habit, maturity, fruit shape, size, colour and surface texture. Being a cross-pollinated crop with high levels of heterozygosity heterosis is well exploited in bitter gourd for earliness, higher yield and other agronomic traits. Monoecious is its primitive sex form; however, gynoecious sex form has been reported from India, Japan

and China (**Behera et al., 2006**). *M. dioca*, *M. cochinchinensis*, *M. balsamina*, *M. tuberosa*, *M. subangulata*, *M. denudata*, and *M. macrocarpa* are some of the other species in this genus that are not commercially cultivated.

Bitter gourd is a monoecious crop having both male and female flowers are present on the same plant. Gynoecium was reported by (**Ram et al., 2002**). Male flowers are smaller than female flowers and have a yellow colour on long thin pedicels and bloom earlier than female flowers. Pistillate flowers have a tiny pedicel with a large size when compared to male flowers, and are easily distinguished by the presence of an ovary that is oblong to long in size and has a greenish colour, as well as yellow blossoms. Bitter gourd flowers have five calyxes, five corollas, and three filaments (**Behera et al., 2010**). Flowering usually begins two months after seeding. Anthesis begins at 4:00 am and ends at 9:00 am. Anther dehiscence starts by 5.00 am and gets completed by 7.30 am. Receptivity of stigma is a maximum of 8 hours before and 12 hours after anthesis. It is mainly pollinated by insects and the major pollinators are honey bees (**Pal et al., 1972**). Hand pollination can be avoided either by introducing beehives. Pollen losses viability as the day advances and may be fully inviable by midday (**Desai and Musmade, 1998**).

Bitter gourd is a fast-growing vine with thin stems and tendrils that can trail or climb. The leaves are heart-shaped with 5-7 lobes and a diameter of 5-10 cm. In the leaf axils, flowers are produced singly. Male flowers appear first and typically outnumber female flowers by a factor of 20:1. The fruits have ridges along the length of the fruit. Light green, rectangular, and pointed at the blossom end, immature fruits feature white flesh. The surface of the fruits turns yellow or orange as they grow. At maturity, it tends to split open, revealing orange flesh and bright red placenta to which the seeds are attached. Seeds are tan and oval, with a rough etched surface; there are about 5 to 7 seeds per gram (**Robinson et al., 1997**).

The selection of parents for hybridization has to be based on the complete genetic information and prepotency of the potential parents. With these points in view, heterosis and combining ability studies are a prerequisite in any plant breeding programme, which provides the desired information regarding the varietal improvement or exploiting heterosis for commercial purposes.

Development of quality F₁ hybrids with better productivity and adaptability is the main focus of bitter gourd breeding throughout the world. The aim of heterosis study was to

identify the best heterotic combinations and its exploitation for commercial purpose. The presence of heterosis indicates the ability of parents to combine well in a hybrid combination. For developing hybrids, the most important task for the plant breeder is the choice of parental line. The success of breeding procedure is determined by the useful gene combination organized in the form of good combining lines produce outstanding progenies on crosses with others, while other may look equally desirable, but may not produce good progenies on crossing. The lines, which perform well in combination, are eventually of great importance to the plant breeders (**Gami *et al.*, 2018**).

The identification of best combiners in hybrid breeding has to be based on the complete genetic information and esteemed prepotency of potential parents. Combining ability analysis gives useful information regarding the selection of parents and provides the desired information about the nature and magnitude of different types of gene actions involved in the expression of quantitative characters. For the development of superior hybrids, estimates of general combining ability of parents and specific combining ability of the crosses help in proper selection of parents for hybridization (**Dogra and Kanwar, 2011**).

The knowledge on the relative importance of the additive (gca) and non-additive (sca) gene actions within a breeding population is significant because it determines the breeding method for genetic improvement (**Sincik *et al.*, 2011**) After identification of appropriate parents and potential crosses through combining ability analysis, the next important step is to adopt suitable breeding methodology to achieve the desired result which depends upon the type of gene action governing the traits.

Though many reports on combining ability and heterosis breeding are available in bitter melon, information on the identification of quality parents for F₁ production is still lacking. In order to find out suitable parents and cross combinations for 16 horticultural traits in bitter melon, range and mean of parents and hybrids, percentage of heterosis over better parent and heterosis over standard parent (Pant Karela-1) and gene action, the present investigation entitled “**Study on heterosis breeding, combining ability and gene action in bitter melon (*Momordica charantia* L.)**” planned with following major objectives:

- a) To estimate heterobeltiosis and standard heterosis.
- b) To determine the general combining ability (gca) and specific combining ability (sca) effects.
- c) To work out the nature and magnitude of gene action.



Review
of
Literature



Chapter-2

REVIEW OF LITERATURE

Bitter gourd (*Momordica charantia* L., $2n=2x=22$) is an economically important member of cucurbitaceae family and considered as a nutritious vegetable crop due to its relatively elevated nutritional content. Fruits are useful against diseases like cancer, malaria, ulcer, dyslipidemia and hypertension (Alam *et al.*, 2015) with its anti-inflammatory, antiviral, and antibacterial properties (Joseph and Jini, 2011).

India is endowed with a wide range of diversity for various morphological traits of bitter gourd i.e., sex expression, growth habit, maturity, fruit shape, size, colour and surface texture, (Behera, 2004). Being a cross-pollinated crop with high levels of heterozygosity, heterosis is well exploited in bitter gourd for earliness, higher yield and other horticulture traits.

Under this chapter an attempt has been made to review the available relevant literature on pertinent aspects of research under study entitled “**Study on heterosis breeding, combining ability and gene action in bitter gourd (*Momordica charantia* L.)**” and review are grouped here under the following headings.

- 2.1 Heterosis studies
- 2.2 Combining abilities
- 2.3 Gene action

2.1. Heterosis

Heterosis is described as the phenomenon in which the F_1 generation produced by crossing two genetically different individuals shows increased or decreased vigour over the better parent (heterobeltiosis), mid parent (relative heterosis) and standard check (standard heterosis). However, from the plant breeder’s viewpoint, heterosis over better parent and standard variety is more effective. The former is designated as heterobeltiosis (Fanseco and Peterson, 1968) and the latter as standard heterosis (Virmani, 1994).

The term ‘heterosis’ was first used by George Harrison Shull (1914). Since then, this has been exploited commercially in several crops. The first suggestion that it could be exploited in vegetables was made by Hayes and Jones (1916) in cucumber. After the exploitation of heterosis in cucumber, it was reported in so many vegetables crops.

Several studies on heterosis about yield and quality traits of bitter gourd have been made at Indian Agricultural Research Institute. One bitter gourd hybrid, Pusa Hybrid-1 is developed and released for commercial cultivation under North Indian plains. It gives 42 % heterosis over better parent and its fruits are suitable for dehydration and making pickles (Sirohi, 2000). Heterosis in crop species can be visualized in terms of increases in growth rate, total biomass, stress resistances, seed yield, and population fitness (Kalloo *et al.*, 2006). Heterosis has the following specific characteristics: firstly, heterosis is highly variable; the degree of heterosis varies with respect to the genetic distance of the parents, their reproductive mode, the traits investigated (Zhou *et al.*, 2012) the developmental stage of the plants (Groszmann *et al.*, 2013) and the environment. Brief reviews present on the heterosis in bitter gourd are described below.

Thangamani *et al.* (2011) conducted a study at the Research Farm, Horticultural College and Research Institute, TNAU, Coimbatore, the evaluation of F1 hybrids in bitter gourd (*Momordica charantia* L.) for yield and quality with 10 diverse parents found that Preethi, CO-1, MC-30, Uchha Bolder, Green Long, and MC-105 were the best genotypes for improving yield, combined with quality characters. For yield and quality metrics, the hybrids Preethi MC-30, KR USL, MC-105 MC-10, and Priyanka CO-1 all displayed favourable mean, significant sca, and standard heterosis values. The hybrid Preethi MC-30 recorded favourable values for the most crucial characteristics, such as earliness, quantity of fruits, fruit production, and quality, while taking into account the mean performance, sca, and standard heterosis.

Singh *et al.* (2013) did an at the experimental farm of the ICAR RCER Research Centre, Ranchi, heterosis for yield and yield components in bitter gourd (*Momordica charantia* L.) was studied for 21 crosses along with their parents. It was found that HABG-24 HABG-30 and HABG-23 HABG-34 showed a significant heterosis in the desired direction for most of the yield characters.

Talekar *et al.* (2013) conducted an experiment on heterosis studies for quantitative traits in bitter gourd (*Momordica charantia* L.) at Department of Genetics and Plant Breeding, Junagadh Agricultural University, Junagadh, Gujarat. The standard heterosis for fruit yield per vine ranged from -55.65 to 73.79 %. The crosses Preethi × HABG-22, Ujjwala × HABG-22, Hirkani × CO-4, Hirkani × HABG-22 and Kalyanpur

Baramasi \times HABG-21 were the best heterotic combinations for fruit yield per vine, which recorded 73.79, 63.10, 57.26, 53.83 and 52.22 % standard heterosis, respectively and could be utilized for hybrid development in bitter gourd.

Thangamani and Pugalendhi (2013) experimented with heterosis studies in bitter gourd for yield and related characters at Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. The hybrid CO-1 \times MC-105 had negative relative standard heterosis for the node at which the first female flower appears. Heterosis for sex ratio was in the desired direction in UB \times GL. The highest positive, and significant, standard heterosis was in the hybrid CO-1 \times MC-105 for fruit length. Estimates of standard heterosis for fruit yield indicated that the hybrid Preethi \times MC-30 had the highest positive value followed by the hybrid KR \times USL. In order of merit, the hybrids Preethi \times MC-30, KR \times USL, MC-105 \times MC-10, and Priyanka \times CO-1 were the best performers for yield and quality.

Al-Mamun *et al.* (2016) carried out an investigation on heterosis studies in bitter gourd with five parents and 16 hybrids. The evaluation was done at the Vegetable Research Field of Olericulture Division of Horticulture Research Centre, Bangladesh, from October, 2009 to March, 2010. Average fruit weight ranged from 115 to 249 g, the heaviest fruit was from the crosses P1 \times P3, P2 \times P3, P3 \times P1, P3 \times P5, and P5 \times P2, hybrids from the crosses P3 \times P4, P4 \times P3, and P5 \times P4 had the smallest fruit. The longest fruit were the crosses P3 \times P1, P2 \times P3, and P1 \times P3, the smallest fruit were from the crosses P4 \times P3, P4 \times P2, and P3 \times P4. The highest yield was from the cross P3 \times P5 followed by the crosses P4 \times P1 and P4 \times P3. Hybrids from crosses P5 \times P4, P3 \times P5, and P2 \times P5 had 102 %, 82.6 %, and 82.4 % higher heterosis over the better parent, respectively, for fruit yield per plant. Based on yield contributing characters and heterotic performance hybrids from crosses P5 \times P4, P3 \times P5, and P2 \times P5 can be used to exploit develop improved commercial lines.

Kandasamy *et al.* (2015) studied heterosis in bitter gourd (*Momordica charantia* L.) at Department of Horticulture, Faculty of Agriculture, Annamalai using 20 F₁ hybrids of bitter gourd in a diallel set involving five parents. Appreciable amount of heterosis was observed for all the characters under this study except node number of first female flower. The F₁ hybrids P5 \times P3 (Panruti Local \times VK-1 Priya), P4 \times P2 (MC -13 \times Arka Harit) and

P2 × P1 (Arka Harit × CO-1) were observed best performing for yield and they showed 46.21, 29.31 and 14.30 per cent heterosis, respectively better parent Arka Harit (P2).

Rao et al. (2017) study genetic components of variation and heterosis in bitter gourd for horticultural traits at Vegetable Research Farm, Division of Vegetable Science, IARI, New Delhi during spring-summer season (February to May) of 2015. The best performing F₁ hybrids with high standard heterosis and mean performance for yield were found in crosses DBGS-54 × DBGS-2 (43.00 %), DBGS-54 × Pusa Vishesh (37.89 %) and Pusa Aushadhi × DBGS-54 (34.57 %). Pusa Aushadhi × DBGS-54, Pusa Aushadhi × DBGS-57 and Pusa Aushadhi × DBGS-37 were best early yielding hybrids.

Bhatt et al. (2017) studies on heterosis in bitter gourd (*Momordica charantia* L.) using 36 F₁ hybrids and their nine parents, was observed in the order of male: female ratio (37.36 %), number of fruits per vine (20.00 %), total fruits yield per vine (9.68 %) and ascorbic acid (2.50 %). The standard heterosis (over best check Pusa Hybrid-1 was observed in the order of days taken to opening of the first female flower (-5.45 %), days taken to first fruits set (-5.45 %), male: female ratio (107.47 %), number of fruits per vine (50.00 %), fruit length (27.59 %), fruit weight (3.33 %), fruit diameter (4.35 %), total fruits yield per vine (21.43 %). Panipat Local × Phule Green, Phule Green × Pusa Do Mausami and Punjab-14 × Pusa Do Mausami. Panipat Local × Phule Green was superior in respect of days taken to the opening first female flower, vine length, days to first fruit harvest, fruit length. Phule Green × Pusa Do Mausami was taking fruit length, fruit weight, fruit diameter and total fruit yield per vine. Punjab-14 × Pusa Do Mausami was better about superior for the number of nodes at which the first female flower appeared, number of fruits per vine and days to first fruit harvest.

Adarsh et al. (2018) investigated a heterosis study in bitter gourd for earliness and qualitative traits at Vegetable Science Farm at Bihar Agricultural University, Sabour, with six parents and their six F₁ random crosses in three replications of Randomized Complete Block Design and they found that heterotic vigour over standard parent was shown by the cross BRBBTL × Pusa Aushadhi and BRBBTL × Gangajalee hybrid for earliness, quantitative and qualitative traits.

Alhariri et al. (2018) conducted an experiment on exploiting gynocious lines for earliness and yield traits in bitter gourd (*Momordica charantia* L.) at the Research

Farm of Division of Vegetable Science, IARI, New Delhi, during spring-summer (February to May) of 2016-17, involving eight parental lines including one gynoeocious line PDMGy-201 (Gy-23) and their 28 F₁ hybrids obtained from half diallel analysis. They obtained the best F₁ hybrid for earliness and desired sex ratio was PDMGy-201 × S-2 which recorded -32.58 % heterosis for days to the opening of first female flower over mid parent and -35.96 % over standard parent and F₁ hybrid PDMGy-201 × PV recorded 67.5 % and 67.22 % higher yield over mid and standard parent and 18.92 % increase in the number of fruits per plant over standard parent which may be exploited for commercial cultivation.

Mishra and Singh (2018) conducted an experiment on heterosis studies in bitter guard (*Momordica charantia* L.) at the Vegetable Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar, during spring-summer seasons of 2013-15. They took eight inbred lines of bitter gourd viz. PDM, VNR-28, VNR-22, MC-84, Pant Karela-1, US-33, Pant Karela-3 and PBIG-2 and make crosses in diallel fashion excluding reciprocals. They recorded the highest amount of standard heterosis for number of fruits per plant and fruit yield per plant in crosses VNR 22 × MC 84 (139.44 %) and US 33 × Pant Karela-3 (26.40 %).

Mallikarjunarao et al. (2018) investigated heterosis for quality and fruit yield of bitter gourd (*Momordica charantia* L.) with eight inbred lines of bitter gourd namely, Phule Green Gold (P1), Improved Katahi (P2), Hikani (P3), CO-1 (P4), Nakhara Local (P5), Preethi (P7), and Pusa Do Mausami (P8). The experiment was done at Orissa University of Agriculture and Technology, Bhubaneswar during Summer season of 2016. It was found that best hybrids, based on standard heterosis for fruit yield per vine and quality traits were Phule Green Gold × Pusa Do Mausami, Phule Green Gold × Preethi and Preethi × Pusa Do Mausami.

Singh et al. (2018) experimented on the manifestation of heterosis in bitter gourd using seven diverse parental lines viz., Kerala White, BG-1346501, Pusa Vishesh, Meghna-2, Itki, Special Boulder and Murhu at Central Research Farm, Gayeshpur, Bidhan Chandra Krishi Viswavidyalaya, Nadia, and West Bengal, and noted that among 10 F₁ hybrids, Meghna-2 × BG-1346501 and BG-1346501 × Special Boulder were recorded to be the two best performing F₁ hybrids for fruit yield per plant.

Acharya et al. (2019) conducted an experiment on heterosis in bitter gourd (*Momordica charantia* L.) at the Horticulture Farm, Department of Horticulture, Rajasthan College of Agriculture, Udaipur and Farmer field of Chittaurgarh district during *kharif* and *zaid* season of 2012-2013 and 2013-14, with ten parents of bitter gourd namely Solan Hara, Pusa Do-Mousmi, BG-14, Green Long, MDU-1, IC-85605, IC-45346, IC-68272-1, IC-68237 and Solan Collection and their 45 crosses along with check viz., Jhalri, US-6214 and US-6203. Heterobeltiosis for fruit yield per vine (kg) was recorded in IC 85605 × IC 45346 (38.94 %) and MDU 1 × IC 85605 (34.98 %) over the environments.

Singh et al. (2020) studies genetic magnitude of heterosis for yield and quality traits in bitter gourd (*Momordica charantia* L.) at the Vegetable Research Farm, Department of Horticulture, Banaras Hindu University, Varanasi (UP) during *Kharif*-2016, *Kharif*-2017 and *Kharif*-2018, with 15 diversified genotypes, three testers and their commercial check (Pusa Do Mausami) to developed 45 hybrids. Among the parents, OBGCBR-2 and IC-085611 have performed as superior genotypes for heterosis. Highest degree of heterosis for most of the traits i.e., earliness and fruit yield traits were registered in desired direction in the hybrid OBGCBR-2 × Jaunpuri Green. Estimation of standard heterosis in cross OBGCBR-1 × IC-085611 recorded desired relative heterosis for days to 50 % pistillate flowering. Heterosis for node at which 1st pistillate flower appears was in the desired direction in cross OBGCBR-2 × Jaunpuri Green for standard check and; hybrid Meghna × Jaunpuri Green for relative heterosis and heterobeltiosis. Hybrids Katehi × IC-085612 exhibited negative and significant relative heterosis and heterobeltiosis for internodal length.

Kumari et al. (2020) studied estimation of heterosis for yield and quality traits in bitter gourd (*Momordica charantia* L.) at the research farm, Department of Horticulture (Vegetable and Floriculture) of Bihar Agricultural College, Sabour, Bhagalpur (Bihar) during two summer season of 2016 and 2017. and they found that the cross-combination Pusa Ausadhi × BRBT Local exhibited maximum heterosis over standard check for yield and yield attributing a trait-like number of primary branches, vine length, fruit length and

fruit weight. In the case of quality parameters, BRBT Local \times Konkan Tara exhibits the highest magnitude of heterosis for ascorbic acid and chlorophyll content.

Kumari et al. (2020) conducted an experiment on the study of heterosis in bitter gourd (*Momordica charantia* L.) for yield and yield-related traits at Sabour Farm, Department of Horticulture (Vegetable and Floriculture), Bihar Agricultural University, Sabour, Bhagalpur and they found significant differences Rasdar, Karela Safed \times Pusa Rasdar and Konkon Tara \times Gangajali Small showed the highest heterosis with 45.65 %, 39.13 % and 35.65 % respectively for fruit yield per plant over check parent Pusa Rasdar. Based on per se performance and high magnitude of heterosis for yield and yield contributing characters, the hybrids Gangajali Small \times Pusa Rasdar (P6 \times P7), Karela Safed \times Pusa Rasdar (P5 \times P7) and Konkon Tara \times Gangajali Small (P2 \times P6) were identified as ideal cross combinations and can be used for the development of improved commercial lines.

Kumar et al. (2020) investigates a line \times tester analysis for estimation of heterosis in bitter gourd (*Momordica charantia* L.) at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, during *Kharif* season of 2017 and 2018, involving 28 cross combinations developed from seven lines and four testers. The result is among the hybrids, the crosses Jaunpuri Green \times Shaktigopal Local, IC085611 \times OBGCS-1, Preethi \times OBGCS-2 and Katheri \times Shaktigopal Local exhibited high *per se* performance as well as high economic heterosis for earliness in flowering with the first female at the lowest node. The cross combinations Katheri \times BGCV-2, Katheri \times OBGCS-1 and Katheri \times OBGCS-2 were found best which expressed significant positive heterosis over mid parent (50.52, 31.62 and 27.06 %), over better parent (37.99, 18.03 and 15.86 %) and over standard parent (47.98, 26.57 and 24.24 %) respectively for total fruit yield.

Kumar et al. (2020) carried out an investigation on studies on effect of heterosis on fruit characters and yield in bitter gourd (*Momordica charantia* L.), and noted that from the study at the Vegetables Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, during *Kharif* season of 2017 and 2018. the cross Jaunpuri Green \times OBGCS-1 exhibited highly significant and positive heterosis over mid parent, better parent as well as standard check. and also, the top three performing hybrids which recorded a higher value of a mean, as well as high percentage of

heterosis, were Meghna \times BGCV-2, Meghna \times OBGCS-2 and Katheri \times OBGCS-2 in the case of total soluble solids. The cross combinations Katheri \times BGCV-2, Katheri \times OBGCS-1 and Katheri \times OBGCS-2 were found to be the best which expressed significant positive heterosis over mid parent (50.52, 31.62 and 27.06 %), better parent (37.99, 18.03 and 15.86 %) and standard parent (47.98, 26.57 and 24.24 %), respectively for total fruit yield.

Naik et al. (2020) conducted an experiment on heterosis studies in bitter gourd (*Momordica charantia* L.) for yield and yield attributes at Bagusala Instructional Farm, M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralekhemundi, Odisha and they found the F₁ crosses Galaxy (Selection 9) \times Special Bolder Uccha had identified most important parameter like the number of fruits per vine and yield per vine. The crosses Shivam (Selection 12) \times Special Bolder Uccha, Galaxy (Selection 9) \times Meghdut Korola and Galaxy (Selection 9) \times Special Bolder Uccha were noted to be the top-performing crosses concerning earliness and yield parameters.

2.2 Combining abilities

The most important need for the production of a high producing and promising hybrid is genetically superior parents. The concept of combining ability has been a powerful and effective method for selecting desirable parents for better hybrids. Combining ability or productivity in crosses is defined as the cultivars or parents' ability to combine among each other during the hybridization process such that desirable genes or characters are transmitted to their progenies. In another definition, combining ability is an estimation of the value of genotypes based on their offspring performance in some definite mating design (**Allard, 1960**). **Sprague and Tatum (1942)** proposed the concept of combining ability as a measure of gene action type while exploring the relative importance of general combining ability in corn. They defined general combining ability (gca) as the average performance of a line in a hybrid combination, whereas specific combining ability (sca) referred to cases in which a specific combination performed relatively better or worse than would be expected based on the average performance of the line involved.

It can seldom be envisaged only based on parental phenotype and thus it is measured by progeny testing. When parental plants produce potent offspring, they are said to have a good combining ability (**Vasal et al., 1986**).

At first, combining ability was a general concept used collectively for classifying an inbred line respective to its cross performance but was later amended. Two concepts of general combining ability (gca) and specific combining ability (sca) have had an important influence on inbred line evaluation and population development in crop breeding (**Sprague and Tatum, 1942**). Sprague and Tatum defined gca as the average performance of a genotype in a series of hybrid combinations. They defined sca as those cases in which certain hybrid combinations perform better or poorer than would be expected based on the average performance of the parental inbred lines. Parents showing a high average combining ability in crosses are considered to have good gca while if their potential to combine well is bounded to a particular cross, they are considered to have good sca. Brief reviews present on the combining abilities in bitter gourd are described below.

Bhave et al. (2004) study combining ability in bitter gourd (*Momordica charantia* L.). Combining ability analysis was carried out in bitter gourd involving six parents and their 15 F₁ progenies obtained through half diallel crossing. The experiment was conducted during rabi, 1997-98 at Research Farm, Department of Agril. Botany, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. Among parents, Konkan Tara and Priya were the best general combiners for fruit yield and the number of fruits per plant. The cross RHR-1 × Priya was the best specific combination for yield and other yield contributing characters.

Sundharaiya and Venkatesan (2007) experimented on studies on combining ability in bitter gourd (*Momordica charantia* L.) including five lines, MC 13 (L1), Panruti Local (L2), Ayakudi Local (L3), Long Green (L4) and Mithipagal (L5) and three testers, viz., Co-1 (T1), VK-1 Priya (T2) and Arka Harit (T3), and indicated that the lines MC 13 (L1) and Panruti Local (L2) were good general combiners for yield per vine. The lines Ayakudi Local (L3) and Mithipagal (L5) recorded negative general combining ability and lower *per se* for days to first female flowering and days to fruit maturity. This can be utilized in breeding programmes to develop earliness in bitter gourd. The hybrids MC 13 × Arka Harit (L1 × T3), Panruti Local × VK 1 Priya (L2 × T2) and MC 13 × Co 1 (L1 × T1) registered higher *per se* and specific combining ability for fruit length, individual fruit weight and yield per vine. The lines L1, L2, L3 and L5 expressed higher *per se* and general combining ability for most of the characters can successfully be utilized for developing superior hybrids in bitter gourd hybrid development programmes.

Verma *et al.* (2013) studied combining ability and gene action in indigenous bitter gourd (*Momordica charantia* L.), involving 12 lines and 3 testers and their 36 hybrids tested into two seasons, namely summer (S) season and rainy (R) season 2010 at the Research Farm of Department of Vegetable Science, ND University of Agriculture & Technology, Kumarganj, Faizabad, UP, India. Parental lines NDBT-13, NDBT-15 and NDBT-19 were identified as superior donor for both seasons and NDBT-10 for summer season and among the testers Kalyanpur Sona for summer season and Pusa Do Mausami for rainy season for fruit yield per plant and its yield contributing traits like number of fruits per plant and average fruit weight. Eight crosses displayed desirable significant sca effects in both seasons for fruit yield per plant. Among these eight crosses the best cross combinations based on desirable sca effects for fruit yield per plant were NDBT-19 \times Pusa Do Mousami in summer season while NDBT-8 \times Pusa Do Mousami, NDBT-15 \times NDBT-12 and NDBT-10 \times Pusa Do Mousami in rainy season.

Singh *et al.* (2013) did an experiment on combining ability analysis in bitter gourd (*Momordica charantia* L.) for twenty-one crosses along with their parents to study heterosis for eight yield and yield components in bitter gourd at the experimental farm of the ICAR RCER Research Centre, Ranchi, and observed that HABG-30 was found to be a good general combiner for most of the characters (yield per plant, yield ton per ha, fruit weight, fruit length, fruit breadth and vine length). HABG-24 \times HABG-30 exhibited a significant SCA effect for all characters except days to 50% flowering and HABG-23 \times HABG-34 showed a significant SCA effect for number of fruits per plant, yield per plant, yield per ha and vine length.

Shukla *et al.* (2014) studied combining ability analysis in bitter gourd using gynoecious lines at Experimental Farm of IIVR, Varanasi in a randomized block design with three replications during rainy season of 2011. They observed that gynoecious line Gy323 was the best combiner for all the traits except fruit diameter and seeds per fruit, whereas monoecious line DRAL-4I was best general combiner for first flower anthesis and internodal length as they have made a significant contribution in yield contributing characters. The gynoecious combination Gy333 \times DRAL41, Gy323 \times DVBTG-7 and Gy323 \times VRBT- 904 exhibited a high sca effect for all traits in the desired direction.

Kandasamy (2015) evaluated twenty F_1 hybrids of bitter gourd in a diallel set involving five parents including reciprocals were evaluated to assess the extent of hybrid vigour in the yield contributing traits. Appreciable amount of heterosis was observed for all the characters under this study except node number of first female flower. The F_1 hybrids $P_5 \times P_3$ (Panruti local \times VK-1 Priya), $P_4 \times P_2$ (MC -13 \times Arka Harit) and $P_2 \times P_1$ (Arka Harit \times CO-1) were observed best performing for yield and they showed 46.21, 29.31 and 14.30 heterosis, respectively over better parent Arka Harit (P_2).

Bhatt et al. (2017) conducted research on combining ability studies in bitter gourd (*Momordica charantia* L.) for quantitative characters with nine diverse genotypes of bitter gourd, during *Kharif* 2015 in a RBD with three replications at Horticulture Farm, S. K. N. College of Agriculture, Jobner Rajasthan. They found three best crosses were, namely Panipat Local \times Phule Green, Phule Green \times Pusa Do Mausami and Punjab-14 \times Pusa Do Mausami. Panipat Local \times Phule Green was superior in respect of days taken to the opening the first female flower, vine length, days to first fruit harvest, fruit length. Phule Green \times Pusa Do Mausami was superior for fruit length, fruit weight, fruit diameter and total fruit yield per vine. Punjab-14 \times Pusa Do Mausami was better with regard to superior for number of nodes at which first female flower appeared, number of fruits per vine and days to first fruit harvest. Hence could be further evaluated in the future breeding programmes for their large-scale testing.

Khan et al. (2017) experimented with combining ability studies in bitter gourd (*Momordica charantia* L.), investigation was carried out during 2015- 16, in three environments viz., *Kharif*, 2015 (E1), Summer 2016 (E2) and *Kharif*, 2016 (E3) at Horticulture farm, Rajasthan College of Agriculture, Udaipur (Rajasthan), with 12 inbred lines (as females), 3 testers (as male) and 36 crosses and they noted that the inbred lines L9, L2 and L4 exhibited positive significant gca effects indicating their good general combining ability for yield per vine and other yield contributing characters. Among the testers, T1 was considered a good general combiner for yield, fruit length, fruit weight, number of primary branches, number of fruits per vine and ascorbic acid content.

Mishra and Singh (2018) conducted an experiment on combining ability studies in bitter guard (*Momordica charantia* L.) at the Vegetable Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar, during spring-summer

seasons of 2013-15. They took eight inbred lines of bitter gourd viz. PDM, VNR-28, VNR-22, MC-84, Pant Karela-1, US-33, Pant Karela-3 and PBIG-2 and make crosses in diallel fashion excluding reciprocals. The best parents with desirable and significant GCA effects may be used in the hybrid breeding programmes for developing high yielding hybrids in bitter gourd.

Mallikarjunarao *et al.* (2018) investigated combining ability for quality and yield of bitter gourd (*Momordica charantia* L.), with eight inbred lines of bitter gourd namely, Phule Green Gold (P1), Improved Katahi (P2), Hikani (P3), CO-1 (P4), Nakhara Local (P5), Preethi (P7), and Pusa Do Mausami (P8), were sown at All India Co-ordinated Research Project on Vegetable Crops, Orissa University of Agriculture and Technology, Bhubaneswar during Summer, 2016. It was found parent Preethi for flesh thickness, Pusa Do Mausami for TSS, and Phule Green Gold for vitamin C, iron content, and fruit yield per vine showed the highest gca effects specific combining ability analysis, revealed that hybrids Improved Katahi × Preethi for flesh thickness; Preethi × Pusa Do Mausami for TSS; Thusi × Pusa Do Mausami for vitamin C; Phule Green Gold × Pusa Do Mausami for iron content and fruit yield per vine showed highest sca effects.

Acharya *et al.* (2019) where conducted an experiment on combining ability study in bitter gourd (*Momordica charantia* L.) with ten parents of bitter gourd Solan Hara, Pusa Do - Mousmi, BG-14, Green Long, MDU-1, IC-85605, IC-45346, IC-68272-1, IC-68237 and Solan Collection and their 45 crosses. Good general combiners for various economic traits were IC- 68237 for the number of primary branches per vine (0.09), fruit length (0.52), fruit diameter (0.17) & the number of fruits per vine (0.22) over the pooled environments. SCA for economic traits was observed in Solan Collection × IC 68237 (1.24) for the number of fruits per vine, IC 68237 × MDU-1 for fruit length (1.82) and fruit weight (7.81).

Mishra *et al.* (2020) carried out an investigation on combining ability studies for yield and plant characters in bitter gourd (*Momordica charantia* L.) at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during the *Kharif* season of 2017-2018. They used 30 hybrids which were derived by crossing ten lines with three testers, they recorded lines IC-085612, OBGCS-4 and Katehi was found to be good general combiners for earliness characters as

well as for fruit yield. Among the hybrids, the crosses OBGCS-4 × Preethi, IC-085612 × Katheri, Katehi × Meghna and Jaunpuri Green × Meghna exhibited high SCA effects for earliness in flowering with the first female at lowest node.

Malve et al. (2021) studies on combining ability in bitter gourd (*Momordica charantia* L.) using seven genotypes and 21 crosses which were obtained in diallel fashion (without reciprocals) at Instructional-Cum-Research Farm, Department of Horticulture, College of Agriculture, Latur. The selected parental lines such as Phule Green Gold (P1), Preethi (P2), Arka Harit (P3), Co-white Long (P4), DVBTG-7 (P5), Hirkani (P6) and Konkan Tara (P7). and they conclude the parent Phule Green Gold (P1) was found good combiners and has high SCA effects for most of the characters. The four crosses viz., P1 × P2 (Phule Green Gold × Preethi), P2 × P5 (Preethi × DVBTG-7), P1 × P3 (Phule Green Gold × Arka Harit) and P6 × P7 (Hirkani × Konkan Tara) have recorded high positive SCA effect as well as high mean performance for most of the characters.

Mishra et al. (2021) investigated combining ability estimates for yield and quality traits in line × tester crosses of bitter gourd (*Momordica charantia* L.) at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during the year 2017-2018, by using 13 parents comprised of ten lines i.e., Katehi, IC-085612, BGCV-2, OBGCS-4, OBGCS-2, OBGCS-3, Jaunpuri Green, Shaktigopal Local, OBGCS-1, IC-085611, and three testers, namely Katheri, Preethi and Meghna, and observed the lines IC-085612, Jaunpuri Green, IC-085611 and Katehi were found to be good general combiners for fruit yield as well as for quality parameters. Among 30 cross combinations, the crosses IC-085611 × Meghna, OBGCS-1 × Katheri and Jaunpuri Green × Meghna exhibited high sca effects for various yields and their attributing traits.

Kundu et al. (2021) studied on Combining ability analysis in bitter gourd (*Momordica charantia* L.) for potential quality improvement for 19 characters were estimated from a 6×6 full diallel analysis technique. The results revealed that the variances due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for most of the important characters. It indicated the importance of both additive and non-additive gene actions. GCA variances were higher in magnitude than SCA variances for all the characters studied indicating the predominance of the additive

gene effects in their inheritance. The parent P2 (BG 009) appeared as the best general combiner for earliness; P1 (BG 006) for number of fruits, average single fruit weight and fruit yield; P4 (BG 027) for node number of first female flower and days to seed fruit maturity; P3 (BG 011) for fruit length and thickness of the fruit flesh; P5 (BG 033) for 100-seed weight; and P6 for number of nodes per main vine. The SCA effect as well as reciprocal effect was also significant for most of the important characters in different crosses.

Naik et al. (2022) conducted an experiment on combining ability studies in bitter gourd (*Momordica charantia* L.) for yield and yield attributes at Bagusala Instructional Farm, Department of Horticulture, M. S. Swaminathan of School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Odisha. It comprised of five genetically diverse parents viz., Shivam (Selection 12), Galaxy (Selection 9), West Godavari (short), Special Bolder Uccha and Meghdut Korola. All the thirteen characters indicated West Godavari (short) and Special Bolder Uccha are the good general combiners. Similarly, evaluation of hybrids revealed Galaxy (Selection 9) × Special Bolder Uccha, Galaxy (Selection 9) × Meghdut Korola and West Godavari (short) × Meghdut Korola are considered as the best specific combiners.

2.3 . Gene action

The knowledge of the nature and magnitude of gene effects controlling inheritance of characters related to productivity would add to the choice of efficient breeding methods and thus accelerated the pace of its genetic improvement and also break the yield barriers. **Griffing (1956)** suggested combining ability analysis, to estimate the type of gene action governing the inheritance of important metric traits in crop plants. The genotype variance obtained from such studies can be subdivided into variance due to general combining ability (gca) and specific combining ability (sca). These studies further led to the estimation of the type of gene action controlling the characters under observation.

Sprague and Tatum (1942) postulated that general combining ability was largely the results of additive gene action while specific combining ability was the result of dominance, epistasis and genotype × environment interaction. **Griffing (1956)** suggested that gca includes both additive effects as well as additive × additive interaction.

The high yielding lines may not necessarily be able to transmit their superiority to their hybrids (**Allard, 1960**). Hence an estimate of gca and sca effect may be a more reliable test rather than the *per se* performance of the lines.

Fisher (1918) divided the genotypic variance into three components i.e., additive, dominance and epistatic components. Additive components arise from differences between the two homozygotes for a gene e.g. AA and aa. Dominance component is due to the deviation at the heterozygote (Aa) from the average of the two homozygotes (AA and aa). This is sometimes referred to as inter-allelic interactions. The epistatic component results from interaction between the two or more genes.

Hayman and Mather (1955) partitioned the epistatic components into three types of interaction viz., additive \times additive, additive \times dominance and dominance \times dominance. The digenic interaction can be classified into two major categories viz.

1. Complementary type interaction: This involves the two non-allelic genes complementating each other to produce a new phenotype which is not ascribable to them individually. They mutually reinforce each other effects. Such a variation is created by the interaction of two homozygotes for the two genes, each acting additively, i.e. additive \times additive interaction (AA). Complementary epistasis (9 : 7), recessive epistasis (9 : 3 : 4) and polymerism (9 : 6 : 1) fall in this category of interaction.

2. Duplicate type interaction: This involves the two non-allelic genes which tend to cancel or weaken the effects of each other when they occur in combination (hybrid). They act in opposite directions hence dilute each other's effects. Such a variation arises from an interaction between a homozygote and a heterozygote or between two heterozygotes. Accordingly, they are termed as additive \times dominance (AD) and dominance \times dominance (DD) epistatic interactions, respectively. Inhibitory factors (13: 3), dominant epistasis (12: 3: 1) and duplicate factor (15: 1) represent duplicate type of non-allelic interaction.

To detect complementary or duplicate epistasis, the signs associated with D and DD are compared. When both D and DD components show the same sign, either (+) or (-), then it is complementary epistasis. When one shows (+) and other (-) sign, then the epistasis is duplicate type. It should be further recognized that the complementary epistasis (AA) is fixable, duplicate epistasis is not. So are the additive (A) and dominance deviations (D), respectively.

The expression of a polygenic trait is under the control of additive and non-additive types of gene action. Simple progeny selection is useful to bring about the genetic improvement of the traits largely governed by additive gene action, while for those traits which are predominantly under the control of non-additive gene action, heterosis breeding is considered to be appropriate. Brief reviews present on the gene action in bitter gourd are described below.

Verma *et al.* (2013) studied on gene action in indigenous bitter gourd (*Momordica charantia* L.) involving 12 lines and 3 testers and their 36 hybrids tested in two environments viz., summer and rainy season 2010 at Research Farm of Department of Vegetable Science, N. D. University of Agriculture & Technology, Kumarganj, Faizabad, UP, India. Among these eight crosses the best cross combinations based on desirable sca effects for fruit yield per plant were NDBT-19 \times Pusa Do Mousami in summer season while NDBT-8 \times Pusa Do Mousami, NDBT-15 \times NDBT-12 and NDBT-10 \times Pusa Do Mousami in rainy season. These crosses have more number of fruits per plant, average fruit weight, fruit diameter and other component traits in both seasons.

Rani *et al.* (2013) study of gene effects for yield and its component traits in bitter gourd (*Momordica charantia* L.) by generation mean analysis at Model orchard, College of Horticulture, Rajendranagar, Hyderabad during summer 2011, involving six generations (P1, P2, F1, F2, BC1 and BC2). The results revealed the presence of additive, dominance gene effects and epistatic interactions for all the characters except for vine length in cross IC-470550 \times IC-470558 indicating the importance of both additive and non-additive gene actions in the expression of the characters. The greater magnitude of dominance gene effect as compare to additive effect for most of the traits suggest that heterosis breeding may be more useful. Biparental mating which could exploit both additive and non-additive type of gene effects is also suggested for the improvement of the traits in bitter gourd.

Saha *et al.* (2021) conducted an experiment on Genetic expression of fruit physico-chemical characters in bitter gourd inter-specific crosses at Central Research Farm, Gayeshpur, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, utilizing two contrasting crosses involving botanical varieties of bitter gourd. The dominance \times dominance interaction effect was larger than the additive \times additive effect. Duplicate epistasis in both crosses indicated hindrance in advancement through selection. Most

characters are under control of non-additive gene action, and the magnitude of additive component was lower than dominance \times dominance component; selection for most characters might be difficult. Dominance estimates indicated there would be less likelihood of isolating genotypes with fruit of increased size and having high β -carotene content from the crosses involving small-fruited *M. charantia* var. *muricata* Willd. as a parent because small fruit exhibited dominance. There would be a possibility of isolating genotype with fruit having high ascorbic acid content in segregating generations of these cross combinations. Selection for improvement of fruit physico-chemical characters should be delayed to later generations of segregating populations in bitter gourd. The modified bulk method of selection is recommended, in which selection is performed after attaining homozygosity for maximum heterozygous loci.

Shukla et al. (2014) conducted an experiment on Genetic analysis of yield and yield attributing traits in bitter gourd at the Indian Institute of Vegetable Research, Varanasi, crosses of gynoeocious \times monoecious. Progeny (F_1 , F_2 , and F_3) from a cross between gynoeocious lines (Gy333 and Gy323) and monoecious line DRAR-1 were used in the present study. The additive \times dominance and dominance \times dominance interaction effects were noted in most of the crosses for the entire traits. The joint scaling test showed that cross Gy333 \times DRAR-1 and Gy323 \times DRAR-1 showed significant epistatic gene effects. χ^2 value was significant for all traits except days to first flowers and anthesis, plant height, internodal length, fruit/ plant seeds/fruit and yield/plant showed non-significant χ^2 value hence the additive – dominance model. In cross Gy323 \times DRAR-1, χ^2 value was significant for all traits except yield/ plant. Both additive and dominance components were significant for most of traits. These traits showed duplicate type of epistasis for the above crosses. The development of early flowering genotypes possessing desirable fruit weight characteristics, however, will likely be complicated by inheritance of gynoeocious in dominance and epistatic effects. Positive additive \times additive is indicating the possibility of obtaining transgressive segregants in later generations, whereas dominance \times dominance gene effects indicated a duplicate epistasis which will be undesirable for selection and genetic improvement in gynoeocious bitter gourd.

Alhariri et al. (2020) did an experiment on Gene action and combining ability analysis for horticultural traits in bitter gourd involving, one gynoeocious and seven monoecious diverse bitter gourd genotypes viz., PDMGy-201 (gynoeocious), S-54, S-2,

Pusa Do Mousami (PDM), Pusa Vishesh (PV), S-32, Pusa Aushadhi (PA), and S-57 were selected and crossed during kharif (August-November, 2015) in diallel mating design (without reciprocal) to develop 28 F1 crosses at the experimental field of Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi during spring-summer (February to May 2016) with prescribed agronomic practices. The role of cumulative effect of additive and additive \times additive gene effects were found in the crosses PDMGy-201 \times S-54 for number of days to first female flower and S-2 \times PDM for yield per plant which had high per se performance with significant sca effects and both the parents of these crosses were good general combiners. The role of dominant gene action denoted in high performed crosses resulted from a combination between one good and one poor general combiner parent such as PDMGy-201 \times S-2 for sex ratio, S-32 \times PA for fruit length, S-54 \times S-57 for fruit diameter, S-54 \times S-57 for flesh thickness, S-2 \times PA for number of fruits per plant, PDMGy-201 \times PDM for average fruit weight and PDMGy-201 \times PV for yield per plant.



Materials
and
Methods



Chapter-3

MATERIALS AND METHODS

The details of materials used and experimental methodology followed during the course of present investigation entitled “**Study on heterosis breeding, combining ability and gene action in bitter gourd (*Momordica charantia* L.)**” have been described in this chapter.

3.1. Experimental site

The present experiment be carried out at Vegetable Research Centre (VRC) of the G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand during summer season of 2022. The university is geographically situated at latitude of 29⁰ North, longitude of 79.30⁰ East and at the altitude of 243.84 meter above the mean sea level. Pantnagar fall under the humid sub-tropical zone, at the foothills of *Shivalik* range of the Himalayas and North of the Indo-Gangatic plain, this narrow belt known as *Tarai*.

3.2. Climatic conditions

The state Uttarakhand falls under the agro-climatic zone-I i.e. Humid Western Himalayan region. Pantnagar is situated in the Southern part of Uttarakhand. The climate of the region is humid sub-tropical climate with large variation in summer and winter temperature. The summer season extends from April to June and the winter season generally extends from October to February. The average annual temperature is 26.2 °C. At an average temperature of 33.4 °C, May is the hottest month of the year and at 18.8 °C on average, January is the coldest month of the year. During the period of July to September, lies the monsoon season, it starts from third week of June and it prolongs up to the end of September with highest in July. The mean relative humidity remained 80-90 percent during March-April.

3.3. Soil characteristics

Moderately fertile sandy loam soil of Pantnagar comes under soil order Mollisols. The mollisoil is rich in calcium, magnesium and organic matter, often dark in colour and has a fine to medium texture with 6.0 to 6.5.

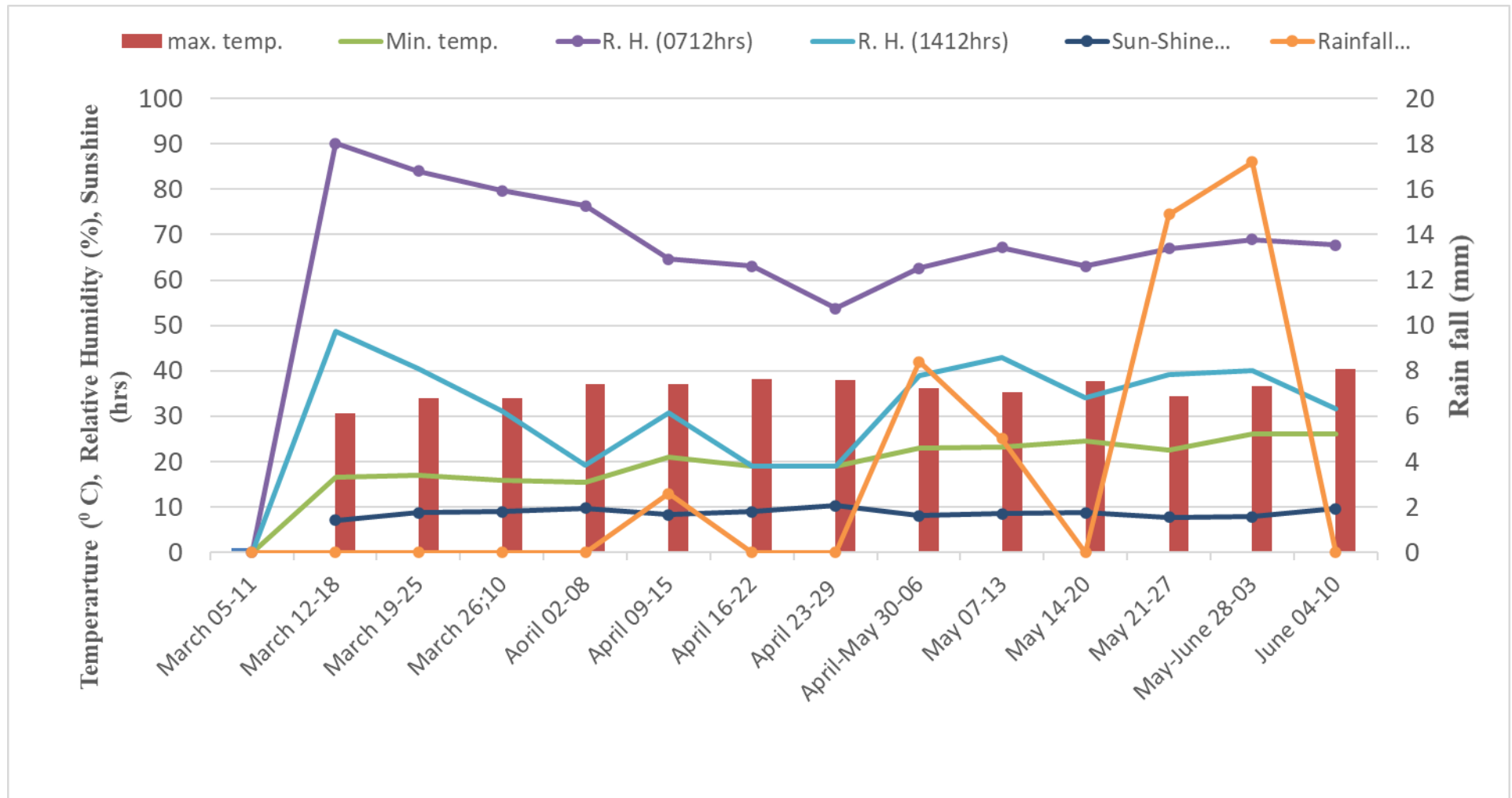


Fig 3.1: Average weekly meteorological condition during the spring-summer season, 2022

3.4. Experimental Material

The experimental material for this study consists of six genotypes which were selected based on the previous year experiment for their diversity of various traits. From these six genotypes, 15 crosses evolved in half diallel mating design (excluding reciprocals). The parents selected for study were as follows:

Table 3.1: List of parents with source and features

Sl. No.	Name of the genotype	Source	Features
1	PBIG – 3/21	IARI, New Delhi	Dark green, spindle shape with discontinuous ridges
2	PBIG – 6/21	Pantnagar, Uttarakhand	Dark green, cylindrical shape with continuous ridges
3	PBIG – 8/21	Varanasi, UP	Light green, spindle shape with continuous ridges
4	PBIG – 9/21	Ghazipur, UP	Dark green, spindle shape with continuous ridges
5	PBIG – 10/21	Lucknow, UP	Light green, spindle shape with discontinuous ridges
6	PBIG – 18/21	Pantnagar, Uttarakhand	Light green, spindle shape with continuous ridges

3.5. Maintenance of parental lines and generation of F₁s

The six parental lines were grown during the winter season of 2021 in naturally ventilated polyhouse and the crosses were made in half diallel combination (excluding reciprocal crosses). Since bitter melon is monoecious in sex expression and bears selfing and crossing is not difficult. Being monoecious in nature it bears staminate (single) and pistillate (single) flowers separately in leaf axils. Maintenance of parental lines were done simply selfing of the true to type plant. Male and female mature flower buds of same plant, which likely to be open by next morning were bagged during evening of previous day with butter paper bags. For selfing the pollen from the bagged male flowers of same plant was dusted on to the stigma of bagged female flower of the receptive female flower of same plant, for maximum fruit setting pollination was done between 6.00 AM to 8.30 AM. However, for crossing male and female mature flower buds of different parental lines (involved in crossing programme), which likely to be open by next morning were bagged

during evening of previous day with butter paper bags. For crossing the pollen from the bagged male flowers was dusted on to the stigma of bagged female flower of the receptive female parents. The pollinated flowers were labelled with paper tags and covered again with the butter paper bag. The paper bags were removed on the next day so as to allow normal fruit development. After maturing the fruits, dry seeds of each cross combination were collected separately and kept in the desiccators for sowing in the next season (summer season, 2022).

3.6. Experimental details and crop raising

The 15 F₁ hybrids along with their six parental lines (21 genotypes) were evaluated in summer season of 2022. The experiment was laid out in Randomized Complete Block Design with three replications. Row to row and plant to plant distance were maintained at 150 cm and 50 cm respectively. Fifteen centimetre deep, one-metre-wide channels were made and the hills were prepared on North side of these channels. This system of growing cucurbits is useful in many ways. Firstly, in summer season less water is required for irrigation as the water is applied in these channels only i.e., efficient use of irrigation water, while in rainy season these channels help in drainage of excess rain water. Secondly, as the whole field does not get wet, there is less weed problem, less occurrence of insect-pests and diseases. Thirdly, as the fruits do not touch the wet ground surface, therefore fruit rot and yellow patches are also reduced drastically.

The recommended NPK fertilizer doses (100: 50: 50 kg/ha, respectively) and cultural practices along with plant protection measures were followed to raise an ideal crop. The fruits were harvested at tender and edible stage, for recording the observations. Five plants were selected after discarding the border plants at both ends and were examined for 16 horticultural traits. The seed sowing was done on 11th March, 2022. Initially, 3-4 sprouted seeds were sown at each hill and when the seedlings were 12-15 cm of height, thinning was done to retain only one plant per hill.

3.7. Observations to be recorded:

All the observation were recorded on the basis of five plants of a genotype in each replication. The observations made on the five plants for 16 quantitative traits, were summed up and divided by five to get the mean value. The observations were recorded for following traits.

3.7.1. Days to anthesis of first male flower

The number of days taken from sowing to the opening of the first male flower appeared was recorded, and average was calculated.

3.7.2. Days to anthesis of first female flower

The number of days taken from sowing to the opening the first female flower appeared was recorded.

3.7.3. No. of nodes to first male flower

Node number from the base of the plant, to which the first male flower appeared was recorded.

3.7.4. No. of nodes to first female flower

Node number from the base of the plant, to which the first female flower appeared was recorded.

3.7.5. Days to first harvest

The number of days taken from sowing to harvesting of the first fruit was recorded on five plants and averaged.

3.7.6. Average fruit weight (g)

Five fruits were randomly taken from each genotype (same five fruits selected for fruit length, diameter and circumference) at edible maturity of 4th harvesting and their mean fruit weight was measured in gram.

3.7.7. Average fruit length (cm)

Fruit length was measured on the same five randomly selected fruits on which average fruit weight was recorded. Fruit length was measured in centimetre from the pedicel end of the fruit to the blossom scar point with the help of measuring tape. Total length of five fruits was divided by five to obtain average length of fruit of the genotypes.

3.7.8. Average fruit diameter (cm)

Diameter of fruits was measured on the same five randomly selected fruits on which average fruit weight was recorded. Fruits were cut in almost middle in halves and the diameter was measured in centimetre average was used for calculation.

3.7.9. Main vine length (m)

The trait was recorded by measuring the length of main vine from the base of the plant up to the tip at the time of fourth fruit harvesting in meters on five plants with the help of meter scale and average was determined.

3.7.10. Number of primary branches per plant

The branches arising from the base of plant or from the main stem were considered as primary branches or vines. The number was recorded while measuring the length of vines at the fourth fruit harvesting and averaged from five plants.

3.7.11. Internodal length (cm)

At the final harvesting stage, length of internode between the 6th and 7th was measured at the third fruit harvesting stage and average was calculated.

3.7.12. Main vine diameter (cm)

At the first harvesting stage, diameter of main vine was measured in cm with vernier calliper, and average was calculated.

3.7.13. Number of harvests per plant

Total number of harvests from all five plant was recorded and average was calculated.

3.7.14. Number of fruits per plant

The number of fruits per plant was obtained by adding the number of fruits of four pickings from all five plants in each treatment and average was calculated for the number of number of fruits per plant.

3.7.15. Average fruit yield per plant (kg)

The fruit yield per plant was calculated by totalling the weight of fruits of five plants over all the picking, and average was calculated in kg per plant.

3.7.16. Fruit yield (q/ha)

Total fruit weight of five plants from all harvest was recorded and the mean fruit yield per plant was calculated in kg and then multiplied with 13333.4 (number of plants/ha) to get fruit yield (q/ha).

3.8 Statistical analysis

3.8.1. Analysis of variance

The analysis of variance (ANOVA) for testing the significance of genotypic difference was as applicable to many standard Randomized Complete Block Design (Gomez and Gomez, 1984). The ANOVA table for testing the significance of genotype differences was as follows:

The mean values of 21 genotypes (6 parents and 15 crosses) in each replication for different characters were used for the analysis of variance. The analysis of variance for randomized complete 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 k^{th} replication

m = general population mean

g_{ij} = effect of the ij^{th} genotype, where $i, j, = 1 \dots g$

b_k = effect of the k^{th} replication, where $k = 1 \dots r$

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 variance (SV)	Degree of Freedom	Mean Sum of Square (MSS)	Variance Ratio (F)
Replication	(r-1)	M_r	M_r/M_e
Treatment	(t-1)	M_t	M_t/M_e
Error	(r-1) (t-1)	M_e	

Where,

r = Number of replications

t = Number of treatments

M_r = Mean Sum of Square due to replication

M_t = Mean Sum of Square due to treatment

M_e = Mean Sum of Square due to error

3.8.2. Test of significance

The significance of difference between mean value of different characters were tested by calculating critical difference (CD) as follows

$$CD = \sqrt{\frac{2Me}{r}} \times t$$

Where,

- t = Table value of 't' at error degree of freedom
 r = Number of replications
 Me = Error mean square

3.8.3. Coefficient of Variance (CV)

Standard deviation (SD) expressed as percentage of mean is known as coefficient of variation. It was calculated using the following formula:

$$CV = \frac{SD}{X} \times 100$$

Where,

- SD = Standard deviation
 X = Mean of the character

This statistic is generally used to judge the precision of the experiment. The value less than 25% is usually accepted as normal in field trials.

3.8.4. Estimation of heterosis

The magnitude of heterosis was estimated in relation to better parent and standard parent. They were thus, calculated as percentage increase or decrease of F_1 s over the better parent (BP) and standard parent (SP) using the methods of Turner (1953) and Hayes *et al.* (1956). The formula used for estimation of heterosis given by Fonseca and Patterson (1968) was used.

Increase or decrease of F_1 s over better parent (heterobeltiosis) and standard check (standard heterosis), was expressed in percentage in the following way:

a. Heterosis (%) over better parent (BP) = $\frac{(F_1 - BP)}{BP} \times 100$

b. Heterosis (%) over standard check (SC) = $\frac{(F_1 - SC)}{SC} \times 100$

where,

- F_1 = Mean of the F_1 generation
 BP = Mean of the better parent
 SC = Mean of the standard check

3.8.5. Test of significance

The significance of heterosis was tested by 't' test:

a. Significance over heterobeltiosis

$$t_{(BP)} = \frac{F_1 - BP}{SE}$$

$$SE = \sqrt{2Me/r}$$

b. Significance of standard check

$$T_{(SC)} = \frac{F_1 - SC}{SE}$$

Where,

$$SE = \sqrt{\frac{3Me}{2r}}$$

3.8.6. Estimation of combining ability

Combining ability analysis was carried out according to **Griffing's (1956)**, using **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 data on parents and one set of $F_1 = [n(n+1)/2]$ were analysed, where n is the number of parental lines. The analysis of variance for combining ability was based on the following mathematical model:

$$X_{ij} = \mu + g_i + g_j + S_{ij} + e_{ijk}$$

Where,

- μ = General mean
 g_i = gca effect of i^{th} line;
 $i = 1, 2, \dots, l$
 g_j = gca effect of j^{th} line;
 $j = 1, 2, \dots, j$
 S_{ij} = sca effect of ij^{th} line;
 e_{ijk} = Error associated with the observation
 $k = 1, 2, \dots, r$

The general and specific combining ability sum of squares were calculated as follows:

$$S_g = \frac{1}{p+2} \left[\sum (X_{i.} + X_{ii})^2 - \frac{4}{n} X^2 \dots \right]$$

$$S_s = \sum X_{ij}^2 - \left[\frac{1}{p+2} \sum (X_{i.} + X_{ii})^2 + \frac{2}{(n+1)(n+2)} X^2 \dots \right]$$

Where,

S_g = Sum of squares due to general combining ability

S_s = Sum of squares due to specific combining ability

P = Number of parents

$X_{i.}$ = Total of i^{th} array

X_{ii} = Mean value of i^{th} parent

$X_{..}$ = Grand total of $[n(n-1)/2]$ progenies and parental values

Analysis of variance based on combining ability

Source of variation	DF	Sum squares	Mean sum of squares	Expected mean sum of squares
General combining ability	$p-1$	S_g	$M_g = S_g/p-1$	$\sigma_e^2 + (p+2) (1/p-1) \sum_i g_i^2$
Specific combining ability	$p(p-1)/2$	S_s	$M_s = S_s/[p(p-1)/2]$	$\sigma_e^2 + 2[1/p(p-1)] \sum_i \sum_j S_{ij}^2 \dots$
Error	$(r-1)(g-1)$	S_e	M'_e	σ_e^2

Where,

$$S_g = \text{sum of squares due to gca} = \frac{1}{n+2} \left[\sum (X_{i.} + X_{ii})^2 - \frac{4}{n} X^2 \dots \right]$$

$$S_s = \text{sum of squares due to sca} = \sum X_{ij}^2 - \left[\frac{1}{n+2} \sum (X_{i.} + X_{ii})^2 + \frac{2}{(n+1)(n+2)} X^2 \dots \right]$$

p = number of parents

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

X_{ii} = mean value of the i^{th} parent

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

Estimation of general and specific combining ability effect

1. General combining ability effect of the i^{th} parent,

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

2. Specific combining ability effects of the i^{th} and j^{th} cross,

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

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 i^{th} parent

X_{jj} = mean value of the j^{th} parent

X_{ij} = progeny mean value of $i^{\text{th}} \times j^{\text{th}}$ hybrid

$X_{..}$ = grand total

Σ_e^2 = error variance

Standard error (SE) estimation

SE of effects was estimated as follows:

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

2. SE 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.



Results
and
Discussion



The present investigation entitled “**Study on heterosis breeding, combining ability and gene action in bitter gourd (*Momordica charantia* L.)**” dealing with determination of heterosis, combining ability and gene action was undertaken using six indigenous parental lines and their fifteen F₁ hybrids, developed through half diallel (excluding reciprocals) mating system. Diallel cross analysis provides the estimates of genetic parameters regarding combining ability as well as a rapid overall picture of the dominance relationship of the parents studied using the first filial generations (F₁) with or without reciprocals. Diallel analysis involving parents gives additional information as presence or absence of epistasis, average degree of dominance, distribution of dominant and recessive genes in the parents.

The evaluation was carried out in the summer season of 2022, using a randomized block design (RBD) with three replications at Vegetable Research Centre of G.B.P.U.A.&T., Pantnagar. The twenty-one genotypes were examined for sixteen quantitative traits i.e. days to anthesis of first male flower, days to anthesis of first female flower, node number to first male flower, node number to first female flower, days to first harvest, average fruit weight (g), average fruit diameter (mm), average fruit length (cm), main vine length (m), primary branch per plant, internodal length (cm), main vine diameter (mm), number of harvests per plant, number of fruits per plant, average fruit yield per plant (kg), fruit yield (q/ha). The result obtained after analysing the 6 × 6 diallel data (excluding reciprocals) on various aspects of the experiments are presented under the following subheads:

- 4.1 Analysis of variance for the experimental design
- 4.2 Mean performance and estimates of heterosis
- 4.3 Analysis of variance for combining ability
- 4.4 Estimation of general and specific combining ability effects
- 4.5 Gene action

4.1 . Analysis of variance

Analysis of variance for sixteen horticultural traits namely days to anthesis of first male flower, days to anthesis of first female flower, node number to first male

flower, node number to first female flower, days to first harvest, average fruit weight (g), average fruit diameter (mm), average fruit length (cm), main vine length (m), primary branch per plant, internodal length (cm), main vine diameter (mm), number of harvests per plant, number of fruits per plant, average fruit yield per plant (kg), fruit yield (q/ha), is presented in Table 4.1. It is evident from the table that the mean squares due to genotypes were significant for all the characters, indicating significant difference among the genotypes for all traits. Similar results were reported by **Naik et al., (2020), Kumari et al., (2020), Singh et al., (2020) and Rani et al., (2014).**

4.2 . Mean performance and estimation of heterosis

Development of quality F₁ hybrids with better productivity and adaptability is the main focus of bitter gourd breeding throughout the world. The aim of heterosis study was to identify the best heterotic combinations and its exploitation for commercial purpose. In order to find out suitable parents and cross combinations for sixteen horticultural traits in bitter gourd, range and mean of parents and hybrids, percentage of heterosis over better parent and heterosis over standard parent (Pant Karela-1) were calculated.

Heterosis was calculated in the favourable direction over better parent (BP) and standard parent (SP). The range of mean value of parents, F₁ hybrids and heterosis percentage are presented in Table 4.2.1 to 4.2.16. It would be imperative to mention here that for the characters days to anthesis of first male and female flower, nodal position of first male and female flower, days to first harvest and internodal length, the negative heterosis estimates were considered to be desirable, as it indicates earliness. However, characters like average fruit weight (g), fruit length (cm), fruit diameter (mm), main vine length (m), number of primary branches, number of fruits per plant (kg) and fruit yield (q/ha), the positive heterosis estimates were considered to be desirable, as it indicates more production. The results on mean performance and estimates of heterosis are described for each character separately, as follows:

4.2.1. Days to anthesis of first male flower

The average mean value of the parents for the anthesis of the first male flower varied from 40 days (PBIG-18) to 49 days (PBIG-8 and PBIG-3) (Table 4.2.1). Among the crosses, PBIG-8 × PBIG-10 was the earliest (37 days) followed PBIG-6 ×

Table 4.1: Analysis of variance for different characters (Summer season, 2022)

Sl. No.	Source of Variance	Replication	Genotypes	Error
1.	Degree of freedom	2	20	40
2.	Days to anthesis of first male flower	4.762	33.49 **	11.262
3.	Nodal position of first male flower	0.19	17.97 **	1.49
4.	Days to anthesis of first female flower	8.048	44.58 **	14.948
5.	Node position of first female flower	0.19	30.18 **	1.524
6.	Days to first harvest	6.302	182.13 **	17.79
7.	Fruit weight (g)	255.125	463.79 **	18.572
8.	Fruit length (cm)	3.393	12.45 **	3.758
9.	Fruit diameter (mm)	0.336	46.80 **	2.303
10.	Main vine length (m)	0.01	1.23 **	0.48
11.	Primary branches per plant	0.526	32.59 **	1.874
12.	Diameter of main vine (mm)	0.004	1.35 **	0.01
13.	Internodal length (cm)	0.13	3.65 **	0.09
14.	Number of harvests per plant	0.03	1.24 **	0.215
15.	Number of fruits per plant	3.55	186.88 **	7.460
16.	Average fruit yield per plant (kg)	0.008	1.25 *	0.008
17.	Fruit yield (q/ha)	555.772	22493.10 **	148.856

Table 4.2.1: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for days to anthesis of first male flower in bitter gourd (Summer season, 2022)

Sl. No.	Parents /crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	49.00	-	-
2	PBIG-3	49.00	-	-
3	PBIG-6	44.00	-	-
4	PBIG-9	48.00	-	-
5	PBIG-18	40.00	-	-
6	PBIG-10	45.00	-	-
7	PBIG-8 × PBIG-3	43.00	-12.24 *	-2.27
8	PBIG-8 × PBIG-6	42.00	-4.55	-4.55
9	PBIG-8 × PBIG-9	41.00	-14.58 *	-6.82
10	PBIG-8 × PBIG-18	41.00	2.50	-6.82
11	PBIG-8 × PBIG-10	37.00	-17.78**	-15.91 *
12	PBIG-3 × PBIG-6	42.00	-4.55	-4.55
13	PBIG-3 × PBIG-9	41.00	-14.58 *	-6.82
14	PBIG-3 × PBIG-18	40.00	0	-9.09
15	PBIG-3 × PBIG-10	40.00	-11.11	-9.09
16	PBIG-6 × PBIG-9	39.00	-11.36	-11.36
17	PBIG-6 × PBIG-18	40.00	0	-9.09
18	PBIG-6 × PBIG-10	39.00	-11.36	-11.36
19	PBIG-9 × PBIG-18	40.00	0	-9.09
20	PBIG-9 × PBIG-10	41.00	-8.89	-6.82
21	PBIG-18 × PBIG-10	45.00	12.50	2.27
22	Pant Karela-1 (Check)	44.00	-	-
	Mean		42.19	
	C.V. (%)		7.95	
	S.E. ±		1.94	
	C.D. (5 %)		5.54	
	C.D. (1 %)		7.41	

PBIG-9 and PBIG-6 × PBIG-10 (39 days each) against 44 days of the standard check Pant Karela-1. However, PBIG-18 × PBIG-10 was the late (45 days) for anthesis among the F₁ hybrids, closely followed by PBIG-8 × PBIG-3 (43 days), PBIG-8 × PBIG-6 and PBIG-3 × PBIG-6 (42 days each).

Estimates of heterobeltiosis for this trait were significant for four crosses with range of -17.78 % (PBIG-8 × PBIG-10) to 12.50 % (PBIG-18 × PBIG-10). Out of 15 crosses, four crosses namely PBIG-8 × PBIG-10 (-17.78), PBIG-8 × PBIG-9 (-14.58), PBIG-3 × PBIG-9 (-14.58) and PBIG-8 × PBIG-3 (-12.24) were significant in negative desirable direction. The result on the estimates of standard heterosis, revealed that out of 15 crosses only one cross PBIG-8 × PBIG-10 (-15.91) exhibited a significant value in desirable direction (negative).

4.2.2. Nodal number of first male flower

For the nodal position of the first male flower, the parental mean ranged from 7.0 (PBIG-8) to 13.0 nodes (PBIG-18) (Table 4.2.2). Among the crosses, PBIG-8 × PBIG-10 (5.0) exhibited the lowest node number for this trait, closely followed by PBIG-8 × PBIG-3, PBIG-6 × PBIG-18 and PBIG-18 × PBIG-10 (6.0 node each) against 7.88 nodal position of the standard check Pant Karela-1. The crosses namely PBIG-3 × PBIG-6 (14.0) closely followed by PBIG-9 × PBIG-10 (12.0) and PBIG-3 × PBIG-18 (11.0) show the highest node number for the first male flower.

Estimates of heterobeltiosis for the node position of the first male flower exhibited that among the 15 crosses four crosses PBIG-3 × PBIG-6 (55.56 %), PBIG-9 × PBIG-10 (50.00), PBIG-9 × PBIG-18 (-41.67) and PBIG-6 × PBIG-18 (-40.00) were showed significant heterosis, out of which two crosses (PBIG-9 × PBIG-18 and PBIG-6 × PBIG-18) were in the desirable negative direction. The negative heterosis for this character is desirable as it indicate earliness. For the estimation of standard heterosis eight crosses exhibits significant value, where four crosses were in negative desirable direction. The crosses showing negative standard heterosis value were PBIG-8 × PBIG-10 (-36.55), PBIG-8 × PBIG-3, PBIG-6 × PBIG-18 and PBIG-18 × PBIG-10 (-23.86 each). The highest positive heterosis was shown by PBIG-3 × PBIG-6 (77.66 %), followed by PBIG-9 × PBIG-10 (52.28 %) and PBIG-3 × PBIG-18 (39.59 %).

Table 4.2.2: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for node number to first male flower in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	7.00	-	-
2	PBIG-3	9.00	-	-
3	PBIG-6	10.00	-	-
4	PBIG-9	12.00	-	-
5	PBIG-18	13.00	-	-
6	PBIG-10	8.00	-	-
7	PBIG-8 × PBIG-3	6.00	14.29	-23.86
8	PBIG-8 × PBIG-6	8.00	14.29	1.52
9	PBIG-8 × PBIG-9	8.00	14.29	1.52
10	PBIG-8 × PBIG-18	9.00	28.57	14.21
11	PBIG-8 × PBIG-10	5.00	-28.57	-36.55 **
12	PBIG-3 × PBIG-6	14.00	55.56 **	77.66 **
13	PBIG-3 × PBIG-9	9.00	0	14.21
14	PBIG-3 × PBIG-18	11.00	22.22	39.59 **
15	PBIG-3 × PBIG-10	9.00	12.5	14.21
16	PBIG-6 × PBIG-9	10.00	0	26.90 *
17	PBIG-6 × PBIG-18	6.00	-40.00 **	-23.86 *
18	PBIG-6 × PBIG-10	8.00	0	1.52
19	PBIG-9 × PBIG-18	7.00	-41.67 **	-11.17
20	PBIG-9 × PBIG-10	12.00	50.00 **	52.28 **
21	PBIG-18 × PBIG-10	6.00	-25.00	-23.86 *
22	Pant Karela-1 (Check)	7.88	-	-
	Mean		8.90	
	C.V. (%)		13.71	
	S.E. ±		0.70	
	C.D. (5%)		2.01	
	C.D. (1%)		2.70	

4.2.3. Days to anthesis of first female flower

The mean value of parents for number of days to anthesis of first female flower varied from 43 days (PBIG-6 and PBIG-18) to 53 days (PBIG-10) (Table 4.2.3). However, among the crosses mean value ranges from 39 days (PBIG-8 × PBIG-10) to 48 days (PBIG-8 × PBIG-6, PBIG-3 × PBIG-6 and PBIG-9 × PBIG-10) against 47 days of the standard check Pant Karela-1.

The estimates of heterobeltiosis for days to anthesis of first female flower was significant for two crosses namely PBIG-8 × PBIG-10 (-25.0 %) and PBIG-8 × PBIG-9 (-17.65 %), where both showed desirable negative heterosis for this trait. For standard heterosis, out of 15 only two crosses *viz.* PBIG-8 × PBIG-10 (-17.02 %) and PBIG-6 × PBIG-18 (-12.77 %) showed significant desirable negative heterosis.

4.2.4. Node number of first female flower

With the respect of node position of first female flower among the parental line, PBIG-10 showed lowest nodal position (4.67 node) and PBIG-18 (16 node) had the highest node number (Table 4.2.4). Among the crosses PBIG-8 × PBIG-10 and PBIG-6 × PBIG-10 (6.0 node each) showed lowest nodal position against 11.9 nodal position of the standard check Pant Karela-1. However, cross PBIG-9 × PBIG-10 (15.0 node) recorded highest nodal position for this trait.

The results of heterosis over the better parent for this trait revealed that out of 15 crosses, 10 crosses exhibited significant heterosis. However, no one in negative direction which is desirable. The crosses with highest positive heterobeltiosis were PBIG-9 × PBIG-10 (221.19 %) closely followed by PBIG-3 × PBIG-10 (135.54 %) and PBIG-8 × PBIG-18 (120.00 %).

For the estimates of heterosis over standard variety, nine crosses showed significant standard heterosis in which seven crosses were in negative direction. The crosses showed maximum standard heterosis in desirable negative directions were PBIG-8 × PBIG-10 and PBIG-6 × PBIG-10 (-49.58 % each), the cross combination PBIG-9 × PBIG-10 (26.05 %) showed least standard heterosis in desirable direction.

Table 4.2.3: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for days to anthesis of first female flower in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	52.00	-	-
2	PBIG-3	51.00	-	-
3	PBIG-6	43.00	-	-
4	PBIG-9	51.00	-	-
5	PBIG-18	43.00	-	-
6	PBIG-10	53.00	-	-
7	PBIG-8 × PBIG-3	46.00	-9.8	-2.13
8	PBIG-8 × PBIG-6	48.00	11.63	2.13
9	PBIG-8 × PBIG-9	42.00	-17.65 **	-10.64
10	PBIG-8 × PBIG-18	45.00	4.65	-4.26
11	PBIG-8 × PBIG-10	39.00	-25.00 **	-17.02 **
12	PBIG-3 × PBIG-6	48.00	11.63	2.13
13	PBIG-3 × PBIG-9	47.00	-7.84	0
14	PBIG-3 × PBIG-18	44.00	2.33	-6.38
15	PBIG-3 × PBIG-10	46.00	-9.8	-2.13
16	PBIG-6 × PBIG-9	42.00	-2.33	-10.64
17	PBIG-6 × PBIG-18	41.00	-4.65	-12.77 *
18	PBIG-6 × PBIG-10	44.00	2.33	-6.38
19	PBIG-9 × PBIG-18	42.00	-2.33	-10.64
20	PBIG-9 × PBIG-10	48.00	-5.88	2.13
21	PBIG-18 × PBIG-10	47.00	9.3	0
22	Pant Karela-1 (Check)	47.00	-	-
	Mean		45.81	
	C.V. (%)		8.44	
	S.E. ±		2.23	
	C.D. (5%)		6.38	
	C.D. (1%)		8.54	

Table 4.2.4: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for node number to first female flower in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	5.00	-	-
2	PBIG-3	11.00	-	-
3	PBIG-6	8.00	-	-
4	PBIG-9	9.00	-	-
5	PBIG-18	16.00	-	-
6	PBIG-10	4.67	-	-
7	PBIG-8 × PBIG-3	8.00	60.00 **	-32.77 **
8	PBIG-8 × PBIG-6	10.00	100.00 **	-15.97
9	PBIG-8 × PBIG-9	9.00	80.00 **	-24.37 **
10	PBIG-8 × PBIG-18	11.00	120.00 **	-7.56
11	PBIG-8 × PBIG-10	6.00	28.57	-49.58 **
12	PBIG-3 × PBIG-6	12.00	50.00 **	0.84
13	PBIG-3 × PBIG-9	11.00	22.22	-7.56
14	PBIG-3 × PBIG-18	14.00	27.27 **	17.65 *
15	PBIG-3 × PBIG-10	11.00	135.54 **	-7.56
16	PBIG-6 × PBIG-9	13.00	62.50 **	9.24
17	PBIG-6 × PBIG-18	9.33	16.62	-21.57 *
18	PBIG-6 × PBIG-10	6.00	28.57	-49.58 **
19	PBIG-9 × PBIG-18	8.00	-11.11	-32.77 **
20	PBIG-9 × PBIG-10	15.00	221.19 **	26.05 **
21	PBIG-18 × PBIG-10	7.00	49.89 *	-41.18 **
22	Pant Karela -1 (Check)	11.9	-	-
	Mean		9.71	
	C.V. (%)		12.71	
	S.E. ±		0.71	
	C.D. (5%)		2.04	
	C.D. (1%)		2.73	

4.2.5. Days to first harvest

The parental mean for days to first harvest range from 56 (PBIG-18) to 79 days (PBIG-8, PBIG-3 and PBIG-18) (Table 4.2.5). Among the crosses, PBIG-6 × PBIG-18 (55.67 days) exhibited the minimum days to first harvest closely followed by PBIG-8 × PBIG-18 and PBIG-6 × PBIG-9 (56.0 days each) and PBIG-8 × PBIG-10 (56.33 days). However, cross combination i.e. PBIG-3 × PBIG-6 (73.67 days) showed maximum days to first harvest, followed by PBIG-8 × PBIG-6, PBIG-3 × PBIG-10 and PBIG-9 × PBIG-18 (62.33 each).

As regards F_1 superiority over better parent for day to first harvest seven crosses showed significant heterosis, out of which five crosses showed negative heterosis. The negative heterosis for this character is desirable. The maximum negative heterobeltiosis was recorded in PBIG-8 × PBIG-10 (-28.69 %), followed by PBIG-8 × PBIG-3 (-21.94 %), PBIG-3 × PBIG-9 (-15.33 %), and PBIG-8 × PBIG-9 and PBIG-9 × PBIG-18 (-15.07 % each). With respect to heterosis over standard cultivar, among the 15 crosses only one cross i.e. PBIG-3 × PBIG-6 (31.55) exhibited significant positive heterosis over the check cultivar (Pant Karela-1).

Earliness is a critical consideration of any breeding programme as it helps the grower to maximize the financial gain by fetching higher market price. Earliness (indicated by negative estimates of heterosis) in bitter melon is attributed to number of days to anthesis of first male and female flower, nodal position of first male and female flower and days to first harvest (Alhariri *et al.*, 2018). Hence, in the present study all the component of earliness were study. The parents, PBIG-6 and PBIG-18 were found most promising lines for earliness. Among the crosses, PBIG-8 × PBIG-10 and PBIG-6 × PBIG-18 were found most promising hybrids for earliness. The results of present investigation are similar to the findings of Kumari *et al.*, (2020), Laxuman *et al.*, (2012), Bhatt *et al.*, (2017) and Mishra and Singh (2018).

4.2.6. Average fruit weight (g)

For average fruit weight, the parental mean ranged from 57.40 g (PBIG-18) to 96.67 g (PBIG-6) (Table 4.2.6). Among the crosses, PBIG-6 × PBIG-9 (85.45 g) exhibited the maximum fruit weight, followed by PBIG-6 × PBIG-18 (84.54 g), PBIG-3 × PBIG-6 (80.50 g), PBIG-8 × PBIG-6 (78.70 g) and PBIG-8 × PBIG-9 (77.13 g) and the least fruit weight was shown by PBIG-8 × PBIG-18 (45.63 g), closely followed by PBIG-8 × PBIG-3 (56.30 g) and PBIG-8 × PBIG-10 (60.68 g).

Table 4.2.5: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for days to first harvest in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	79.00	-	-
2	PBIG-3	79.00	-	-
3	PBIG-6	62.00	-	-
4	PBIG-9	73.00	-	-
5	PBIG-18	56.00	-	-
6	PBIG-10	79.00	-	-
7	PBIG-8 × PBIG-3	61.67	-21.94 **	10.12
8	PBIG-8 × PBIG-6	62.33	0.54	11.31
9	PBIG-8 × PBIG-9	62.00	-15.07**	10.71
10	PBIG-8 × PBIG-18	56.00	0.00	0.00
11	PBIG-8 × PBIG-10	56.33	-28.69**	0.59
12	PBIG-3 × PBIG-6	73.67	18.82**	31.55 **
13	PBIG-3 × PBIG-9	61.67	-15.53**	10.12
14	PBIG-3 × PBIG-18	61.67	10.12	10.12
15	PBIG-3 × PBIG-10	62.33	21.10**	11.31
16	PBIG-6 × PBIG-9	56.00	-9.68	0
17	PBIG-6 × PBIG-18	55.67	-0.58	-0.6
18	PBIG-6 × PBIG-10	62.00	0.00	10.71
19	PBIG-9 × PBIG-18	62.33	11.31	11.31
20	PBIG-9 × PBIG-10	62.00	-15.07**	10.71
21	PBIG-18 × PBIG-10	62.00	10.71	10.71
22	Pant Karela-1 (Check)	56.00	-	-
	Mean	64.08		
	C.V. (%)	6.58		
	S.E. ±	2.43		
	C.D. (5%)	6.96		
	C.D. (1%)	9.31		

Table 4.2.6: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for average fruit weight in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	67.58	-	-
2	PBIG-3	81.42	-	-
3	PBIG-6	96.67	-	-
4	PBIG-9	86.53	-	-
5	PBIG-18	57.40	-	-
6	PBIG-10	66.45	-	-
7	PBIG-8 × PBIG-3	56.30	-30.85 **	-10.42 *
8	PBIG-8 × PBIG-6	78.70	-18.59 **	25.21 **
9	PBIG-8 × PBIG-9	77.13	-10.86 *	22.72 **
10	PBIG-8 × PBIG-18	45.63	-32.49 **	-27.39 **
11	PBIG-8 × PBIG-10	60.68	-10.21 *	-3.45
12	PBIG-3 × PBIG-6	80.50	-16.72 **	28.08 **
13	PBIG-3 × PBIG-9	66.23	-23.46 **	5.37
14	PBIG-3 × PBIG-18	62.35	-23.42**	-0.79
15	PBIG-3 × PBIG-10	61.62	-24.31 **	-1.95
16	PBIG-6 × PBIG-9	85.45	-11.60 **	35.95 **
17	PBIG-6 × PBIG-18	74.42	-23.01**	34.51 **
18	PBIG-6 × PBIG-10	84.54	-12.54 **	18.40 **
19	PBIG-9 × PBIG-18	67.45	-22.05**	7.31
20	PBIG-9 × PBIG-10	75.57	-12.66**	20.23 **
21	PBIG-18 × PBIG-10	61.48	-7.47	-2.17
22	Pant Karela-1 (Check)	62.85	-	-
	Mean		71.15	
	C.V. (%)		6.06	
	S.E. ±		2.49	
	C.D. (5%)		7.11	
	C.D. (1%)		9.52	

Estimates of heterobeltiosis for this trait were significant for all the crosses except PBIG-18 × PBIG-10 (-7.47). The range of heterobeltiosis for significant crosses were from -10.21 % (PBIG-8 × PBIG-10) to -30.85 % (PBIG-8 × PBIG-3), where all were in negative direction. For standard heterosis, nine crosses showed significant heterosis with the range of 35.95 % (PBIG-6 × PBIG-9) to -27.39 % (PBIG-8 × PBIG-18). The other top performing hybrids were PBIG-6 × PBIG-18 (34.51 %), PBIG-3 × PBIG-6 (28.08 %), PBIG-8 × PBIG-6 (25.21 %) and PBIG-8 × PBIG-9 (22.72 %).

4.2.7. Average fruit length (cm)

A perusal of Table 4.2.7. revealed that among the parents, PBIG-3 (19.58 cm) showed maximum and PBIG-8 (11.77 cm) showed minimum value for fruit length, respectively. Among the crosses there was a large variation from 10.76 cm (PBIG-18 × PBIG-10) to 16.63 cm (PBIG-9 × PBIG-10). In between other good performing crosses were PBIG-8 × PBIG-9 and PBIG-6 × PBIG-10 (16.55 cm each), PBIG-8 × PBIG-3 (16.53 cm) and PBIG-6 × PBIG-18 (16.26 cm).

For estimates of heterobeltiosis for fruit length, six crosses showed significant standard heterosis, ranges from -17.06 % (PBIG-3 × PBIG-18) to -26.50 % (PBIG-18 × PBIG-10), where all were in negative direction. With respect to heterosis over standard cultivar 11 crosses showed significant standard heterosis, where all were in desirable positive direction. The hybrid with highest positive standard heterosis was PBIG-9 × PBIG-10 (47.79 %), closely followed by PBIG-8 × PBIG-9 (47.11 %), PBIG-6 × PBIG-10 (47.08 %) and PBIG-8 × PBIG-3 (46.93 %).

4.2.8. Average fruit diameter (mm)

The mean performance of parents for average fruit diameter ranges from 31.50 mm (PBIG-3) to 49.67 mm (PBIG-6) (Table 4.2.8). Among the crosses, PBIG-6 × PBIG-9 (44.0 mm) exhibited maximum fruit diameter, followed by PBIG-6 × PBIG-10 (42.60 mm), PBIG-3 × PBIG-6 (41.58 mm), PBIG-18 × PBIG-10 (41.45 mm) and PBIG-8 × PBIG-6 (41.42 mm). The least fruit diameter was observed in PBIG-8 × PBIG-18 (34.42 mm) followed by the PBIG-3 × PBIG-18 and PBIG-3 × PBIG-10 (35.50 mm each). For the estimates of heterobeltiosis for fruit diameter, the number of crosses with significant estimates were 11, with the range of -24.66 % (PBIG-6 × PBIG-18) to -7.72 % (PBIG-8 × PBIG-10). All showed negative heterosis. With respect to heterosis over standard cultivar,

Table 4.2.7: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for average fruit length in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	11.77	-	-
2	PBIG-3	19.58	-	-
3	PBIG-6	14.42	-	-
4	PBIG-9	17.67	-	-
5	PBIG-18	13.86	-	-
6	PBIG-10	14.64	-	-
7	PBIG-8 × PBIG-3	16.53	-15.57	46.93 **
8	PBIG-8 × PBIG-6	14.46	0.27	28.56 *
9	PBIG-8 × PBIG-9	16.55	-6.34	47.11 **
10	PBIG-8 × PBIG-18	12.68	-8.53	12.68
11	PBIG-8 × PBIG-10	12.67	-13.45	12.65
12	PBIG-3 × PBIG-6	14.97	-23.54 **	33.07 *
13	PBIG-3 × PBIG-9	15.37	-21.50**	36.65 *
14	PBIG-3 × PBIG-18	16.24	-17.06 *	44.39 **
15	PBIG-3 × PBIG-10	15.51	-20.78 **	37.84 *
16	PBIG-6 × PBIG-9	15.13	-14.37	34.46 *
17	PBIG-6 × PBIG-18	16.26	12.76	44.56 **
18	PBIG-6 × PBIG-10	16.55	12.13	47.08 **
19	PBIG-9 × PBIG-18	16.63	-18.90 *	27.41
20	PBIG-9 × PBIG-10	14.33	-5.88	47.79 **
21	PBIG-18 × PBIG-10	10.76	-26.50 *	-4.33
22	Pant Karela -1 (Check)	11.25	-	-
	Mean	15.08		
	C.V. (%)	12.86		
	S.E. ±	1.12		
	C.D. (5%)	3.20		
	C.D. (1%)	4.28		

Table 4.2.8: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for average fruit diameter in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	43.08	-	-
2	PBIG-3	31.50	-	-
3	PBIG-6	49.67	-	-
4	PBIG-9	40.22	-	-
5	PBIG-18	38.85	-	-
6	PBIG-10	36.45	-	-
7	PBIG-8 × PBIG-3	36.58	-15.08**	32.74 **
8	PBIG-8 × PBIG-6	41.42	-16.61 **	50.28 **
9	PBIG-8 × PBIG-9	38.40	-10.86**	39.33 **
10	PBIG-8 × PBIG-18	34.42	-20.10**	24.88 **
11	PBIG-8 × PBIG-10	39.75	-7.72*	44.23 **
12	PBIG-3 × PBIG-6	41.58	-16.28 **	50.88 **
13	PBIG-3 × PBIG-9	36.45	-9.37 **	32.26 **
14	PBIG-3 × PBIG-18	35.50	-8.62 *	28.81 **
15	PBIG-3 × PBIG-10	35.50	-2.61	28.81 **
16	PBIG-6 × PBIG-9	44.00	-11.41 **	59.65 **
17	PBIG-6 × PBIG-18	37.42	-24.66**	35.76 **
18	PBIG-6 × PBIG-10	42.60	-14.43 **	54.57 **
19	PBIG-9 × PBIG-18	38.83	-3.45	40.90 **
20	PBIG-9 × PBIG-10	39.67	-1.36	43.93 **
21	PBIG-18 × PBIG-10	41.45	6.69	50.40 **
22	Pant Karela-1 (Check)	27.56	-	-
	Mean	39.21		
	C.V. (%)	3.87		
	S.E. ±	0.88		
	C.D. (5%)	2.50		
	C.D. (1%)	3.35		

all crosses showed positive heterosis ranging from 24.88 % (PBIG-8 × PBIG-18) to 59.65 % (PBIG-6 × PBIG-9). The other top performing cross combinations were PBIG-6 × PBIG-10 (54.57 %), PBIG-3 × PBIG-6 (50.88 %), PBIG-18 × PBIG-10 (50.40 %) and PBIG-8 × PBIG-6 (50.28 %).

Fruit appearance exhibited by its length; diameter and length is also a very important aspect from the consumer point of view. Uniformly long, spindle shape fruits with medium length to diameter ratio are generally preferred in India for vegetable purpose. Therefore, hybrids with medium size fruits at marketable stage should be given preference, while evaluating for their yield potentials. Characters like fruit weight, fruit length and fruit diameter was studied in this experiment and several hybrids were found promising for these traits. The parents, PBIG-6, PBIG-3 and PBIG-6 were found most promising lines for fruit weight, fruit length and fruit diameter respectively. Among the crosses, PBIG-6 × PBIG-9 was found most promising cross combination for fruit weight and fruit diameter respectively. However, cross combination, PBIG-9 × PBIG-10 was the best for fruit length against standard check i.e. Pant Karela-1. Heterotic effect for fruit weight, fruit length and fruit diameter were also reported by **Sanandia *et al.* (2008)**, **Narasannavar *et al.*, (2014)** and **Parkash *et al.* (2014)**.

4.2.9. Main vine length (m)

The main vine length of the parental line i.e. PBIG-8 (4.69 m) was the longest, followed by PBIG-6 (4.55 m). However, PBIG-3 (3.72 m) showed shortest vine length (Table 4.2.9). Among the crosses, PBIG-3 × PBIG-9 (5.82 m) showed the longest vine length, followed by PBIG-8 × PBIG-3 (5.42 m), while cross combination, PBIG-6 × PBIG-18 (3.29 m) showed shortest vine length.

As regards F_1 superiority over better parent for main vine length, three crosses showed significant better parent heterosis, with the range of -29.76 % (PBIG-6 × PBIG-18) to 32.57 % (PBIG-3 × PBIG-9). With respect to the magnitude of heterosis over the standard cultivar for main vine length, all the crosses exhibited significant and positive heterosis except PBIG-6 × PBIG-18 (53.11 %). The top performing cross combinations for standard heterosis were PBIG-3 × PBIG-9 (178.63 %), PBIG-8 × PBIG-3 (159.33 %) and PBIG-3 × PBIG-18 (158.85 %). However, least performing hybrid combination was PBIG-8 × PBIG-9 (60.29 %).

Table 4.2.9: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for main vine length in bitter gourd (Summer season 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	4.69	-	-
2	PBIG-3	3.72	-	-
3	PBIG-6	4.55	-	-
4	PBIG-9	4.39	-	-
5	PBIG-18	4.30	-	-
6	PBIG-10	4.52	-	-
7	PBIG-8 × PBIG-3	5.42	15.57	159.33 **
8	PBIG-8 × PBIG-6	4.62	-1.42	121.13 **
9	PBIG-8 × PBIG-9	3.35	-28.57*	60.29 *
10	PBIG-8 × PBIG-18	4.49	-4.27	114.67 **
11	PBIG-8 × PBIG-10	3.63	-22.61	73.52 *
12	PBIG-3 × PBIG-6	4.75	4.39	127.11 **
13	PBIG-3 × PBIG-9	5.82	32.57*	178.63 **
14	PBIG-3 × PBIG-18	5.41	25.81	158.85 **
15	PBIG-3 × PBIG-10	4.45	-1.54	112.76 **
16	PBIG-6 × PBIG-9	4.58	0.65	118.98 **
17	PBIG-6 × PBIG-18	3.20	-29.67*	53.11
18	PBIG-6 × PBIG-10	4.27	-6.15	104.31 **
19	PBIG-9 × PBIG-18	4.06	-7.51	94.42 **
20	PBIG-9 × PBIG-10	4.36	-3.53	108.61 **
21	PBIG-18 × PBIG-10	4.70	3.98	124.88 **
22	Pant Karela-1 (Check)	2.09	-	-
	Mean	4.44		
	C.V. (%)	15.61		
	S.E. ±	0.40		
	C.D. (5%)	1.14		
	C.D. (1%)	1.53		

4.2.10. Number of primary branches

For the number of primary branches per plant, the parental lines PBIG-6 (23.75) and PBIG-10 (14.25) came out to be at the top and bottom, respectively (Table 4.2.10). Among the crosses, there was a large variation from 11.75 (PBIG-9 × PBIG-18) to 19.25 (PBIG-8 × PBIG-10). In between the other good-performing, crosses were PBIG-3 × PBIG-18 (18.67), PBIG-8 × PBIG-6 (18.60), PBIG-8 × PBIG-3 (17.77) and PBIG-3 × PBIG-10 (17.75). The least performing cross combination was PBIG-9 × PBIG-18 (11.75).

The data about the number of primary branches per plant revealed that nine crosses manifested significant heterobeltiosis, where three crosses in desirable positive direction. The most heterotic hybrid was PBIG-9 × PBIG-18 (33.80 %), followed by PBIG-18 × PBIG-10 (21.68 %) and PBIG-8 × PBIG-18 (17.56 %). The cross combination, PBIG-6 × PBIG-10 (-42.11 %) showed the highest negative heterosis over better parent. The result of estimation of standard heterosis for this trait indicated that seven crosses showed significant heterosis over the standard check (Pant Karela-1), where five crosses namely PBIG-8 × PBIG-10 (26.22 %), PBIG-3 × PBIG-18 (22.42 %), PBIG-8 × PBIG-6 (21.96 %), PBIG-8 × PBIG-3 (16.52 %) and PBIG-18 × PBIG-10 (13.71 %) were in positive direction.

4.2.11. Internodal length (cm)

The mean value of the parents for internodal length showed the shortest in PBIG-6 (7.83 cm) and longest in PBIG-18 (9.54 cm) (Table 4.2.11). Among the crosses the shortest internode was in PBIG-6 × PBIG-9 (6.30 cm), closely followed by PBIG-6 × PBIG-10 (6.48 cm), PBIG-8 × PBIG-10 (8.27 cm) and PBIG-3 × PBIG-6 (8.45 cm). The longest internode was observed in PBIG-9 × PBIG-18 (11.46 cm).

As regards F_1 superiority over better parent for internode length, the number of crosses with significant estimates were ten, with the range of -14.63 (PBIG-6 × PBIG-9) to 37.90 % (PBIG-9 × PBIG-18). The other top performing combinations were PBIG-6 × PBIG-10 (-12.19 %) and PBIG-18 × PBIG-10 (-10.41 %). Concerning heterosis over standard cultivar, all crosses exhibited significant heterosis in positive direction, which is undesirable.

Table 4.2.10: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for number of primary branches in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	18.50	-	-
2	PBIG-3	18.25	-	-
3	PBIG-6	23.75	-	-
4	PBIG-9	17.75	-	-
5	PBIG-18	13.75	-	-
6	PBIG-10	14.25	-	-
7	PBIG-8 × PBIG-3	17.77	-3.94	
8	PBIG-8 × PBIG-6	23.60	-0.63	21.96 **
9	PBIG-8 × PBIG-9	13.58	-0.63	-10.95
10	PBIG-8 × PBIG-18	21.75	17.56*	9.83
11	PBIG-8 × PBIG-10	19.25	4.05	26.22 **
12	PBIG-3 × PBIG-6	15.25	-35.78**	-2.62
13	PBIG-3 × PBIG-9	16.75	-8.21*	9.38
14	PBIG-3 × PBIG-18	18.67	2.31	22.42**
15	PBIG-3 × PBIG-10	17.75	-2.73	16.39*
16	PBIG-6 × PBIG-9	17.50	-26.31 **	-18.03*
17	PBIG-6 × PBIG-18	16.00	-32.63**	4.91
18	PBIG-6 × PBIG-10	13.75	-42.11**	-9.83
19	PBIG-9 × PBIG-18	11.75	33.80**	-11.75 *
20	PBIG-9 × PBIG-10	12.50	-29.57**	8.19
21	PBIG-18 × PBIG-10	17.34	21.68*	13.71 *
22	Pant Karela-1 (Check)	14.85	-	-
	Mean		17.15	
	C.V. (%)		7.98	
	S.E. ±		0.79	
	C.D. (5%)		2.26	
	C.D. (1%)		3.02	

Table 4.2.11: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for internodal length in bitter gourd (Summer season 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	8.61	-	-
2	PBIG-3	8.54	-	-
3	PBIG-6	7.38	-	-
4	PBIG-9	8.31	-	-
5	PBIG-18	9.54	-	-
6	PBIG-10	9.51	-	-
7	PBIG-8 × PBIG-3	8.55	0.11	64.42 **
8	PBIG-8 × PBIG-6	9.53	29.13**	83.26 **
9	PBIG-8 × PBIG-9	8.59	3.36	65.19 **
10	PBIG-8 × PBIG-18	8.58	-0.34	65.00 **
11	PBIG-8 × PBIG-10	8.27	-0.48	59.03 **
12	PBIG-3 × PBIG-6	8.45	14.49**	62.50 **
13	PBIG-3 × PBIG-9	9.26	11.43**	78.07 **
14	PBIG-3 × PBIG-18	9.48	11.01**	82.31 **
15	PBIG-3 × PBIG-10	8.47	-0.81	62.89 **
16	PBIG-6 × PBIG-9	6.30	-14.63**	21.15 **
17	PBIG-6 × PBIG-18	8.68	17.61**	66.92 **
18	PBIG-6 × PBIG-10	6.48	-12.19**	24.62 **
19	PBIG-9 × PBIG-18	11.46	37.90**	120.39 **
20	PBIG-9 × PBIG-10	9.56	15.04**	83.84 **
21	PBIG-18 × PBIG-10	8.52	-10.41**	63.84 **
22	Pant Karela-1 (Check)	5.20	-	-
	Mean		8.66	
	C.V. (%)		3.52	
	S.E. ±		0.18	
	C.D. (5%)		0.50	
	C.D. (1%)		0.67	

4.2.12. Diameter of main vine (mm)

The parental mean for the diameter of main vine ranges from 3.50 mm (PBIG-8) to 4.47 mm (PBIG-9) (Table 4.2.12). Among the crosses, top performing cross combination were PBIG-8 × PBIG-3 (5.25 mm), followed by PBIG-8 × PBIG-6 (4.86 mm) and PBIG-3 × PBIG-10 (4.72 mm). The least performing hybrid for this trait was PBIG-8 × PBIG-9 (2.49 mm).

For the estimation of heterosis over better parent, the number of crosses with the significant estimates were eleven, out of which four crosses namely PBIG-8 × PBIG-3 (32.91 %), PBIG-8 × PBIG-6 (30.99 %), PBIG-6 × PBIG-18 (14.84 %) and PBIG-3 × PBIG-10 (14.56 %) were in positive direction. The least heterobeltiosis was seen in PBIG-8 × PBIG-9 (-44.29 %). For standard heterosis, all the crosses exhibited significant heterosis for diameter of main vine. The top performing hybrid was PBIG-8 × PBIG-3 (95.89 %), followed by PBIG-8 × PBIG-6 (81.34 %), PBIG-3 × PBIG-10 (76.12 %), PBIG-6 × PBIG-9 (71.26 %) and PBIG-6 × PBIG-18 (64.55 %). However, least performing cross combination was PBIG-8 × PBIG-9 (-7.09 %).

It is a well-construed fact that plant growth traits like main vine length, diameter of vine, number of primary branches per plant is positively associated with number of fruits per pant, thus total yield, in cucurbits including bitter gourd (**Khattara et al., 1994; Mangal et al., 1981; Srivastava and Srivastava, 1976**). Although there are some contradicting reports regarding the positive association of vine length with fruit yield, as **Bhagchandani et al., (1980) and Dogra et al., (1997)** have reported that vine length did not contribute to yield. But in this experiment, it was noted that as the crop duration progressed, the vine length kept on increasing, bearing more female flowers, therefore adding to the total yield. In general, a greater number of primary branches, and longer vines with more and shorter internodes are found to exhibit significant positive association with number of fruits per plant and thus yield. The ideal plant type should have maximum vine length, maximum number of primary branches and short internodal length which may lead higher fruit yield (**Sirohi and Choudhury, 1978**). The parents, PBIG-8, PBIG-6, PBIG-9 and PBIG-6 were found most promising lines for main vine length, number of primary branches per plant, diameter of main vine and internodal length respectively. Among the crosses PBIG-3 × PBIG-9, PBIG-8 × PBIG-10 and PBIG-8 × PBIG-3 were

Table 4.2.12: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for diameter of main vine in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	3.50	-	-
2	PBIG-3	3.95	-	-
3	PBIG-6	3.71	-	-
4	PBIG-9	4.47	-	-
5	PBIG-18	3.84	-	-
6	PBIG-10	4.12	-	-
7	PBIG-8 × PBIG-3	5.25	32.91**	95.89 **
8	PBIG-8 × PBIG-6	4.86	30.99**	81.34 **
9	PBIG-8 × PBIG-9	2.49	-44.29**	-7.09 *
10	PBIG-8 × PBIG-18	2.91	-24.21**	8.46 **
11	PBIG-8 × PBIG-10	3.58	-13.11 **	33.58 **
12	PBIG-3 × PBIG-6	3.38	-14.43**	26.11 **
13	PBIG-3 × PBIG-9	4.37	-2.23	63.05 **
14	PBIG-3 × PBIG-18	3.79	-4.05	41.41 **
15	PBIG-3 × PBIG-10	4.72	14.56**	76.12 **
16	PBIG-6 × PBIG-9	4.59	2.68	71.26 **
17	PBIG-6 × PBIG-18	4.41	14.84**	64.55 **
18	PBIG-6 × PBIG-10	4.27	3.64	59.32 **
19	PBIG-9 × PBIG-18	3.51	-21.46**	30.97 **
20	PBIG-9 × PBIG-10	3.92	-12.31 **	46.26 **
21	PBIG-18 × PBIG-10	3.21	-22.08 **	19.78 **
22	Pant Karela-1 (Check)	2.68	-	-
	Mean		3.94	
	C.V. (%)		2.57	
	S.E. ±		0.06	
	C.D. (5%)		0.17	
	C.D. (1%)		0.22	

found best for main vine length, number of primary branches per plant, diameter of main vine and internodal length respectively. Similar result was supported by **Kumari *et al.*, (2020)**, **Tewari *et al.*, (2001)** and **Naik *et al.*, (2020)**.

4.2.13. Number of harvests per plant

Mean performance for number of harvests per plant ranges from 4.0 (PBIG-8, PBIG-9 and PBIG-10) to 5.0 (PBIG-18) (Table 4.2.13). Among the crosses, PBIG-8 × PBIG-18 and PBIG-3 × PBIG-6 (6.0 each), showed the highest number of harvests per plant, followed by PBIG-6 × PBIG-10 (5.33), PBIG-3 × PBIG-9 (5.15) and PBIG-6 × PBIG-9 (5.14).

The better parent heterosis for number of harvests per plant were significant for seven crosses. Among them, five crosses showed significant positive heterosis. The maximum heterobeltiosis were recorded in PBIG-8 × PBIG-9, PBIG-8 × PBIG-18 and PBIG-8 × PBIG-9 (25.0 % each), followed by PBIG-8 × PBIG-18 (20.0 %) and PBIG-3 × PBIG-6 (19.99%). The least heterobeltiosis was exhibited in PBIG-8 × PBIG-6 (-20.05 %). For the estimation of standard heterosis for number of harvests per plant, 11 crosses exhibited significant value. The top performing cross combination was PBIG-3 × PBIG-6 (50.08 %), followed by PBIG-8 × PBIG-18 (50.00), where all in positive direction.

4.2.14. Number of fruits per plant

Estimation of average performance of the parents for number of fruits per plant, PBIG-18 (31.72) was the top performing parent and least performing parent was PBIG-8 (6.92) (Table 4.2.14). Among the crosses there was a large variation from 7.99 (PBIG-9 × PBIG-18) to 29.46 (PBIG-8 × PBIG-10). In between, the other good-performing crosses were PBIG-3 × PBIG-9 (26.51), PBIG-9 × PBIG-10 (25.65), PBIG-6 × PBIG-18 (24.54) and PBIG-8 × PBIG-6 (20.55).

The heterosis data about the number of fruits per plant revealed that 12 crosses manifested significant heterobeltiosis, where six were in positive direction. The most heterotic hybrid was PBIG-8 × PBIG-10 (208.88 %) and other promising hybrids with significant positive estimates were PBIG-3 × PBIG-9 (206.63 %), PBIG-6 × PBIG-18 (157.32 %), PBIG-8 × PBIG-6 (116.35 %), PBIG-8 × PBIG-9 (105.90 %) and PBIG-6 × PBIG-9 (97.05 %). The result on the estimation of standard heterosis for this trait 12

Table 4.2.13: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for number of harvests per plant in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	4.00	-	-
2	PBIG-3	4.53	-	-
3	PBIG-6	5.00	-	-
4	PBIG-9	4.00	-	-
5	PBIG-18	5.00	-	-
6	PBIG-10	4.00	-	-
7	PBIG-8 × PBIG-3	4.00	-11.76	0
8	PBIG-8 × PBIG-6	4.00	-20.05 *	0
9	PBIG-8 × PBIG-9	5.00	25.00 *	25.00 **
10	PBIG-8 × PBIG-18	6.00	20.00 *	50.00 **
11	PBIG-8 × PBIG-10	5.00	25.00 *	25.00 **
12	PBIG-3 × PBIG-6	6.00	19.99 *	50.08 **
13	PBIG-3 × PBIG-9	5.15	13.68	28.83 **
14	PBIG-3 × PBIG-18	5.00	0.00	25.08 **
15	PBIG-3 × PBIG-10	5.00	25.00*	25.00 **
16	PBIG-6 × PBIG-9	5.14	2.80	28.42 **
17	PBIG-6 × PBIG-18	5.00	0.00	25.00 **
18	PBIG-6 × PBIG-10	5.33	6.67	33.33 **
19	PBIG-9 × PBIG-18	4.00	-20.00 *	0
20	PBIG-9 × PBIG-10	4.00	0	0
21	PBIG-18 × PBIG-10	5.00	0	25.00 **
22	Pant Karela-1 (Check)	4.00	-	-
	Mean		4.77	
	C.V. (%)		9.72	
	S.E. ±		0.27	
	C.D. (5%)		0.7652	
	C.D. (1%)		1.024	

Table 4.2.14: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for number of fruits per plant in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	6.92	-	-
2	PBIG-3	8.50	-	-
3	PBIG-6	9.50	-	-
4	PBIG-9	8.65	-	-
5	PBIG-18	31.72	-	-
6	PBIG-10	9.54	-	-
7	PBIG-8 × PBIG-3	11.55	35.88	-38.07 **
8	PBIG-8 × PBIG-6	20.55	116.35 **	10.18
9	PBIG-8 × PBIG-9	17.80	105.90 **	-4.55
10	PBIG-8 × PBIG-18	10.51	-66.89 **	-43.64 **
11	PBIG-8 × PBIG-10	29.46	208.88 **	57.96 **
12	PBIG-3 × PBIG-6	8.53	-10.18	-54.26 **
13	PBIG-3 × PBIG-9	26.51	206.63 **	42.14 **
14	PBIG-3 × PBIG-18	14.47	-54.39 **	-22.41 **
15	PBIG-3 × PBIG-10	9.51	-0.28	-49.1 **
16	PBIG-6 × PBIG-9	18.72	97.05**	0.37
17	PBIG-6 × PBIG-18	11.58	-63.50 **	31.58 **
18	PBIG-6 × PBIG-10	24.54	157.32**	-37.90 **
19	PBIG-9 × PBIG-18	7.99	-74.81**	-57.15 **
20	PBIG-9 × PBIG-10	25.65	-168.86**	37.53 **
21	PBIG-18 × PBIG-10	14.12	-55.48 **	-24.29 **
22	Pant Karela-1 (Check)	18.65	-	-
	Mean		15.54	
	C.V. (%)		17.58	
	S.E. ±		1.58	
	C.D. (5%)		4.51	
	C.D. (1%)		6.03	

crosses showed significant heterosis, among them three crosses namely PBIG-8 × PBIG-10 (57.96 %), PBIG-3 × PBIG-9 (42.14 %) and PBIG-9 × PBIG-10 (37.53 %) showed positive heterosis. The highest negative heterosis was exhibited by the cross combination PBIG-9 × PBIG-18 (-57.15 %).

4.2.15. Average fruit yield per plant (kg)

For fruit yield per plant, the parental mean ranges from 0.46 (PBIG-8) to 1.82 kg (PBIG-10) (Table 4.2.15.). Among the crosses PBIG-6 × PBIG-18 (2.074 kg) exhibited the maximum fruit yield per plant, followed by PBIG-9 × PBIG-10 (1.93 kg), PBIG-8 × PBIG-10 (1.77 kg) and PBIG-3 × PBIG-9 (1.75 kg). However, least fruit yield per plant was observed in cross combination PBIG-8 × PBIG-18 (0.48 kg), followed by PBIG-9 × PBIG-18 (0.54 kg) and PBIG-3 × PBIG-10 (0.57 kg).

Results about heterobeltiosis for fruit yield per plant revealed that 12 crosses showed significant heterobeltiosis, where six crosses were in positive direction. The maximum heterobeltiosis was recorded in PBIG-3 × PBIG-9 (134.62 %), followed by PBIG-6 × PBIG-18 (126.66 %), while minimum heterobeltiosis was observed in cross PBIG-3 × PBIG-18 (32.07 %). Based on the result on standard heterosis it was apparent that all the crosses exhibited significant heterosis over the check cultivar (Pant Karela-1), out of which six crosses exhibited significant positive heterosis. The best performing cross was PBIG-6 × PBIG-18 (76.92 %), closely followed by PBIG-9 × PBIG-10 (64.95 %). However, lowest standard heterosis was recorded in PBIG-8 × PBIG-18 (-58.97 %).

4.2.16. Fruit yield (q/ha)

The average mean value of the parents for fruit yield ranges from 62.1 q/ha (PBIG-8) to 242.6 q/ha (PBIG-10) (Table 4.2.16). Among the crosses PBIG-6 × PBIG-18 (276.5 q/ha) was the most heterotic hybrid, followed by PBIG-9 × PBIG-18 (259.2 q/ha), PBIG-8 × PBIG-10 (236.8 q/ha) and PBIG-3 × PBIG-9 (234.1 q/ha). However, least performing hybrid was PBIG-8 × PBIG-18 (63.86 q/ha).

Regarding the heterosis over better parent, among the 15 cross combinations, 12 crosses manifested significant heterobeltiosis for fruit yield, out of which six crosses exhibited positive heterobeltiosis. The maximum heterobeltiosis was recorded in PBIG-3 × PBIG-9 (134.80 %), followed by PBIG-6 × PBIG-18 (126.45 %). The least performing hybrid for fruit yield was PBIG-3 × PBIG-10 (-67.80 %), followed by PBIG-6 × PBIG-10

Table 4.2.15: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for average fruit yield per plant in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	0.465	-	-
2	PBIG-3	0.689	-	-
3	PBIG-6	0.915	-	-
4	PBIG-9	0.748	-	-
5	PBIG-18	0.633	-	-
6	PBIG-10	1.820	-	-
7	PBIG-8 × PBIG-3	0.660	-4.20	-43.59 **
8	PBIG-8 × PBIG-6	1.610	75.95 **	-37.60 **
9	PBIG-8 × PBIG-9	1.372	83.42 **	17.09 **
10	PBIG-8 × PBIG-18	0.479	-24.32 **	-58.97 **
11	PBIG-8 × PBIG-10	1.770	-2.74	51.28 **
12	PBIG-3 × PBIG-6	0.686	-25.02 **	-41.02 **
13	PBIG-3 × PBIG-9	1.755	134.62 **	49.57 **
14	PBIG-3 × PBIG-18	0.910	32.07 **	-22.23 **
15	PBIG-3 × PBIG-10	0.586	-67.82 **	-51.28 **
16	PBIG-6 × PBIG-9	1.599	74.75 **	35.89 **
17	PBIG-6 × PBIG-18	2.074	126.66 **	76.92 **
18	PBIG-6 × PBIG-10	0.861	-52.69 **	-26.49 **
19	PBIG-9 × PBIG-18	0.538	-28.07 **	-53.84 **
20	PBIG-9 × PBIG-10	1.933	6.20	64.95 **
21	PBIG-18 × PBIG-10	0.868	-52.30 **	-25.64 **
22	Pant Karela-1 (Check)	1.17	-	-
	Mean		0.97	
	C.V. (%)		9.06	
	S.E. ±		0.05	
	C.D. (5%)		0.14	
	C.D. (1%)		0.19	

Table 4.2.16: Mean performance, heterobeltiosis and standard heterosis of parents and crosses for fruit yield (q/ha) in bitter gourd (Summer season, 2022)

Sl. No.	Parents / Crosses	Mean value	Heterobeltiosis (%)	Standard Heterosis (%)
1	PBIG-8	62.1	-	-
2	PBIG-3	91.8	-	-
3	PBIG-6	122.1	-	-
4	PBIG-9	99.7	-	-
5	PBIG-18	63.8	-	-
6	PBIG-10	242.6	-	-
7	PBIG-8 × PBIG-3	88.7	-3.37	
8	PBIG-8 × PBIG-6	214.6	75.76 **	37.47 **
9	PBIG-8 × PBIG-9	182.9	83.45 **	-17.16 **
10	PBIG-8 × PBIG-18	63.86	-24.33 *	-59.09 **
11	PBIG-8 × PBIG-10	236.8	-2.39	51.69 **
12	PBIG-3 × PBIG-6	91.46	-25.09 *	-41.40 **
13	PBIG-3 × PBIG-9	234.1	134.80 **	49.96 **
14	PBIG-3 × PBIG-18	122.4	33.34 **	-21.58 **
15	PBIG-3 × PBIG-10	78.1	-67.80 **	-49.96 **
16	PBIG-6 × PBIG-9	231.9	89.92 **	48.55
17	PBIG-6 × PBIG-18	276.5	126.45 **	77.13 **
18	PBIG-6 × PBIG-10	114.8	-52.67 **	-26.45 **
19	PBIG-9 × PBIG-18	71.7	-28.08 **	-54.06 **
20	PBIG-9 × PBIG-10	259.2	6.20	66.04 **
21	PBIG-18 × PBIG-10	115.7	-52.07**	-25.89 **
22	Pant Karela -1 (Check)	156.1	-	-
	Mean	129.23		
	C.V. (%)	9.44		
	S.E. ±	7.04		
	C.D. (5%)	20.13		
	C.D. (1%)	26.94		

(-52.67 %). For the estimates of heterosis over standard variety (Pant Karela-1) among 15 crosses, 11 crosses showed significant standard heterosis, out of which six crosses exhibited significant positive standard heterosis. The two best performing crosses for economic heterosis for this trait were PBIG-6 × PBIG-18 (77.13 %) and PBIG-9 × PBIG-10 (66.04 %), while least performing hybrid was PBIG-8 × PBIG-18 (-59.09 %).

Yield heterosis has never been an individual and isolated effect, but it is expressed through component heterosis (**Mohanty and Mishra, 1999**). Hybrid vigour of even small magnitude of individual yield components may have additive or synergistic effect on the end product, as **Grafius (1959)** had mentioned that heterosis for yield is the result of interaction of simultaneous increase in the expression of heterosis for yield components.

Yield improvement is the foremost breeding objective of any production breeding programme. In recent years heterosis breeding is gaining importance in vegetable crops for increasing productivity. Yield at marketable stage in bitter gourd is dependent primarily on fruit weight, number of fruits per plant and number of harvests. The latter however, is a function of time, which is under the control of grower. **Hayes and Jones (1916)** and **Singh and Amarchand (1970)** reported that the most important character in cucurbits which may be considered as the best measure of increased vigour is the number of fruits per plant with. Therefore, yield can more accurately be estimated by the number of fruits per plant, and it would be possible to achieve yield improvement in this crop by manipulating this particular trait. Hence, breeders should concentrate mainly on fruit number rather than fruit size, in their efforts to increase yield. Parents PBIG-18 was found best performing line for number of harvests per plant and number of fruits per plant. However, PBIG-10 was good for average fruit yield per plant and fruit yield (q/ha). Among the crosses PBIG-3 × PBIG-6 and PBIG-8 × PBIG-10 were found most heterotic hybrid for number of fruits per plant and number of harvests per plant respectively. However, crosses PBIG-6 × PBIG-18 and PBIG-9 × PBIG-10 were found best for average fruit yield per plant and fruit yield (q/ha). In present study similar findings were also reported by **Kumari et al., (2020)**, **Mishra et al., (1994)** and **Jadav et al., (2009)**.

Combining ability

4.3. Analysis of variance for combining ability

The analysis of variance of combining ability was done for all the 16 characters and the results are presented in Table 4.4.1. The mean squares were divided into three parts *viz.* mean squares due to gca, sca and error. The results revealed that the mean squares of specific combining ability (sca) were significant for all the characters. Likewise, the general combining ability (gca) mean squares were also significant for most of the characters except days to anthesis of first male flower and main vine length.

The results for analysis of variance for gca and sca presented revealed that sca components of variance was higher than gca components of variance for traits like days to anthesis of first male flower, main vine length (m), main vine diameter (mm), number of harvests per plant, number of fruits per plant, average fruit yield per plant (kg) and fruit yield (q/ha), which indicated the importance of non-additive gene action in expression of these characters. Therefore, heterosis breeding could be effective for the genetic improvement of these quantitative traits. However, gca components of variance was higher than sca components of variance for traits like days to anthesis of first female flower, node number to first male flower, node number to first female flower, days to first harvest, average fruit weight (g), average fruit diameter (mm), average fruit length (cm), primary branches per plant and internodal length (cm), which indicated the predominance of additive gene action in expression of these characters. Therefore, both selection and heterosis breeding could be effective for the genetic improvement of these quantitative traits of bitter gourd. The results of the present investigation are similar to the findings of **Thakur and Kumar (2020) and Bairagi *et al.*, (2013).**

4.4. General (gca) and specific combining ability (sca) effects

The identification of best combiners in hybrid breeding has to be based on the complete genetic information and esteemed prepotency of potential parents. Combining ability analysis gives useful information regarding the selection of parents and provides the desired information about the nature and magnitude of different types of gene actions involved in the expression of quantitative characters. For the development of superior hybrids, estimates of general combining ability of parents and specific combining ability of the crosses help in proper selection of parents for hybridization (**Dogra and Kanwar, 1997**).

Table 4.3 Analysis of variance for combining ability for different characters in bitter gourd (Summer season, 2022)

S. No.	Source of variation/ characters	Mean squares		
		GCA (5)	SCA (15)	Error (40)
1.	Days to anthesis of first male flower	6.33	12.771 **	3.75
2.	Days to anthesis of first female flower	15.933 *	14.505 **	4.98
3.	Node number to first male flower	7.333 **	5.543 **	0.5
4.	Node number to first female flower	17.483 **	7.584 **	0.51
5.	Days to first harvest	73.065 **	56.592 **	5.93
6.	Average fruit weight	473.718 **	48.226 **	6.19
7.	Average fruit length	9.082 **	2.508 *	1.25
8.	Average fruit diameter	44.785 **	5.874 **	0.77
9.	Main vine length	0.15	0.497 **	0.16
10.	Primary branch per plant	17.65 **	8.604 **	0.63
11.	Main vine diameter	0.297**	0.503**	0.003
12.	Internodal length	1.709 **	1.052 **	0.03
13.	Number of harvests per plant	0.378 **	0.425 **	0.07
14.	Number of fruits per plant	37.839 **	70.449 **	2.49
15.	Average fruit yield per plant	0.166 **	0.504 **	0.003
16.	Fruit yield (q/ha)	2984.57 **	9002.07 **	49.26

General combining ability (gca) has immense value in the breeding programmes for the species which are amenable to the development of F₁ hybrids. The estimate of gca of a line indicates its suitability to be used as parent in combination with other lines. The identified parental lines with superior performance can be crossed in suitable combinations to exploit heterosis. Crosses with high sca may be used in heterosis breeding for commercial use.

Though, interestingly combining ability analyses were recently performed in bitter gourd and many reports are available and information on identification of better parents for hybrid production is lacking. The present investigation was therefore, undertaken to identify the best combiners among the existing inbreds and the crosses as well as gene action of different quantitative traits in 6 × 6 half-diallel set to facilitate the formulation of a sound breeding programme in bitter gourd. The diallel data comprising six parents and 15 crosses were subjected to combining ability analysis following by **Method 2** and **Model 1** as given by **Griffing (1956)**.

The estimated effects for the gca of the six parental lines and sca effects of the 15 F₁ hybrids for yield and yield attributing traits are presented in 4.3.2 and 4.3.3, respectively. It would be imperative to mention here that for the characters days to anthesis of first male and female flower, nodal position of first male and female flower, days to first harvest and internodal length, the negative gca and sca effects were considered to be desirable, as it indicates earliness. However, characters like average fruit weight (g), fruit length (cm), fruit diameter (mm), main vine length (m), number of primary branches, number of fruits per plant and fruit yield (q/ha), the positive gca and sca effects were considered to be desirable. The results on estimates of gca and sca of parents and crosses are described for each character separately, as follows:

4.4.1.1. Days to anthesis of first male flower

The findings showed that among the parental lines none of the parents showed significant gca effects for number of days to anthesis of first male flower. Among the 15 crosses, eight crosses exhibited significant sca effects, where all were in negative direction, except PBIG-18 × PBIG-10 (4.39). The cross combination, PBIG-8 × PBIG-18 (-5.61) showed highest negative sca effect followed by PBIG-3 × PBIG-18 and PBIG-6 × PBIG-9 (-2.86 each), PBIG-3 × PBIG-9 (-2.61), PBIG-8 × PBIG-9 (-2.36), PBIG-3 × PBIG-10 and PBIG-6 × PBIG-18 (-2.11 each).

Table 4.4.1: Estimation of general combining ability (GCA) effects of parents for different characters in bitter gourd (Summer season, 2022)

Parents \ Characters	Days to anthesis of first male flower	Days to anthesis of first female flower	Nodal position of first male flower	Nodal position of first female flower	Days to first harvest	Average fruit weight (g)	Average fruit length (cm)	Average fruit diameter (cm)	Main vine length (m)	Primary branches per plant	Internodal length (cm)	Diameter of main vine (mm)	Number of harvests per plant	Number of fruits per plant	Fruit yield per plant (kg)	Fruit yield (g/ha)
PBIG-8	0.83	0.42	-1.54**	-1.75**	0.97	-5.55**	-1.14**	0.29	-0.03	1.54**	0.01	-0.19**	-0.17	-0.63	-0.13**	-18.12**
PBIG-3	1.08	1.54 *	0.58*	1.25**	3.81**	-1.03	1.53**	-3.23**	0.27*	0.16	0.08	0.22**	0.1	-2.65**	-0.18**	-24.23**
PBIG-6	-0.67	-1.46 *	0.46*	-0.21	-1.86*	12.36**	0.08	3.99**	-0.07	1.95**	-0.81**	0.17**	0.26**	-0.73	0.11**	14.38**
PBIG-9	0.33	0.29	0.96**	0.75**	0.18	5.86**	0.98**	0.42	-0.02	-1.64**	0.14*	0.03	-0.26**	0.65	0.12**	15.25**
PBIG-18	-1.17	-1.96**	0.33	1.67**	-4.86**	-7.97**	-0.66	-1.14**	-0.08	-0.75**	0.62	-0.26**	0.20*	3.87**	0.16**	21.01**
PBIG-10	-0.42	1.17	-0.79**	-1.71**	1.76*	-3.67**	-0.80*	-0.32	-0.08	-1.25**	-0.057	0.04*	-0.13	-0.51	-0.06**	-8.30**
S.E. (gi)	0.625	0.720	0.227	0.230	0.786	0.803	0.361	0.283	0.129	0.255	0.057	0.019	0.086	0.509	0.016	2.273
S.E. (gi-gj)	0.969	1.116	0.352	0.356	1.217	1.244	0.560	0.438	0.200	0.395	0.088	0.029	0.134	0.788	0.025	3.522

Table 4.4.2: Estimation of specific combining ability (SCA) effects of parents for different characters in bitter melon (Summer season, 2022)

Characters Crosses	Days to anthesis of first male flower	Days to anthesis of first female flower	Nodal position of first male flower	Nodal position of first female flower	Days to first harvest	Average fruit weight (g)	Average fruit length (cm)	Average fruit diameter (cm)
PBIG-8 × PBIG -3	-1.11	-1.95 **	-1.77	-1.21 **	-7.19 **	-8.27 **	1.06 *	0.32
PBIG-8 × PBIG-6	-0.36	0.18	3.23 **	2.24 **	-0.86	0.74	0.44	-2.06 **
PBIG-8 × PBIG-9	-2.36 **	-0.32	-4.52 **	0.29	-3.23 **	5.68 **	1.63 **	-1.51 **
PBIG-8 × PBIG-18	-5.61 **	-1.57 **	-8.39 **	-0.26	-10.48 **	-1.24	-0.46	0.58
PBIG-8 × PBIG-10	-0.86	1.30 **	0.73	1.37 **	-4.19 **	-11.99 **	-0.61	-3.93 **
PBIG-3 × PBIG-6	-0.61	4.05 **	2.11 *	1.24 **	7.64 **	-1.99	-1.72 **	1.62 **
PBIG-3 × PBIG-9	-2.61 **	-1.45 **	-0.64	-0.71 *	-6.40 **	-9.75 **	-2.21 **	0.05
PBIG-3 × PBIG-18	-2.86 **	0.3	-2.52 *	1.74 **	-7.32 **	-4.84 **	-0.3	-0.16
PBIG-3 × PBIG-10	-2.11 *	1.18 **	-1.39	1.37 **	-1.36	0.2	0.29	0.66
PBIG-6 × PBIG-9	-2.86 **	-0.32	-2.64 **	2.74 **	-6.40 **	-3.92 **	-1.01 *	0.39
PBIG-6 × PBIG-18	-2.11 *	-0.57	-1.52	-1.80 **	-1.98	4.70 **	2.19 **	-0.27
PBIG-6 × PBIG -10	-0.36	-3.70 **	-1.39	-1.84 **	-1.69	-1.12	1.76 **	-4.64 **
PBIG-9 × PBIG -18	-1.11	2.93 **	0.73	6.24 **	-4.02 **	-5.89 **	-0.92	0.37
PBIG-9 × PBIG -10	-1.36	-3.20 **	-2.14 *	-4.13 **	2.93 **	6.54 **	1.23 *	0.35
PBIG-18 × PBIG-10	4.39 **	-2.45 **	1.98 *	-2.67 **	1.02	1.98	-2.85 **	3.71 **

Count.....

Characters Crosses	Main vine length (m)	Primary branches per plant	Internodal length (cm)	Diameter of main vine (mm)	Number of harvests per plant	Number of fruits per plant	Fruit yield per plant (kg)	Fruit yield (q/ha)
PBIG-8 × PBIG -3	0.73 **	-1.08 **	-0.20 **	1.27 **	-0.70 **	-0.71	0.01	1.83
PBIG-8 × PBIG-6	0.28	2.96 **	1.66 **	0.94 **	-0.86 **	6.38 **	0.24 **	32.01 **
PBIG-8 × PBIG-9	-1.05 **	-3.47 **	-0.23 **	-1.29 **	0.67 **	2.25 **	0.29 **	38.95 **
PBIG-8 × PBIG-18	-0.71 **	3.82 **	-0.36 **	-0.58 **	0.54 **	15.06 **	-0.77 **	-101.82 **
PBIG-8 × PBIG-10	0.15	1.81 **	-0.72 **	-0.22 **	1.20 **	-8.27 **	1.00 **	133.99 **
PBIG-3 × PBIG-6	0.1	-4.01 **	0.51 **	-0.95 **	0.87 **	-3.62 **	-0.68 **	-90.92 **
PBIG-3 × PBIG-9	1.12 **	1.08 **	0.38 **	0.17 **	0.54 **	12.97 **	0.87 **	116.85 **
PBIG-3 × PBIG-18	-0.19	2.11 **	-0.23 **	-0.12 **	0.26 *	-2.87 **	-0.03	-3.62
PBIG-3 × PBIG-10	0.77 **	1.69 **	0.11	0.51 **	-0.07	-2.30 **	-0.31 **	-41.20 **
PBIG-6 × PBIG-9	0.22	0.03	-1.70 **	0.46 **	0.37 **	3.26 **	0.54 **	73.04 **
PBIG-6 × PBIG-18	-0.02	-2.36 **	-1.33 **	0.56 **	0.43 **	10.24 **	1.12 **	149.59 **
PBIG-6 × PBIG -10	-1.09 **	-3.44 **	0.20 *	0.12 **	-0.23 *	-7.11 **	-0.71 **	-95.12 **
PBIG-9 × PBIG -18	0.02	-3.01 **	0.80 **	-0.20 **	-0.38 **	-7.69 **	-0.59 **	-78.08 **
PBIG-9 × PBIG -10	-0.28	-1.76 **	2.03 **	-0.09 **	-0.71 **	5.59 **	0.70 **	93.71 **
PBIG-18 × PBIG-10	0.42 *	2.19 **	-0.82 **	-0.51 **	0.16	-4.78 **	-0.21 **	-27.64 **

4.4.1.2. Days to anthesis of first female flower

The results reveal that among the parental lines, PBIG-18 (-1.96) and PBIG-6 (-1.46) showed significant negative value, while PBIG-3 (1.54) showed significant positive gca effects for days to anthesis of first female flower. Among the 15 crosses, eight crosses exhibited significant sca effects, where five crosses showed negative desirable sca effect. The crosses with negative sca effects were PBIG-8 × PBIG-18 (-8.39), PBIG-8 × PBIG-9 (-4.52), PBIG-6 × PBIG-9 (-2.64), PBIG-3 × PBIG-18 (-2.52) and PBIG-9 × PBIG-10 (-2.14). On the other hand, PBIG-8 × PBIG-6 (3.23), PBIG-3 × PBIG-6 (2.11) and PBIG-18 × PBIG-10 (1.98) were the crosses with significant positive sca effects.

4.4.1.3. Nodal position of first male flower

For nodal position of first male flower, PBIG-8 (-1.54) and PBIG-10 (-0.79) showed significant negative desirable gca effect and PBIG-9 (0.96), PBIG-3 (0.58) and PBIG-6 (0.46) showed significant positive gca effects. As regard sca effects, 10 crosses exhibited significant (six were in negative direction) with the range of -3.70 (PBIG-6 × PBIG-10) to 4.05 (PBIG-3 × PBIG-6). The other top performing crosses in desirable direction were PBIG-9 × PBIG-10 (-3.20), PBIG-18 × PBIG-10 (-2.45), PBIG-8 × PBIG-3 (-1.95), PBIG-8 × PBIG-18 (-1.57) and PBIG-3 × PBIG-9 (-1.45).

4.4.1.4. Nodal position of first female flower

Analysis of gca effects for this character revealed that PBIG-8 (-1.75) and PBIG-10 (-1.71) recorded significant negative value however, PBIG-18 (1.67), PBIG-3 (1.25) and PBIG-9 (0.75) showed significant positive gca effects. Out of 15 crosses, 13 crosses exhibited significant sca value, out of which six crosses namely PBIG-9 × PBIG-10 (-4.13), PBIG-18 × PBIG-10 (-2.67), PBIG-6 × PBIG-10 (-1.84), PBIG-6 × PBIG-18 (-1.80), PBIG-8 × PBIG-3 (-1.21), PBIG-8 × PBIG-3 (-1.21) exhibited significant negative sca effects. However, seven crosses *viz.* PBIG-9 × PBIG-18 (6.24), PBIG-6 × PBIG-9 (2.74), PBIG-8 × PBIG-6 (2.24), PBIG-3 × PBIG-18 (1.74), PBIG-8 × PBIG-10 and PBIG-3 × PBIG-10 (1.37 each) and PBIG-3 × PBIG-6 (1.24) possessed significant positive sca effects for this trait.

4.4.1.5. Days to first harvest

The results revealed that among the parental lines, PBIG-18 (-4.86) and PBIG-6 (-1.86) showed significant negative gca values for day to first harvest, while PBIG-3 (3.81)

and PBIG-10 (1.76) showed positive gca values. Among the 15 crosses, 10 crosses exhibited significant sca values, out of which eight crosses showed negative sca value. The top performing hybrid with desirable sca value was PBIG-8 × PBIG-18 (-10.48), closely followed by PBIG-3 × PBIG-18 (-7.32), PBIG-8 × PBIG-3 (-7.19), PBIG-3 × PBIG-9 and PBIG-6 × PBIG-9 (-6.40). The least performing hybrid for sca value of this trait was PBIG-3 × PBIG-6 (7.64), followed by PBIG-9 × PBIG-10 (2.93).

4.4.1.6. Average fruit weight (g)

Analysis of gca effects for this character revealed that PBIG-6 (12.36) and PBIG-9 (5.86) recorded significant positive gca and PBIG-18 (-7.97), PBIG-8 (-5.55) and PBIG-10 (-3.67) significant negative gca effects. Out of 15 crosses, only three crosses namely PBIG-9 × PBIG-10 (6.54), PBIG-8 × PBIG-9 (5.68) and PBIG-6 × PBIG-18 (4.70) exhibited significant positive sca effects. However, six crosses *viz.* PBIG-8 × PBIG-10 (-11.99), PBIG-3 × PBIG-9 (-9.75), PBIG-8 × PBIG-3 (-8.27), PBIG-9 × PBIG-18 (-5.89), PBIG-3 × PBIG-18 (-4.84) and PBIG-6 × PBIG-9 (-3.92) possessed significant negative effects.

4.4.1.7. Average fruit length (cm)

As regards gca effects for this character, PBIG-3 (1.53) and PBIG-9 (0.98) were the two parental lines exhibiting significantly positive estimates. On the other hand, PBIG-8 (-1.14) and PBIG-10 (-0.80) expressed significant negative gca effects. Among the 15 crosses, five crosses showed significant positive sca effects. The highest value showed by PBIG-6 × PBIG-18 (2.19), followed by PBIG-6 × PBIG-10 (1.76), PBIG-8 × PBIG-9 (1.63), PBIG-9 × PBIG-10 (1.23) and PBIG-8 × PBIG-3 (1.06). However, the crosses which exhibited significant negative effects were PBIG-18 × PBIG-10 (-2.85), PBIG-3 × PBIG-9 (-2.21), PBIG-3 × PBIG-6 (-1.76) and PBIG-6 × PBIG-9 (-1.01).

4.4.1.8. Average fruit diameter (mm)

The results revealed that for average fruit diameter only one parent i.e. PBIG-6 (3.99) showed significant positive gca value, while PBIG-3 (-3.23) and PBIG-18 (-1.14) showed significant negative gca effects. As regards sca effects, altogether six crosses exhibited significant estimates, among them two crosses PBIG-18 × PBIG-10 (3.71) and PBIG-3 × PBIG-6 (1.62) were with positive sca effects and other four crosses had significant negative estimate.

4.4.1.9. Main vine length (m)

Estimates of gca effects revealed that out of six, only one parent i.e. PBIG-3 (0.27) exhibited significant estimates in positive direction. Out of 15 crosses, four crosses *viz.* PBIG-3 × PBIG-9 (1.12), PBIG-3 × PBIG-10 (0.77), PBIG-8 × PBIG-3 (0.73) and PBIG-18 × PBIG-10 (0.42), expressed significant positive effects, while three hybrids namely PBIG-6 × PBIG-10 (-1.09), PBIG-8 × PBIG-9 (-1.05) and PBIG-8 × PBIG-18 (-0.71) showed significant negative sca effects.

4.4.1.10. Primary branch per plant

Significant gca effects were obtained for number of primary branches per plant. Parental lines *viz.*, PBIG-6 (1.95) and PBIG-8 (1.54) exhibited significantly positive estimates. Likewise, PBIG-9 (-1.64), PBIG-10 (-1.25) and PBIG-18 (-0.75) showed significantly negative gca values. A number of crosses expressed significant sca effects for this trait. The cross combination PBIG-8 × PBIG-18 (3.82) had the highest significant positive sca value, closely followed by PBIG-8 × PBIG-6 (2.96), PBIG-18 × PBIG-10 (2.19), PBIG-3 × PBIG-18 (2.11) and PBIG-8 × PBIG-10 (1.81). There were seven crosses with significant negative value *viz.*, PBIG-3 × PBIG-6 (-4.01), PBIG-8 × PBIG-9 (-3.47), PBIG-6 × PBIG-10 (-3.44), PBIG-9 × PBIG-18 (-3.01), PBIG-6 × PBIG-18 (-2.36), PBIG-9 × PBIG-10 (-1.76) and PBIG-8 × PBIG-3 (-1.08).

4.4.1.11. Internodal length (cm)

For this trait, out of six parental lines, only one parent i.e. PBIG-6 (-0.81) exhibiting significant negative value, while PBIG-18 (0.62) and PBIG-9 (0.14) showed significant positive gca effects. As regards sca effect for internodal length, 14 crosses exhibited significant estimates, out of which eight crosses were in negative desirable direction with the range of -1.70 (PBIG-6 × PBIG-9) to 2.03 (PBIG-9 × PBIG-10). It is noteworthy here that the negative gca and sca values are desirable for this trait in bitter gourd.

4.4.1.12. Main vine diameter (mm)

Estimates of gca effects for this trait revealed that, PBIG-3 (0.22 mm) showed highest positive gca value, followed by PBIG-6 (0.17 mm), PBIG-10 (0.04 mm). The highest negative gca value was observed in PBIG-18 (-0.26 mm). Among the 15 crosses, all showed significant sca value, out of these seven were in positive direction. The highest sca value was recorded in PBIG-8 × PBIG-3 (1.27), followed by PBIG-8 × PBIG-6 (0.94).

The lowest sca value was observed in PBIG-8 × PBIG-9 (-1.29), followed by PBIG-3 × PBIG-6 (-0.95).

4.4.1.13. Number of harvests per plant

Analysis of gca effects for this character revealed that out of six parental lines, PBIG-6 (0.26) recorded significant positive and PBIG-9 (-0.26) significant negative gca effects. Out of 15 crosses, eight crosses namely PBIG-8 × PBIG-10 (1.20), PBIG-3 × PBIG-6 (0.87), PBIG-8 × PBIG-9 (0.67), PBIG-8 × PBIG-18 and PBIG-3 × PBIG-9 (0.54 each), PBIG-6 × PBIG-18 (0.43), PBIG-3 × PBIG-9 (0.37) and PBIG-3 × PBIG-18 (0.26) exhibited significant positive sca effects. The highest negative sca effect was observed in cross combination, PBIG-8 × PBIG-6 (-0.86).

4.4.1.14. Number of fruits per plant

The results revealed that among the parental lines, PBIG-18 (3.87) showed significant positive gca value, while PBIG-3 (-2.65) showed significant negative gca value for this trait. Among the 15 crosses, 14 crosses exhibited significant positive sca effects. The highest gca value was estimated in cross combination, PBIG-8 × PBIG-18 (15.06), followed by PBIG-3 × PBIG-9 (12.97), PBIG-6 × PBIG-18 (10.24), PBIG-8 × PBIG-6 (6.38), PBIG-9 × PBIG-10 (5.59) and PBIG-6 × PBIG-9 (3.26). The lowest sca value was observed in PBIG-8 × PBIG-10 (-8.27), followed by PBIG-9 × PBIG-18 (-7.69).

4.4.1.15. Average fruit yield per plant (kg)

The results for fruit yield per plant revealed that significant positive desirable gca effects were found in PBIG-18 (0.16), PBIG-9 (0.12) and PBIG-6 (0.11). However, PBIG-3 (-0.18), PBIG-8 (-0.13) and PBIG-10 (-0.06) showed significantly negative gca values. The cross combination i.e. PBIG-6 × PBIG-10 (1.12) had highest significant positive sca value for fruit yield per plant, followed by PBIG-8 × PBIG-10 (1.00), PBIG-3 × PBIG-9 (0.87), PBIG-9 × PBIG-10 (0.70), PBIG-6 × PBIG-9 (0.54), PBIG-8 × PBIG-9 (0.29) and PBIG-8 × PBIG-6 (0.24). However, cross combination with significant negative value was PBIG-8 × PBIG-18 (-0.77).

4.4.1.16. Fruit yield per plant (q/ha)

Among the six parental lines, PBIG-18 (21.01), PBIG-9 (15.25) and PBIG-6 (14.38) showed significant positive desirable gca effects, while parents namely PBIG-3 (-

24.23), PBIG-8 (-18.12) and PBIG-10 (-8.30) exhibited significant negative gca effects for this trait. Among the 15 crosses, 13 crosses exhibited significant sca effect for fruit yield (q/ha), out of which seven crosses namely PBIG-6 × PBIG-10 (149.59), PBIG-8 × PBIG-10 (133.99), PBIG-3 × PBIG-9 (116.85), PBIG-9 × PBIG-10 (93.71), PBIG-6 × PBIG-9 (73.04), PBIG-8 × PBIG-9 (38.95) and PBIG-8 × PBIG-6 (32.01) showed significant positive sca value.

General combining ability (gca) has immense value in the breeding programmes for the species which are amenable to the development of F₁ hybrids. GCA studies revealed that among the six parents, none of parental line exhibited significant gca effect for all the traits. General combining ability (gca) effects for earliness (days to anthesis of first male and female flower and days to first harvest) revealed that PBIG-18 found best combiners due to its significant negative gca effects. This parental line also exhibited desirable gca for number of fruits per plant, average fruit yield per plant and fruit yield. Beside this, the parental line, PBIG-6 also exhibited significant positive general combining ability (gca) effect for average fruit weight, average fruit diameter, primary branches per plant, number of harvests per plant. However, PBIG-3 was the best general combiner for average fruit length, main vine length, main vine diameter. The parental line PBIG-8 was the good general combiner for nodal position of first male flower and nodal position of first female flower. In most of the cases it was observed that *per se* performance of parents bear direct reflection of their respective gca effects, i.e. parents showing highest gca effects for a character, were also observed to be good performer with respect to that particular character.

Specific combining ability effect helps in identifying the best cross combinations for various traits. These effects arise due to non-additive gene interactions. The hybrid combinations PBIG-8 × PBIG-18 showed significant sca effects in desirable direction for days to anthesis of first male flower (-5.61), days to anthesis of first female flower (-8.39), days to first harvest (-10.48), number of fruits per plant (15.06), primary branch per plant (3.82). However, PBIG-6 × PBIG-18 found to be found good specific combiner for average fruit length (2.19 cm), average fruit yield per plant (1.12 kg), fruit yield (149.59 q/ha). For nodal position of first female flower (-4.13), internodal length (2.03 cm), average fruit weight (6.54 g). The parent PBIG-6 × PBIG-10 for nodal position of first male flower (-3.70), PBIG-8 × PBIG-3 for main vine diameter (1.27 mm), PBIG-3 ×

PBIG-9 for main vine length (1.12 m), PBIG-18 × PBIG-10 for average fruit diameter (3.71 mm), PBIG-8 × PBIG-10 for number of harvests per plant (1.20). The result of present study was supported by **Alhariri *et al.*, (2020) and Mishra *et al.*, (2020)**.

4.5. Gene action

Combining ability is one of important genetic parameters for breeding improved cultivars. The variances of general combining ability (gca) and specific combining ability (sca) are related to the type of gene action involved. The variance of gca includes the additive nature of the total variance, whereas sca includes the non-additive nature of the total variance, arising largely from dominance and epistatic deviations (**Malik *et al.*, 2003**). The knowledge on the relative importance of the additive (gca) and non-additive (sca) gene actions within a breeding population is significant because it determines the breeding method for genetic improvement. After identification of appropriate parents and potential crosses through combining ability analysis, the next important step is to adopt suitable breeding methodology to achieve the desired result which depends upon the type of gene action governing the traits. Mean sum of squares due to gca and sca were used to estimate the variances for general combining ability (gca) and specific combining ability (sca), respectively, based on which nature of gene action has been worked out. The relevant results regarding relative importance of gca and sca (predictability ratio) observed to be <0.5 for days to anthesis of first male flower (0.03), days to anthesis of first female flower (0.14), node number to first male flower (0.16), node number to first female flower (0.29), days to first harvest (0.16), primary branch per plant (0.26), main vine diameter (0.07), internodal length (0.19), number of harvests per plant (0.10), number of fruits per plant (0.06), average fruit yield per plant (0.04), fruit yield (q/ha) (0.04), thus suggesting the predominant role of non-additive components of variance for improvement of these characters. Average degree of dominance which was found to be >1 for these characters further confirmed the results. Predictability ratio and average degree of dominance was observed to be >0.5 and <1 for Average fruit length (0.77), indicating the predominance of additive gene action for improvement of these characters. Again it confirmed the role of non-additive gene action governing different traits in bitter gourd.

Table 4.5.1: Gene action for different characters in bitter gourd (Summer season, 2022)

Source of variation/ characters	Mean squares						
	GCA (5)	SCA (15)	Error (40)	σ^2g	σ^2s	PR	Add
Days to anthesis of first male flower	6.33	12.771 **	3.75	0.32	9.01	0.03	14.07
Days to anthesis of first female flower	15.933 *	14.505 **	4.98	1.36	9.55	0.14	3.51
Node number to first male flower	7.333 **	5.543 **	0.5	0.85	5.04	0.16	3.15
Node number to first female flower	17.483 **	7.584 **	0.51	2.12	7.07	0.29	1.66
Days to first harvest	73.065 **	56.592 **	5.93	8.39	50.66	0.16	3.01
Average fruit weight (g)	473.718 **	48.226 **	6.19	58.44	42.03	1.39	0.25
Average fruit length (cm)	9.082 **	2.508 *	1.25	0.97	1.25	0.77	0.64
Average fruit diameter (mm)	44.785 **	5.874 **	0.77	5.50	5.10	1.07	0.46
Main vine length (cm)	0.15	0.497 **	0.16	-0.011	0.33	-0.03	-15
Primary branch per plant	17.65 **	8.604 **	0.63	2.12	7.97	0.26	1.87
Main vine diameter (mm)	0.297**	0.503**	0.003	0.036	0.49	0.07	6.80
Internodal length (cm)	1.709 **	1.052 **	0.03	0.20	1.02	0.19	2.55
Number of fruits per plant	37.839 **	70.449 **	2.49	4.41	67.96	0.06	7.70
Number of harvests per plant	0.378 **	0.425 **	0.07	0.038	0.35	0.10	4.60
Average fruit yield per plant (kg)	0.166 **	0.504 **	0.003	204.83	5013.67	0.04	12.23
Fruit yield (q/ha)	2984.57 **	9002.07 **	49.26	366.86	8952.45	0.04	12.20

Predictability ratio (PR) = $2 \sigma^2g / 2 \sigma^2g + \sigma^2s$; Average degree of dominance (Add) = $\sigma^2s / 2 \sigma^2g$;

Best performing hybrids with highest specific combining ability (sca) effects developed by crossing parents with general combining ability (high \times high), (high \times low) and (low \times low) effects denotes presence of additive, dominance and epistatic gene actions respectively. Three best performed hybrids based on *per se* performance, sca effects and mode of gene action involved in each trait based on the high or low parental gca effects are presented in Table 4.5.1. For days to anthesis of first male flower, in hybrids *viz.*, PBIG-8 \times PBIG -18, PBIG-6 \times PBIG-9 and PBIG-3 \times PBIG -18 (high \times low) dominant gene action was detected. For number of days to anthesis of first female flower, in hybrids namely PBIG-8 \times PBIG-18, PBIG-8 \times PBIG-9 and PBIG-9 \times PBIG-6 (high \times low) dominant gene action was detected. For node number to first male flower, dominant gene action (high \times low) was observed in PBIG-6 \times PBIG-10, PBIG-9 \times PBIG-10 and PBIG-18 \times PBIG-10. For the node number to first female flower dominant gene action (high \times low) was observed in PBIG-9 \times PBIG-10 and PBIG-18 \times PBIG-10, whereas additive gene action was observed in the cross PBIG-6 \times PBIG-10. For Days to first harvest dominant gene action were observed in PBIG-8 \times PBIG-18 and PBIG-3 \times PBIG-18, whereas epistatic gene action (low \times low) was found in cross PBIG-8 \times PBIG-3. For Average fruit weight (g) dominant gene action (high \times low) to be recorded in the crosses PBIG-9 \times PBIG -10, PBIG-8 \times PBIG-9 and PBIG-6 \times PBIG -18. For Average fruit diameter (mm) crosses PBIG-18 \times PBIG-10 and PBIG-3 \times PBIG-10 (low \times low) epistatic gene action was to be observed, whereas in PBIG-3 \times PBIG-6 (high \times low) dominant gene action was recorded. For Average fruit length (cm) dominant gene action (high \times low) were to be observed in PBIG-6 \times PBIG -18, PBIG-6 \times PBIG -10 and PBIG-8 \times PBIG -9. For Main vine length (m) dominant gene action (high \times low) were to be observed in PBIG-3 \times PBIG-9, PBIG-3 \times PBIG-10 and PBIG-8 \times PBIG-3. For Primary branch per plant dominant gene action (high \times low) was detected in PBIG-8 \times PBIG-18, whoever cross PBIG-8 \times PBIG-6 (high \times high) additive gene action was observed and in PBIG-18 \times PBIG-10 (low \times low) epistatic gene action was recorded. For Internodal length (cm) dominant gene action (high \times low) were to be observed in cross PBIG-9 \times PBIG-10, whereas epistatic gene action (low \times low) was recorded in cross PBIG-8 \times PBIG-6 and in PBIG-9 \times PBIG-18 (high \times high) additive gene action was observed. For Main vine diameter (mm) dominant gene action (high \times low) were to be observed in crosses PBIG-8 \times PBIG-3, PBIG-8 \times PBIG-6 and PBIG-6

Table 4.5.2: Overall performances of superior crosses based on *per se* performance and sca effects for different traits in bitter melon (Summer season, 2022)

S. No.	crosses	<i>per se</i> performance	sca effect	gca effect
1	Days to anthesis of first male flower			
	PBIG-8 × PBIG -18	41.00	-5.61	L × H
	PBIG-3 × PBIG -18	40.00	-2.86	L × H
	PBIG-6 × PBIG -9	39.00	-2.86	H × L
2	Days to anthesis of first female flower			
	PBIG-8 × PBIG-18	45.00	-8.39	L × H
	PBIG-8 × PBIG-9	42.00	-4.52	L × L
	PBIG-6 × PBIG-9	42.00	-2.64	H × L
3	Node number to first male flower			
	PBIG-6 × PBIG-10	9.00	-3.70	L × H
	PBIG-9 × PBIG-10	12.00	-3.20	L × H
	PBIG-18 × PBIG-10	6.00	-1.57	L × H
4	Node number to first female flower			
	PBIG-9 × PBIG-10	15.00	-4.13	L × H
	PBIG-18 × PBIG-10	7.00	-2.67	L × H
	PBIG-6 × PBIG-10	6.00	-1.84	H × H
5	Days to first harvest			
	PBIG-8 × PBIG-18	56.00	-10.48	L × H
	PBIG-3 × PBIG-18	61.67	-7.32	L × H
	PBIG-8 × PBIG-3	61.67	-7.19	L × L
6	Average fruit weight (g)			
	PBIG-9 × PBIG-10	75.57	6.54	H × L
	PBIG-8 × PBIG-9	77.13	5.68	L × H
	PBIG-6 × PBIG-18	84.54	4.70	H × L
7	Average fruit diameter (mm)			
	PBIG-18 × PBIG-10	41.45	3.71	L × L
	PBIG-3 × PBIG-6	41.58	1.62	L × H
	PBIG-3 × PBIG-10	35.50	0.66	L × L
8	Average fruit length (cm)			
	PBIG-6 × PBIG -18	16.26	2.19	H × L
	PBIG-6 × PBIG -10	16.55	1.76	H × L
	PBIG-8 × PBIG -9	16.55	1.63	L × H

Count.....

9	Main vine length (m)			
	PBIG-3 × PBIG-9	5.82	1.12	H × L
	PBIG-3 × PBIG-10	4.45	0.77	H × L
	PBIG-8 × PBIG-3	5.42	0.73	L × H
10	Primary branch per plant			
	PBIG-8 × PBIG-18	16.75	3.82	H × L
	PBIG-8 × PBIG-6	18.60	2.96	H × H
	PBIG-18 × PBIG-10	17.34	2.19	L × L
11	Internodal length (cm)			
	PBIG-9 × PBIG-10	9.56	2.03	L × H
	PBIG-8 × PBIG-6	9.53	1.66	L × L
	PBIG-9 × PBIG-18	11.46	0.80	H × H
12	Main vine diameter (mm)			
	PBIG-8 × PBIG-3	5.25	1.27	L × H
	PBIG-8 × PBIG-6	4.86	0.94	L × H
	PBIG-6 × PBIG-18	4.41	0.56	H × L
13	Number of harvests per plant			
	PBIG-8 × PBIG-10	5.00	1.20	L × L
	PBIG-3 × PBIG-6	6.00	0.87	L × H
	PBIG-8 × PBIG-9	5.00	0.67	L × L
14	Number of fruits per plant			
	PBIG-8 × PBIG-18	0.51	15.06	L × H
	PBIG-3 × PBIG-9	26.51	12.97	L × H
	PBIG-6 × PBIG-18	24.54	10.24	L × H
15	Average fruit yield per plant (kg)			
	PBIG-6 × PBIG-18	2.07	1.12	H × H
	PBIG-8 × PBIG-10	1.77	1.00	L × L
	PBIG-3 × PBIG-9	1.75	0.87	L × H
16	Fruit yield (q/ha)			
	PBIG-6 × PBIG-18	276.5	149.59	H × H
	PBIG-18 × PBIG-10	115.7	133.99	H × L
	PBIG-3 × PBIG-9	234.1	116.85	L × H

× PBIG-18. For number of harvests per plant epistatic gene action (low × low) was recorded in crosses PBIG-8 × PBIG-10 and PBIG-8 × PBIG-9 however dominant gene action (high × low) was detected in PBIG-3 × PBIG-6. For number of fruits per plant dominant gene action (high × low) were to be observed in crosses PBIG-8 × PBIG-18, PBIG-3 × PBIG-9 and PBIG-6 × PBIG-18. For average fruit yield per plant (kg), cross PBIG-6 × PBIG-18 (high × high) observed additive gene action, In PBIG-8 × PBIG-10 (low × low) epistatic gene action was observed whereas dominant gene action (high × low) was to be observed in cross PBIG-3 × PBIG-9. For fruit yield (q/ha) dominant gene action (high × low) were to be observed in crosses PBIG-18 × PBIG-10 and PBIG-3 × PBIG-9 however additive gene action (high × high) was to be observed in cross PBIG-6 × PBIG-18. These results were in conformity with those of **Alhariri *et al.*, (2020)**, **Dey *et al.*, (2010)**, **Singh *et al.*, (2013)** and **Shukla *et al.*, (2014)**.



PBIG-6/21



PBIG-18/21



PBIG-9/21



PBIG-10/21



PBIG-8/21



PBIG-3/21

Plate 4.1: Parental lines



PBIG-6



PBIG-18



PBIG-6 × PBIG-18

276q/ha

Plate 4.2: Best performing F₁ hybrid



PBIG-9



PBIG-10



PBIG-9 × PBIG-10

259q/ha

Plate 4.3: Best performing F₁ hybrid



Summary
and
Conclusions



Chapter-5

SUMMARY AND CONCLUSION

The development of the varietal hybrid provides a quick approach to ensure high yield with better quality fruits in bitter gourd, in comparatively short span of time and with the least expenditure. Moreover, it also provides the basic information about the heterotic patterns of the source materials to be used as parents in the future hybrid breeding programme. The heterosis expressed by the genetically diverse varietal crosses can be exploited and the ultimate success will depend on the efficiency with which the superior varietal crosses are identified.

The present investigation entitled “**Study on heterosis breeding, combining ability and gene action in bitter gourd (*Momordica charantia* L.)**” was undertaken in a half diallel cross (excluding reciprocals) involving six parental lines and their 15 F₁ hybrids. The parental lines used were PBIG-3, PBIG-6, PBIG-8, PBIG-9, PBIG-10 and PBIG-18. Pant Karela-1 was used as standard check variety. The experiment was conducted at the Vegetable Research Centre (VRC) of the GBPUA&T, Pantnagar, U. S. Nagar, Uttarakhand. Evaluation was done during the summer season of 2022. The experiment was laid out in a Randomized Complete Block Design (RCBD) using three replications. Each genotype was directly sown in the main field with a spacing of 150 cm × 50 cm. There were seven plants per treatment, out of which on five plants observations were recorded for 16 different horticultural traits namely days to anthesis of first male flower, days to anthesis of first female flower, node number to first male flower, node number to first female flower, days to first harvest, average fruit weight (g), average fruit diameter (mm), average fruit length (cm), main vine length (m), primary branch per plant, internodal length (cm), main vine diameter (mm), number of harvests per plant, number of fruits per plant, average fruit yield per plant (kg) and fruit yield (q/ha), The mean data obtained on individual plant basis were analysis.

The salient findings of the study are summarized as below:

- Analysis of variance (ANOVA) revealed highly significant variations among the genotypes for all the characters, indicating significant difference among the genotypes for all traits.

- As regards heterotic effects, none of the hybrid could come out outstanding for all the 16 characters. Some hybrids were promising for one set of characters and some were for other.
- The outstanding F_1 hybrid exceeding their better parents and the standard check (Pant Karela-1) were PBIG-8 \times PBIG-10, PBIG-6 \times PBIG-18, and PBIG-6 \times PBIG-10 for earliness, PBIG-6 \times PBIG-9, PBIG-9 \times PBIG-10 and PBIG-6 \times PBIG-18 for fruit characters. PBIG-3 \times PBIG-9, PBIG-8 \times PBIG-3 and PBIG-8 \times PBIG-10 for vegetative traits. PBIG-8 \times PBIG-10, PBIG-6 \times PBIG-18 and PBIG-9 \times PBIG-10 for fruit yield and its attributing characters.
- The results for analysis of variance for combining ability revealed that, sca components of variance was higher than gca components of variance for traits like days to anthesis of first male flower, main vine length (m), main vine diameter (mm), number of harvests per plant, number of fruits per plant, average fruit yield per plant (kg) and fruit yield (q/ha), which indicated the importance of non-additive gene action in expression of these characters. Therefore, heterosis breeding could be effective for the genetic improvement of these quantitative traits.
- However, gca components of variance was higher than sca components of variance for traits like days to anthesis of first female flower, node number to first male flower, node number to first female flower, days to first harvest, average fruit weight (g), average fruit diameter (mm), average fruit length (cm), primary branches per plant and internodal length (cm), which indicated the predominance of additive gene action in expression of these characters. Therefore, selection could be effective for the genetic improvement of these quantitative traits.
- None of the parents under the present study showed consistently good gca effects for all the characters. For earliness PBIG-18 was the best general combiner, however PBIG-6 was the good general combiner for four characters namely average fruit weight, average fruit diameter, primary branches per plant, number of harvests per plant. Parent PBIG-3 found outstanding for three characters i.e. average fruit length, main vine length, main vine diameter, while parent PBIG-8 was the good general combiner for two characters i.e. nodal position of first male flower and nodal position of first female flower.

- None of the crosses expressed high sca effects for all the characters. However, the crosses namely PBIG-8 × PBIG-18, PBIG-6 × PBIG-18, PBIG-9 × PBIG-10, PBIG-6 × PBIG-10, PBIG-3 × PBIG-9 were noted consistent good specific combiners for most of the economic traits including number of fruits per plant, fruit yield per plant and fruit yield (q/ha).
- Regarding the gene action, predictability ratio and average degree of dominance was observed <0.5 and >1.0, respectively for all the characters except average fruit length, indicating the predominance of non-additive (dominance and epistasis) gene action in the expression of different traits under study, hence heterosis breeding will be an effective tool for genetic improvement of these traits in bitter gourd. However, predictability ratio and average degree of dominance for average fruit length was >0.5 and <1.0 respectively, indicating the predominance of additive gene action in the expression of this trait under study, hence selection breeding will be an effective tool for genetic improvement of fruit length in bitter gourd.
- Based on *per se* performance, sca effects and mode of gene action involved for fruit yield (q/ha). The two best performed hybrids (PBIG-18 × PBIG-10 and PBIG-3 × PBIG-9) involved parents having high × low gca values, indicating dominant gene action in these crosses for superior heterosis for fruit yield.

Conclusion

In light of the above results, it may be concluded that three parental lines namely PBIG-18, PBIG-6 and PBIG-9 were the superior lines based on their gca performance, and their contribution to give better heterotic combinations as compared to other lines. Therefore, these parental lines can be included in the future hybrid breeding programmes of bitter gourd. The two crosses namely PBIG-6 × PBIG-18, PBIG-9 × PBIG-10 were found best heterotic combinations along with best sca effects for most of the important economic traits and are worth exploiting on commercial scale. These crosses yielded 276.5 q/h, and 259.2 q/ha as compared to the 156.1 q/ha of the standard check i.e. Pant Karela-1. The promising heterotic hybrids identified in this study may be evaluated in multiple locations to assess their potential as hybrids for commercial use in future.



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Appendices



APPENDIX

Weekly weather data

STATION NAME
LATITUDE

Pantnager
29 deg. N

LONGITUDE
ALTITUDE

79 deg. 30' E
243.84 m. AMSL

Month	Date	Year	Metro Week No.	Temperature (°C)		Related Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (Km/hr.)	Evap. (mm)
				Max.	Min.	712am	1412pm					
Mar	05-11	2022	10	27.5	11.3	92	48	0	0	7	3.4	3.2
Mar	12-18	2022	11	30.7	16.6	90	49	0	0	7.1	1.9	2.9
Mar	19-25	2022	12	33.9	17.1	84	40	0	0	8.8	2.4	3.4
Mar-Apr	26-01	2022	13	34.0	15.9	80	31	0.0	0	9.0	4.6	4.8
April	02-08	2022	14	37.0	15.5	76	19	0.0	0	9.8	2.6	5.9
April	9-15	2022	15	37.1	20.9	65	31	2.6	1	8.3	5.1	6.1
April	16-22	2022	16	38.2	19.1	63	19	0.0	0	9.0	3.5	7.1
April	23-29	2022	17	38.0	19.0	54	19	0.0	0	10.3	4.0	8.8
April-May	30-06	2022	18	36.1	23.0	63	39	8.4	1	8.1	5.5	7.8
May	7-13	2022	19	35.2	23.3	67	43	5.0	1	8.5	4.1	6.8
May	14-20	2022	20	37.8	24.6	63	34	0.0	0	8.8	4.9	7.8
May	21-27	2022	21	34.5	22.6	67	39	14.9	2	7.8	5.8	6.8
May-Jun	28-03	2022	22	36.7	26.1	69	40	17.2	1	7.9	4.5	6.4
June	04-10	2022	23	40.4	26.1	68	32	0.0	0	9.6	5.8	7.8
June	11-17	2022	24	40.2	26.8	65	32	24.2	1	8.6	6.2	9.8
June	18-24	2022	25	35.0	24.5	73	43	0.0	0	7.3	5.1	6.2

CURRICULUM VITAE

Name : Amit Nawani **Phone Number** : 7668319855

Mailing Address : S/o Basant Ballabh Nawani, Vill – Gawani, Post office – Gawani, Pauri Garhwal, Uttarakhand **Permanent Address** : Same as mailing address

E- mail : amitnawani01041997@gmail.com

Career objectives : To secure a challenging position in a reputable agriculture organisation to expand learning, knowledge and skills.

Educational Qualifications

S. No	Examination Passed	Institution	Year	Per cent
1	Post graduation	G.B.P.U.A&T. Pantnagar Uttarakhand	2022	76.9 %
2	Graduation	V.C.S.G. U.U.H.F. Bharsar, Pauri Grhwal Uttarakhand	2020	73.4 %
3	Intermediate	B.O.S. E.U.	2015	66.8 %
4	High School	B.O.S. E.U.	2013	69.4 %

Specialization : **Major** : Horticulture (Vegetable Science)

Minor : Nil

Thesis Title : “Study on heterosis breeding, combining ability and gene action in bitter gourd (*Momordica charantia* L.)”

Publications : Nil

Conferences/ Seminars/Workshops/Trainings Attended : 1

List of papers presented in conference/seminar during degree programme : Nil

Software Skills : MS Word, MS Excel and MS PowerPoint

Professional Skills : Nil

Professional Affiliations (Membership, etc.) : Nil

Awards / Honours/Achievements : Nil

Place : Pantnagar

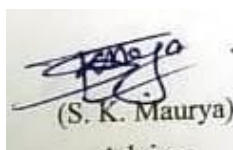

(Amit Nawani)

Date :

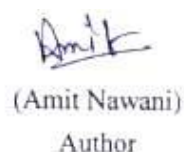
Name : Amit Nawani **Id. No.** : 56600
Semester & year of admission : 1st Sem., 2020-21 **Degree** : M.Sc. (Ag.)
Major : Horticulture (Vegetable Science) **Department** : Vegetable Science
Thesis title : “Study on heterosis breeding, combining ability and gene action in bitter gourd (*Momordica charantia* L.)”
Page No : 1-82 **Advisor** **Dr. S. K. Maurya**

ABSTRACT

The present investigation entitled “Study on heterosis breeding, combining ability and gene action in bitter gourd (*Momordica charantia* L.)” was carried out at the experimental field of Vegetable Research Centre of G.B.P.U.A.&T., Pantnagar during summer season of 2022. The six diverse monoecious bitter gourd genotypes viz., PBIG-3, PBIG-6, PBIG-8, PBIG-9, PBIG-10, PBIG-18, and PBIG-18 were selected and crossed during *rabi* season (2021-22) in diallel mating design (without reciprocal) to develop 15 F₁ crosses. The F₁s and parents were sown at a spacing of 150 cm × 75 cm in randomized complete block design with three replications. Observations were recorded on five randomly tagged plants in each entry for 16 quantitative traits of bitter gourd. The data were subjected to appropriate statistical analysis. The analysis of variance indicated significant difference among all the genotypes for all the characters. The combining ability analysis revealed that both *gca* and *sca* variance were significant for all the characters. Non-additive gene action played a major role in controlling the characters like days to anthesis of first male and female flower, node number to first male and female flower, primary branch per plant, internodal length (cm), main vine diameter (m), days to first harvest, average fruit yield per plant (kg) and fruit yield (q/ha). On the basis of *gca* effects, among parental lines, PBIG-18 showed highest *gca* effects for days to anthesis of first male and female flower, days to first harvest, internodal length, number of fruits per plant, average fruit yield per plant (kg) and fruit yield (q/ha). Among hybrids, PBIG-8 × PBIG-18 showed highest *sca* effects for days to anthesis of first male and female flower, days to first harvest and primary branch per plant, whereas, hybrid PBIG-6 × PBIG-18 showed ideal *sca* effects for fruit yield per plant (kg) and fruit yield (q/ha). The gene action, predictability ratio and average degree of dominance was observed <0.5 and >1.0, respectively for all the characters except average fruit length, indicating the predominance of non-additive (dominance and epistasis) gene action in the expression of different traits under study, hence heterosis breeding will be an effective tool for genetic improvement of these traits in bitter gourd. The two crosses namely PBIG-6 × PBIG-18, PBIG-9 × PBIG-10 were found best heterotic combinations along with best *sca* effects for most of the important economic traits and are worth exploiting on commercial scale. These crosses yielded 276.5 q/h, and 259.2 q/ha as compared to the 156.1 q/ha of the standard check i.e. Pant Karela-1.



(S. K. Maurya)
Advisor

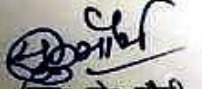


(Amit Nawani)
Author

नाम	:	अमित नवानी	परिचयांक	:	56600
षट्मास एवं प्रवेश वर्ष	:	प्रथम, 2020-21	उपाधि	:	स्नातकोत्तर (कृषि)
प्रमुख विषय	:	उद्यान (सब्जी विज्ञान)	विभाग	:	सब्जी विज्ञान
शोध का शीर्षक	:	"करेला में संकर ओज प्रजनन, संयोजन क्षमता और जीन व्यवहार पर अध्ययन (मोमोर्डिका चरैन्शिया एल।)"			
पृष्ठ संख्या	:	1-82	सलाहकार	:	डॉ० एस० के० मौर्य

सारांश

वर्तमान जांच शीर्षक करेला में संकर ओज प्रजनन, संयोजन क्षमता और जीन व्यवहार पर अध्ययन (मोमोर्डिका चरैन्शिया एल।)" 2022 के गर्मी के मौसम के दौरान गोविंद बल्लभ पंत कृषि और प्रौद्योगिकी विश्वविद्यालय पंतनगर के सब्जी अनुसंधान केंद्र के प्रयोगात्मक क्षेत्र में किया गया। छह द्विलिंगी करेला जननद्रव्यो जैसे पीबीआईजी-3, पीबीआईजी-6, पीबीआईजी-8, पीबीआईजी-9, पीबीआईजी-10, पीबीआईजी-18, और पीबीआईजी-18 का चयन रबी मौसम (2021-22) के दौरान अर्ध डायलेल विविध (पारस्परिक के बिना) में 15 संकर विकसित करने के लिए संकरण किया गया। संकरो और पितृ को तीन पुनरावृत्ति के साथ यादृच्छिक पूर्ण खंड अभिकल्पना में 150 सेमी × 50 सेमी की दूरी पर बोया गया। करेले के 16 मात्रात्मक लक्षणों के लिए प्रत्येक प्रविष्टि में पांच यादृच्छिक रूप से चिन्हित किए गए पौधों पर अवलोकन दर्ज किए गए थे। जानकारी को उपयुक्त सांख्यिकीय विश्लेषण के अधीन किया गया था। विचरण के विश्लेषण ने सभी गुणों के लिए सभी जननद्रव्यो के बीच महत्वपूर्ण अंतर का संकेत दिया। संयोजन क्षमता विश्लेषण से पता चला है कि सभी गुणों के लिए जी. सी. ए. और एस. सी. ए. विचरण दोनों महत्वपूर्ण थे। गैर-योज्य जीन व्यवहार ने पहले नर और मादा फूल के प्रफुल्लन के दिन, पहले नर और मादा फूल के लिए आसंधि संख्या, प्रति पौधे प्राथमिक शाखा, पोरी लंबाई (सेमी), मुख्य बेल व्यास (मिमी) जैसे लक्षणों को नियंत्रित करने में एक प्रमुख भूमिका निभाई। पहली कटाई के दिन, प्रति पौधे औसत फल उपज (किलो) और फल उपज (क्विंटल/हैक्टर)। जी. सी. ए. प्रभावों के आधार पर, पैतृक वंशों में, पीबीआईजी-18 ने पहले नर और मादा फूल के प्रफुल्लन, पहली कटाई के दिन, पोरी लंबाई, प्रति पौधे फलों की संख्या, प्रति पौधा औसत फल उपज (किलो) और फल उपज (क्विंटल/हैक्टर) के लिए उच्चतम जी. सी. ए. प्रभाव दिखाया। संकरों में, पीबीआईजी-8 × पीबीआईजी-18 ने पहले नर और मादा फूल के प्रफुल्लन, पहली कटाई के दिन और प्रति पौधे प्राथमिक शाखा के दिनों के लिए उच्चतम प्रभाव दिखाया, जबकि, संकर पीबीआईजी-6 × पीबीआईजी-18 ने प्रति पौधा फल उपज (किलो) और फल उपज (क्विंटल/हैक्टर) के लिए आदर्श एस. सी. ए. प्रभाव दिखाया। औसत फल लंबाई को छोड़कर सभी लक्षणों के लिए जीन व्यवहार, पूर्वानुमेयता अनुपात और प्रभुत्व की औसत डिग्री क्रमशः < 0.5 और > 1.0 देखी गई, जो विभिन्न लक्षणों की अभिव्यक्ति में गैर-योज्य (प्रभुत्व और एपिस्टासिस) जीन व्यवहार की प्रबलता को दर्शाती है। इसलिए, करेले में इन लक्षणों के आनुवंशिक सुधार के लिए संकर ओज प्रजनन, एक प्रभावी उपकरण होगा। पीबीआईजी-6 × पीबीआईजी-18, पीबीआईजी-9 × पीबीआईजी-10 नाम के दो संकरण को सबसे महत्वपूर्ण आर्थिक लक्षणों के लिए सबसे अच्छा एस. सी. ए. प्रभावों के साथ सबसे अच्छा विषम संयोजन पाया गया और वाणिज्यिक पैमाने पर शोषण के लायक हैं। मानक चेक यानी पंत करेला-1 के 156.1 क्विंटल/हेक्टेयर की तुलना में इन संकरण से 276.5 क्विंटल/हैक्टर और 259.2 क्विंटल/हैक्टर का उत्पादन हुआ।


(एस० के० मौर्य)
सलाहकार


(अमित नवानी)
लेखक